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The potential of terrestrial and aquatic molluscs for the temporal analysis of Deckenschotter deposits and younger Quaternary sediments from the Swiss Plateau

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1 Introduction

The main aim of this study has been to investigate whether the analysis of molluscan remains can add to our understanding of the dating and depositional environment of key sequences from the Höhere Deckenschotter and Tiefere Deckenschotter sedimentary complexes in northern Switzerland and the neighbouring area of southern Germany. The results of the analyses clearly demonstrate that the study of sub-fossil mollusc shells[1] represents a powerful tool for the investigation of both Deckenschotter deposits and other Quaternary sediments. Not only can they establish the climatic and environmental context in which deposits were formed, but they provide biostratigraphical information that greatly contributes to our understanding of the dating framework for these deposits. Although the study of Early, Middle and Late Pleistocene molluscan faunas in Switzerland is some way behind what is known from neighbouring areas in south and central Germany, Austria and France, the results from this study have considerably expanded our knowledge base.

A second major goal of this research study was to provide identified molluscan material for Amino Acid Racemisation (AAR) Dating (cf. Penkman et al. 2013), in order to establish a viable aminostratigraphy for Switzerland that could help with establishing reliable ages for Höhere and Tiefere Deckenschotter deposits and other Quaternary sediments. A number of museums and researchers were contacted in order to discover whether there might be suitable Early, Middle and Late Pleistocene shell material accessible from previously investigated sites that could be borrowed for analysis and for sampling. Although the main area of focus for this study has been northern Switzerland, there are relatively few interglacial assemblages available from this region, so the research area was expanded to include the whole of the Swiss Plateau. Subsequently, most of the borrowed material was fully analysed and several sites were sampled for AAR Dating measurements. Molluscan assemblages from several other Late Pleistocene and Holocene sites have also been included, as their climato-stratigraphic context is known and warm period biosuccessional patterns have been established, so they can act as a useful comparison for the older faunas. The findings from the molluscan study of these sites are presented here, together with a summary of the AAR Dating results from these and the Deckenschotter sites mentioned above.

Institutions that lent material include the Muséum d'Histoire Naturelle Genève, the Musée cantonal de Géologie Lausanne, the Naturhistorisches Museum Bern, the Naturhistorisches Museum Basel, the ETHZ collection Zürich, and the Palaeontological Museum of the University of Zurich (PIMUZ). Individuals who provided shell material include Robert Arn, Marius Büchi, Louis Chaix, Heinz Furer, Christian Schlüchter and especially Daniel Kälin. Thomas Bolliger made documentation available for the material from several of the sites he had previously donated to the PIMUZ.

Figure 1 shows the locations of all the Swiss sites with molluscan material discussed in this text.

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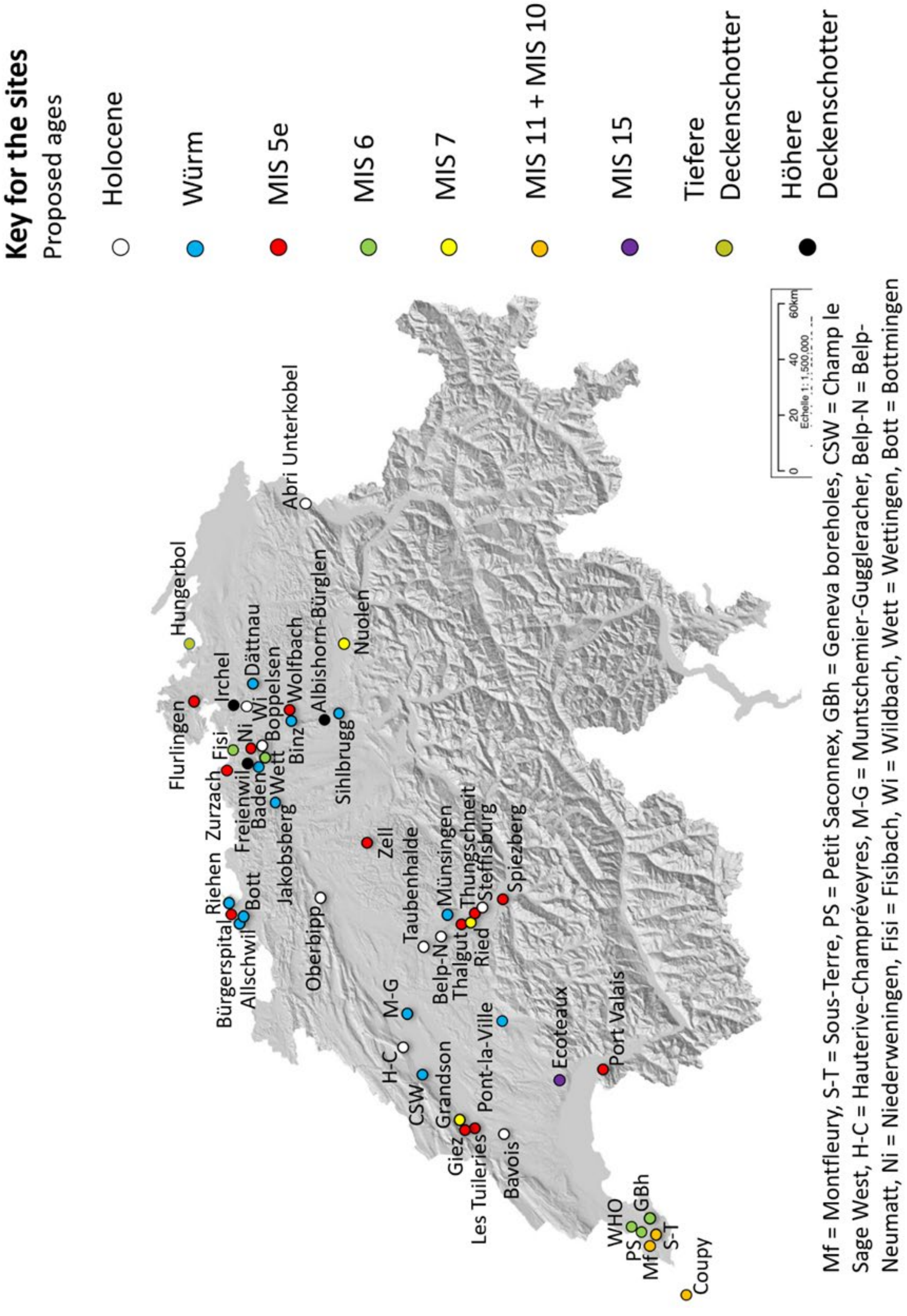
[1] Shells from Quaternary deposits, which have normally not been significantly altered by recrystallisation.



Mf = Montfleury, S-T = Sous-Terre, PS = Petit Saconnex, GBh = Geneva boreholes, CSW = Champ le Sage West, H-C = Hauterive-Champréveyres, M-G = Muntschemier-Guggleracher, Belp-N = Belp-Neumatt, Ni = Niederweningen, Fisi = Fisibach, Wi = Wildbach, Wett = Wettingen, Bott = Bottmingen

Figure 1: The Location of Swiss sites with molluscan material mentioned in the text

2 Methods

From the new study columns taken at Irchel Hasli, Irchel Steig, Irchel Amselboden, Irchel Hochwacht, Wilemerirchel, Hungerbol and Albishorn-Bürglen, sediment samples of between 1.5 and 6.5 kg were taken for the analysis of the molluscan remains and processed using a standard procedure. In addition, shells were extracted from much larger samples taken to recover small mammal remains. For the samples borrowed from museum collections, many consisted of shells that had already been picked out, although some had shell material accompanied by sieve residues that could be resorted, and a few had a mixture of pre-sorted shells and sediment that could be processed using the same laboratory procedures as the new samples.

All samples taken for molluscan analysis were washed through a series of sieves with 8, 4, 2, 1, 0.5 and 0.3 mm mesh sizes. After drying, the residues were sorted in their entirety with the aid of a high-powered binocular microscope in order to extract the molluscan material, as well as other biological remains like earthworm granules, bone fragments, ostracods and *Chara*. All shells and fragments were picked out from the sieve fractions of 0.5 mm and above. For the 0.3 mm fraction, all material was extracted for samples with few molluscs, while for those with richer assemblages only complete shells, apices and quantifiable shell fragments were picked out for the more common species, as well as all identifiable fragments for rarer taxa. Larger samples taken to recover small mammal remains were processed in a similar manner, although the smallest sieve size was 0.5 mm.

The totality of the extracted shell material was then identified to species level with the aid of the author's personal reference collection. This collection includes both juvenile and adult shells for the majority of species likely to be encountered in Switzerland and adjoining countries, including taxa that have been absent from this region for many millennia. Nevertheless, during the analysis of the Irchel and the Hungerbol material, shells and fragments were discovered that come from species that are now extinct or live far from Switzerland, requiring the use of key reference works like Ložek 1964, Frank 2006, Gargominy and Neubert 2011, Gargominy and Ripken 2011, Welter-Schulthes 2012 and Glöer 2019, 2022a, 2022b. Specimens of the terrestrial taxa *Ciliella ciliata*, *Trochulus filicinus* and *Trochulus leucozonus* could be verified with the help of shells from the Naturhistorisches Museum Bern, while rare Clausiliidae were identified with the guidance of Helmut Nordsieck, and two aquatic taxa are yet to be determined. The identification of shell fragments to species level requires an in-depth knowledge of the morphological characteristics and microsculpture of the diagnostic parts of all relevant molluscan taxa. It is important to accurately identify the greater part of the shell material to species level in order to prevent biases in the resulting data set, ensuring that climatic and environmental inferences are as objective as possible and making sure that no biostratigraphically important species have escaped attention.

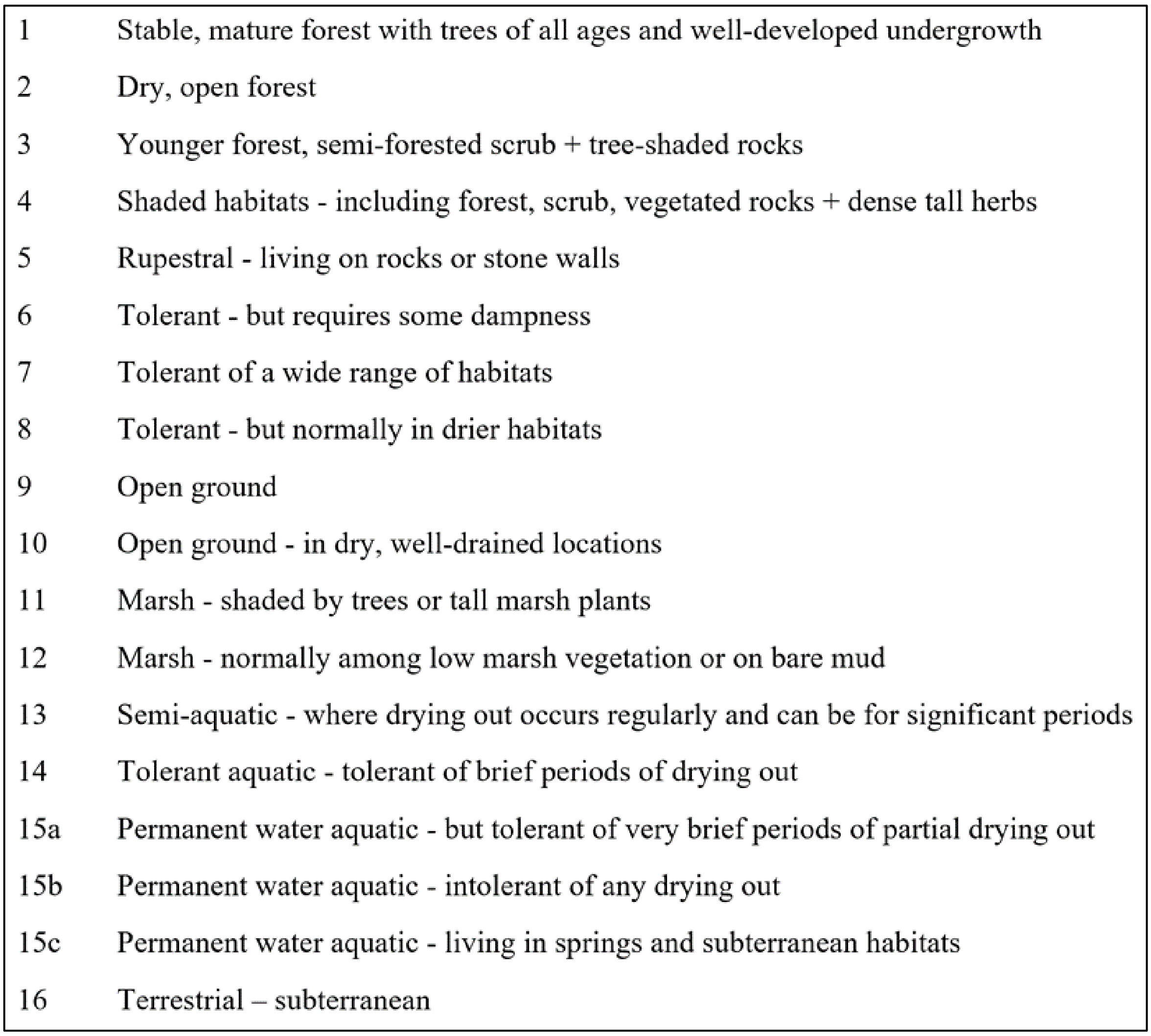
After identification, for the majority of samples all fragments were quantified for less well represented species, with differences in shell colour, thickness and preservation (surface freshness, traces of corrosion or erosion, discolouration etc.) being used to estimate the Minimum Number of Individuals (MNI). For more common taxa, quantification was partially based upon the counting of unique shell elements (such as apices, mouths and umbilici), but as the material was often fairly fragmented, the ratio of fragments to MNI values for rarer species was used to estimate MNI values for common taxa based on the number of fragments present and the size of complete shells.

The MNI values for all of the identified shell material are listed by sample and by species in the results tables for each site. To facilitate interpretation, the taxa were placed in one of sixteen ecological groups for both terrestrial and aquatic habitats (Figure 2), defined by the author according to published ecological data (Favre 1927, 1935, 1941, Boycott 1934, 1936, Ellis 1962, Puisségur 1976, Mouthon 1980, Kerney et al. 1983, Økland 1990, Turner et al. 1998, Kerney 1999, Glöer 2002, 2020 and Welter-Schultes 2012), as well as personal field observations in Switzerland and adjoining countries. Most of the taxonomic, climatic and ecological information used during this study has been taken from the same sources, unless otherwise stated. In the results tables, percentage values for all of the terrestrial groups make ecological trends easier to discern. For a few samples with rather abundant molluscan material from Steig, Amselboden, Hochwacht and Wilemeirchel, a lack of time meant that instead of absolute counts, one to three crosses were used to indicate approximate frequencies. The results tables also record the presence of biological remains from terrestrial organisms (earthworm granules, bird egg-shell, insect remains, bone fragments from both larger mammals and smaller vertebrates, charcoal, wood, plant remains and *Cenococcum*) and of aquatic origin (*Chara* oospores and ostracod valves).

For sites with a series of samples, the molluscan assemblages have been divided into malacozones based upon the frequency or absence of biostratigraphic marker species, significant changes in the frequencies of more common taxa, the proportional representation of the various ecological groups and overall molluscan abundance. These have been further subdivided into subzones based upon finer differences between the assemblages. These malacozones reflect climatic variations and changes in the local floodplain environment due to natural warm period biosuccession within the floodplain forest or modifications within the fluvial regime linked to channel migration, channel morphology or fluvial aggradation/incision.

Earthworm granules are common in many samples, which is unsurprising as worms excrete large numbers of multi-crystalline calcite granules from their calciferous glands during their life-time, mostly in the upper 20 cm of a soil profile (Canti 1998). From their size and morphology, these granules were produced by *Lumbricus* species of earthworms, especially *L. terrestris* (Bräm 1956, Canti and Piearce 2003, Canti 2007). *Lumbricus terrestris* thrives in fairly damp, loamy soils where the pH is neutral or alkaline, there is a relatively abundant supply of surface leaf litter (Canti 2007) and the climate is relatively warm, as it is rarely found today north of 60°N in Europe (Tiunov et al. 2006).

Finally, although most of the analysed shell material is white and shows no traces of alteration, among the material from the Deckenschotter sites at Irchel, Albishorn-Bürglen and Hungerbol, there are small frequencies of shell fragments that have a notably different appearance, as they are light to darkish brown/light brownish-grey or dark-grey/grey/whitish. Moreover, although the surface of many of these fragments is rather well preserved, they all show some degree of recrystallisation within the interior of the shell structure, indicating that they have been eroded from significantly older molassic strata (see Section 3.1.1). Although the presence of these fragments has been noted in the results tables, no species identifications or frequencies have been recorded.



1	Stable, mature forest with trees of all ages and well-developed undergrowth
2	Dry, open forest
3	Younger forest, semi-forested scrub + tree-shaded rocks
4	Shaded habitats - including forest, scrub, vegetated rocks + dense tall herbs
5	Rupestral - living on rocks or stone walls
6	Tolerant - but requires some dampness
7	Tolerant of a wide range of habitats
8	Tolerant - but normally in drier habitats
9	Open ground
10	Open ground - in dry, well-drained locations
11	Marsh - shaded by trees or tall marsh plants
12	Marsh - normally among low marsh vegetation or on bare mud
13	Semi-aquatic - where drying out occurs regularly and can be for significant periods
14	Tolerant aquatic - tolerant of brief periods of drying out
15a	Permanent water aquatic - but tolerant of very brief periods of partial drying out
15b	Permanent water aquatic - intolerant of any drying out
15c	Permanent water aquatic - living in springs and subterranean habitats
16	Terrestrial – subterranean

Figure 2: The Ecological Groups used in the results tables for the Molluscan analyses (Appendix 1: Tables 1 to 45)

3 Molluscan faunas from the Höhere (Upper) Deckenschotter

3.1 The sites from the Irchel Plateau, ZH

Tables 1 to 4 present detailed descriptions of the stratigraphy, samples and sample processing for the profiles at Hasli, Steig, Hochwacht and Amselboden, which were excavated and documented between 2018 and 2021, as well as for Wilemerirchel that was investigated in 2021-2023. Tables 5, 6a and 6b present the results of the molluscan analysis for all of the Irchel sites for which material is available. Table 5 gives the results for profiles sampled between 1955 and 2017, while Tables 6a and 6b gives the results from all the profiles sampled between 2018 and 2022.

3.1.1 The stratigraphy of the Irchel Plateau

The earliest deposits of the Irchel Plateau are found at Irchel Ebni, with over 5 m of partially cemented, fine to coarse horizontal bedded fluvioglacial gravels (boulders up to 1 m) typical of a braided channel (the *Langacher-Schotter*; Graf in Preusser et al. 2011). These are succeeded by finely bedded fine to medium gravels, then by up to 0.8 m of cemented dark beige sands with some gravel and calcareous nodules, and then up to 1.6 m of olive-grey/grey sandy-silts and silts with bands and lenses of sand and fine gravel, nodules up to 10 cm, and staining by Fe and Mn (Graf 1993, p.35-36), truncated at the summit. The bedding structures, calcareous nodules and the presence of molluscs, ostracods and *Chara*, suggest that these sediments were deposited at the margins of a meandering river during a warm period (cf. Section 3.2). The silts are strongly deformed by what appear to be loading structures, caused by the weight of the overlying gravels.

There follows a unit of massive, horizontally-bedded fluvioglacial gravels from 13-25 m thick, known as the *Irchel-Schotter* (Graf in Preusser et al. 2011), which underlies much of the Plateau and is associated with a flow direction from SE to NW (Graf 1993, fig.22). The bedding structures are typical of a braided river that was active during a period of cold climate,[2] while their coarseness (boulders up to 1.5 m) suggests that at times the ice front was nearby. Mineral analysis has shown that these gravels were predominantly deposited by a river fed by the Walensee-Rhine Glacier, together with a smaller possible input from the Reuss-Aar Glacier (Graf 1993, p.19-21, 42-43).

Graf (1993, Preusser et al. 2011, p.285) identified a separate unit of fluvioglacial gravel up to 12 m thick, called the *Steig-Schotter*, which is horizontally bedded, has boulders up to 1 m and again seems to have been deposited by a braided river. These gravels have a notably higher proportion of dolomite, and were deposited by a channel flowing from S to N that cut the Irchel-Schotter at the south-eastern end of the Plateau. The Steig-Schotter underlies both Hasli and Steig and continues westwards as far as Buechemer Irchel, where there are signs of weathering and modest soil formation between these two gravel units

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[2] Numerous studies of fluvial behaviour during the Pleistocene in Northern, Western and Central Europe (e.g. Cordier et al. 2006) have established that the conditions necessary for the rapid deposition of coarse gravels by braided rivers in lowland situations were predominantly found during glacial periods (Gibbard and Lewin 2002, Antoine et al. 2003. See Miall 1977, 1996, plus Berendsen and Stouthamer 2001 for detailed descriptions and classifications of braided river deposits).

(Graf 1993, p.39), although the Steig-Schotter is always underlain by the Irchel-Schotter.[3] The greater part of all three gravel units is partially to heavily cemented, generating vertical cliffs around much of the Irchel Plateau in which the more or less horizontal bedding structures can be clearly observed. Clast morphometric analysis has confirmed a fluvioglacial origin for the Langacher, Irchel and Steig-Schotters (Dieleman et al. 2022a).

Overlying both the Irchel-Schotter and the Steig-Schotter are a series of interbanded silts and fine sands known as the *Hasli Formation* (HF), that contain a variety of biological remains, including mollusc shells, ostracods, *Chara* oospores, pollen, the teeth from small mammals and rare bone fragments from larger mammals. They represent overbank flood sediments deposited at the floodplain surface by a meandering river during a period of warm interglacial climate (cf. Sections 3.1.3 to 3.1.5). It is these deposits that have been studied at the five sites discussed here, with up to 6.2 m of the HF at Hasli, 4 m at Steig, 2.5 m at Hochwacht, 2.1 m at Amselboden and >1.6 m at Wilemerirchel. This unit is regularly present at the south-western margin of much of the Irchel Plateau, as illustrated by Graf (1993, fig.23), and can also be found intermittently at the north-eastern side of the Plateau (Thew et al. 2024). In the gravel quarry at Steig the HF is present in the southern wall of the quarry but becomes notably thinner in its north-eastern wall, suggesting that the HF may thin from SW to NE. The HF seems to be missing between Schartenflue and Hörnlihalden, where the ground surface dips below c.665 m asl due to later erosion. At Hochwacht there are up to 0.3 m of sands with fine gravel that overlie 0.2 m of very sandy fine to medium gravel at the base of the HF that include warm-period molluscs, while at Amselboden there are up to 1 m of bedded sands over 0.2 m of sandy fine gravels that also have molluscs. These sediments represent a sandy facies at the base of the HF (Tables 3a and 4; cf. Graf 1993, fig.14D), and suggest that the river that deposited the HF probably flowed to the SW of the Irchel Plateau.

At Hochwacht, the silts and sands of the HF are succeeded by up to 4.5 m of fluvial gravels with fairly regular gently inclined bedding, newly named the *Hochwacht-Schotter.*[4] In their upper part they include a number of silty soft clasts and a little above these a large lens of finely-bedded silts and fine sands, c.2.5 m wide by up to 0.4 m thick, which lies c.1.2 m below the summit of these gravels. The largest of the soft clasts (0.37 x 0.11 m) yielded a rich molluscan assemblage typical of a forested interglacial floodplain environment (cf. Section 3.1.7), while the sandy lens had a similarly abundant well-preserved molluscan fauna, together with aquatic shells indicating gently flowing water within a meandering channel. The molluscs clearly indicate that the sandy lens and surrounding gravels were deposited during a warm interglacial period by a meandering river in an 'upper channel' that lay a little to the NE of the original river channel, (cf. Section 3.1.7). This evidence means that the Hochwacht-Schotter and the associated fine sediments cannot be correlated with the cold climate deposits of the Forenirchel-Schotter (see below). Graf included the Hochwacht-Schotter within the Forenirchel-Schotter complex, although the flow direction shown by a sample from the Hochwacht gravels is SSW to NNE, in sharp contrast to the flow direction shown by the fluvioglacial gravels of the Forenirchel-Schotter, which is ESE to WNW (Graf 1993, fig.22).

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[3] A petrographic analysis at the base of the Plateau gravels at Berghof (Graf 1993, GA3) clearly shows that they correspond to the Irchel-Schotter (just 0.5% dolomite).

[4] These gravels are better sorted and lack the large boulders found within the braided river gravels of the Irchel-, Steig- and Forenirchel-Schotters.

At all sites the upper levels of the HF are truncated by erosion, with this being especially severe at Amselboden. Here, a clear erosion surface is succeeded by 0.3-0.6 m and 0.6 of olive-brown matrix-supported strongly weathered gravel, with no preferred clast orientation, and frequent decomposed sandstone pebbles, separated by 0.25-0.55 m of sterile sand. Above this comes 1 m of similar but only moderately weathered olive-grey matrix-supported gravel, which has a soft-clast >0.7 m across of brownish-grey sandy-silt with pebbles that seems to be glaciogenic. All three gravels (Layers 6 to 8b) have a clast petrography dominated by sandstones and with no limestone clasts, which corresponds to the newly defined *Amselboden-Schotter* (Thew et al. 2024). Above this comes 0.1 m of sterile laminated glaciogenic silt, followed by >2 m of brownish-olive-grey more sandy gravel, with mostly sub-horizontal or imbricated clasts, which also represents the Amselboden-Schotter (Layers 9 to 10, Table 4a). At Hasli the HF is capped by 0.2 m of strongly weathered fine-medium matrix-supported silty gravel with frequent clasts of decomposed sandstone that also represents the Amselboden-Schotter (Layer 3), succeeded by 0.5 m of glaciogenic deposits (Layer 2, Table 1), while at Steig the HF is directly succeeded by 0.8 m (Layers 4 to 2, Table 2b) of more or less gravelly glaciogenic deposits. At Hochwacht East the Hochwacht-Schotter is truncated by an erosion surface that is followed by 0.4 m of strongly weathered fine-medium, matrix-supported silty gravel with no preferred clast orientation and frequent decomposed sandstones, which may also correspond to the Amselboden-Schotter (Layers 4, Table 3a), succeeded by 0.8 m of glaciogenic sediments (Layers 3 and 2), while at Hochwacht West the Hochwacht-Schotter is directly succeeded by c.0.9 m of glaciogenic deposits (Layer 22, Table 3b). In the south-western part of the Irchel Plateau that has the study sites, the HF or the Hochwacht-Schotter are thus succeeded by either the Amselboden-Schotter or glaciogenic deposits. At Forenirchel and Buechemer Irchel, the Amselboden-Schotter may be covered by sandy fluvioglacial gravels that correspond to the youngest Höhere Deckenschotter (HDS) unit from the Plateau, which Graf has called the *Forenirchel-Schotter* (1993, Preusser et al. 2011, fig.3). By contrast, at the north-eastern margin of the Plateau, at Wilemerirchel, Schaffhuser and Rütelbuck, the HF is directly succeeded by the Forenirchel-Schotter, while the Amselboden-Schotter is missing (Table 4b). At these sites the gravels of the Forenirchel-Schotter are largely cemented, reach up to over 8 m thick, and are capped by around 1 m of the same glaciogenic deposits seen across much of the Plateau. In Graf's figure the Forenirchel-Schotter is up to 18 m thick, although this seems to include all of the deposits that succeed the HF, and covers the highest parts of the Plateau between Forenirchel, Buechemer Irchel and Wilemerirchel. The glaciogenic deposits documented in the profiles at Hasli, Steig and Hochwacht and also observed at Wilemerirchel, may correspond to the strongly weathered later Early/Middle Pleistocene tills that are shown on the geological map for this area (Haldimann et al. 2017, p.60), although these have never been dated or characterised petrographically.

3.1.2 Overview of the molluscan faunas

Molluscan material that predates the NAGRA excavations of 2018-22 includes shells recovered by Bräm in 1955 at Hasli (Bräm 1956), the 1990/91 Graf sites at Hochwacht NE and Forenirchel (Graf 1993), the Bolliger/Kälin dig at Hasli in 1994/95 (Bolliger et al. 1996), and the NAGRA excavations at Ebni and Hasli in 2017. Some preliminary identifications of the Bräm material were made by L. Forcart, of the Graf molluscs by H.

Turner, and of the 1994/95 shells by T. Bolliger. While some identifications needed revising, most of the material remained unstudied, which is why all of the shells have been completely reanalysed for this study. The results of the new analysis are shown in Table 5. In total, there are shells from a minimum of 7,602 individuals, including 7,384 terrestrial molluscs from 65 species and 218 aquatic molluscs from 10 taxa. The great majority of the shells are from the Bräm material and from other samples taken at Hasli where sieve residues were available that could be re-sorted for shell fragments.

During the NAGRA excavation at Hasli in 2018/19, a column of 37 samples was taken through the whole of the HF. All but one of these have been analysed. In addition, 7 large samples were taken in 2018/19 to recover small mammals remains, and the molluscs from 3 of these have been added to the sequence. In total, shell material from a minimum of 21,204 individuals has been identified, including 19,885 terrestrial molluscs from 64 species and 1,319 aquatic molluscs from 14 taxa (Table 6a).

During the 2018/19 NAGRA excavation at Steig West, a series of 24 samples were taken in two columns through the HF. Of the 22 processed, 8 have been fully analysed, 1 partially analysed and 9 more have been scanned. The 9 analysed samples have yielded shell material from a minimum of c.6,400 individuals, including c.5,550 terrestrial molluscs from 44 species and c.850 aquatic molluscs from 14 taxa (Table 6a). In a new profile from Steig East in 2020, 16 samples were taken. Of these, 14 have been fully analysed and 2 partially analysed. In total, there is shell material from a minimum of c.5,150 individuals, including c.5,050 molluscs from 50 terrestrial species and c.100 molluscs from 7 aquatic taxa. Steig has thus yielded total shell material from a minimum of c.11,550 individuals, including c.10,600 terrestrial molluscs from 52 species and c.950 aquatic molluscs from 16 taxa.

During the NAGRA excavation at Hochwacht in 2019, 15 samples were taken from the HF at Hochwacht East and 4 at Hochwacht West. Of these, all 15 from Hochwacht East have fully analysed, while of 4 from Hochwacht West, 1 from the ‘upper channel’ has been fully analysed and 3 from the HF have been partially analysed (Table 6b). In addition, 3 more samples were taken in 2021 at Hochwacht West in the fine deposits of the ‘upper channel’, all of which have been partially analysed. The 18 samples from the HF have yielded a minimum of c.16,175 individuals, including c.15,540 terrestrial molluscs from 70 species and 635 aquatic molluscs from 19 taxa. The 4 samples from the ‘upper channel’ have yielded a minimum of c.9,745 individuals, including c.9,600 terrestrial molluscs from 72 species and 144 aquatic molluscs from 18 taxa. This gives a total for Hochwacht of c.25,920 individuals, including c.25,140 terrestrial molluscs from 81 species, and 779 aquatic molluscs from 23 taxa.

Of 6 samples taken from the HF during the 2021 NAGRA excavation at Amselboden, 3 have been fully analysed and 3 partially examined. These samples have yielded a minimum of c.5,600 individuals, including c.5,500 terrestrial molluscs from 58 species and c.100 aquatic molluscs from 11 taxa (Table 6b). Five samples taken in the HF during the NAGRA excavation at Wilemerirchel in 2021-2023 have been partially analysed. These have yielded a minimum of c.3410 individuals, including c.3390 terrestrial molluscs from 56 species and 21 aquatic molluscs from 4 taxa (Table 6b). Three samples taken during a small excavation by NAGRA at Hütz in 2019 proved to be sterile for sub-fossil shells (Table 6a), but as the samples come from near the base of the modern forest soil, shells and fragments from recent molluscs were found that provide a useful comparison for the sub-fossil faunas from Irchel. Of the 36 terrestrial species present in the deciduous forest that covers the Irchel Plateau today, 10 were not found in any of the samples taken from the HF.

A detailed examination of available documentation by D. Kälin has shown that the Bräm material (shells and small mammals) comes from the HF at Hasli. The site assemblages from the 1955 and 2018/2019 excavations have 54 terrestrial species and 8 aquatic taxa in common, including most of the major biostratigraphic indicators, which means that the total site assemblage from Hasli has 69 terrestrial species and 15 aquatic taxa. The archived Bräm material is labelled as coming from levels “5m” and “5o”, which is taken to mean “5mittlere” (5middle) and “5obere” (5upper), although Bräm’s original field notes have unfortunately been lost. A comparison between this material and the assemblages from the 2018 sequence at Hasli demonstrates that the Bräm shells and small mammal remains probably come from two large bulk samples, 5m and 5o, which correspond to the two main levels recognised in 1994/95 that contain both small mammal remains and abundant shells (2018 Layers 23/22 and 13/12). Unfortunately, at some stage during storage the sieve residues from the two samples became mixed together, so the Bräm shells can only be treated as a whole. Moreover, there are no sieve residues available to be resorted from the samples taken in 1994/95 from the rich upper level, meaning that some important information has been lost. This means that the molluscan material from the 2018/2019 samples represents the reference sequence for this site.

Thus, for all of the Irchel sites sampled between 1955 and 202 (Tables 5, 6a, 6b), a minimum of c.75,280 individuals have been identified, which includes c.71,890 terrestrial molluscs (95.5%) coming from 89 species and c.3,390 aquatic molluscs (4.5%) from 28 taxa. Of these, the HF has 83 terrestrial and 27 aquatic species from 104 samples, while the ‘upper channel’ has 72 terrestrial and 18 aquatic taxa from just 4 samples. This represents an exceptional faunal assemblage for both Switzerland and for Western and Central Europe as a whole, as it matches or surpasses the most important sites for Pleistocene molluscan palaeontology known from this area.

Of the five principal sites studied from the Hasli Formation, Hochwacht has the most diverse faunas for both terrestrial (71 species) and aquatic molluscs (19 taxa), while Hasli comes second for terrestrial species if the Bräm material is included (69), but is third for aquatic taxa (15). Amselboden has 58 terrestrial and 11 aquatic species, while Wilemerirchel has 56 terrestrial and 4 aquatic taxa. Steig has a notably poorer terrestrial fauna (52 species), but comes second for aquatic taxa (16). By contrast, the fine deposits from the ‘upper channel’ at Hochwacht have the most diverse faunas of all, with 72 terrestrial and 18 aquatic taxa. As the majority of significant molluscan biostratigraphic marker species are present at all five sites (Figures 3, 8 and 10, cf. Section 5.5.1), while the faunas and the sediments indicate very similar climatic, environmental and sedimentological conditions, this indicates that the sites were all more or less concurrent and that the HF represents a single stratigraphic entity. The molluscs from the HF at Forenirchel (Graf 1993, p.41) include several of the same marker species, so were also probably contemporary. By contrast, although the molluscan faunas from the fine sediments of the ‘upper channel’ share the same biostratigraphic marker species and have a similar climatic, environmental and sedimentological context, they include 5 terrestrial

Terrestrial Molluscan species (never before found in CH [Switzerland] unless marked with *; extinct †)	Period when last present in the Swiss Plateau	Biostratigraphic details	Modern or palaeo-distribution relative to CH	Climate status	Hasli (Pt = Part)				Steig East & West				Wilemer -irchel	Foren-irchel (Graf 1993)	Amselboden		Hochwacht East & West				Hoch-wacht 'Upper level'	Albishorn-Bürglen 2		Albishorn -Bürglen 1	Hungerbol 2
					Pt 1	Pt 2	Pt 3	Pt 4	Pt 1	Pt 2	Pt 3	Pt 4			Pt 1	Pt 2	Pt 1	Pt 2	Pt 3	Pt 4		P1E	P2		
Aegopinella ressmanni	Eemian Interglacial	still living, absent from CH after Eemian	E	Int	x	x	x	x		x	x		x	x	x	x	x	x	x	x	x	x	x	x	x
*Discus perspectivus**			E	Int									x			x	x	x	x		x				
Urticicola umbrosus	later Middle Pleistocene 0.48-0.13 Ma	still living, absent from CH after MIS 7	E, NE	Int	x	x	x	x			x		x		x	x	x	x	x	x	x	x	x		
Clausilia pumila		still living, absent from CH after MIS 11 or MIS 9	E, NE																		x			x	x
*Perforatella bidentata**			E, NE		x	x	x	x			x		x				x	x	x		x		x		x
Clausilia rugosa antiquitatis†		globally extinct after MIS 11	C. Europe	Int	x	x	x	x			x		x		x	x	x	x	x		x		x		x
Neostyriaca corynodes ornatula†	Early Pleistocene or early Middle Pleistocene before 0.48 Ma	globally extinct after MIS 13	E		x						x		x		x	x		x	x		x	x	x	x	x
*Causa holosericea**		still living, never before identified from pre-Holocene strata in CH	S, SE, E	Int ws																	x				
*Ciliella ciliata**		still living, never before identified in CH north of the Alps	S, SW, SE	Int ws									x					x	x		x				
*Oxychilus clarus**			S, SE	Int ws												x		x	x		x				
Macrogastra densestriata	later Early Pleistocene (EP3) 1.22-0.77 Ma	still living, probably absent from CH after EP3	E	Int ws																		x	x		x
Monachoides vicinus			E	Int ws		x	x	x			x		x		x		x	x	x		x	x	x	x	x
Trochulus filicinus			SE	Int ws	x		x				x	x	x	x	x	x	x	x	x		x	x	x		x
Azeca goodalli	middle Early Pleistocene (EP2) 1.78 - 1.22 Ma	still living, possibly absent from CH after EP1 or EP2	NW, W, SW	Int mw	x	x	x	x			x	x	x			x	x	x	x	x	x				
Cepaea nemoralis			W, SW	Int mw									x								x				
Soosia diodonta			SE	Int ws									x												
Trochulus leucozonus			SE	Int ws		x							x			x	x	x	x		x		x		
Retinella elephantium†		globally extinct after MIS 11, absent from CH after EP1 or EP2	W, SW	Int mw			x			x	x		x			x	x	x	x		x		x		
Acicula parcelineata	older Early Pleistocene (EP1) 2.6 -1.78 Ma	still living, probably absent from CH after EP1	E	Int vws														x			x		x		
Poiretia dilatata dilatata			S	Int vws									x			x	x	x	x		x		x		
Spermodea lamellata			NW, W	Int mw			x								x			x	x						
Serrulella sp.†		globally extinct after EP3, probably absent from CH after EP1	S, E	Int ws									x				x	x							
Archaegopis (Retinella) acutus†		globally extinct after EP2, probably absent from CH after EP1	SE, E	Int ws			x						x			x	x	x	x		x		x		
Macrogastra sessenheimensis†			E	Int ws	x	x	x				x		x	x		x	x	x	x		x	x	x		
Oxychilus steiningeri†			E	Int ws																	x				
***Clausilia stranzendorfensis*†**		globally extinct after EP1	E	Int ws	x	x	x	x			x		x	x		x	x	x	x		x	x	x		
***Cochlostoma salomoni*†**			W, SW	Int mw	x	x	x	x		x	x		x	x	x	x	x	x	x		x	x	x		
Neostyriaca dehmi†			C. Europe	Int												x		x							
Triptychia new sp.†			S, E	Int									x												

Climate key: Int = Interglacial indicator species; Int ws = with notably warm summers, Int vws = with very warm summers; Int mw = with very mild winters

Species in bold = principal biostratigraphic marker species for the older Early Pleistocene in Central Europe.

The older Early Pleistocene (2.6–1.78 Ma) = Gelasian; middle Early Pleistocene (1.78–1.22 Ma) = Santernian + Emilian Stages of the Calabrian; later Early Pleistocene (1.22–0.77 Ma) = Sicilian Stage of the Calabrian

Figure 3: Important Molluscan species for Early Pleistocene biostratigraphy and climate from the Irchel Plateau, Albishorn-Bürglen and Hungerbol, based on the new analyses from Switzerland and a wider literature search

and 1 aquatic taxon not found in the HF and seem to be somewhat younger, in keeping with their stratigraphic position, although they clearly belong within the same time period.

Finally, most samples from all four study sites have redeposited fragments of mollusc shell (see Section 2) from both terrestrial and aquatic species. There are slightly recrystallised shell fragments with a brown/light brown/pale brownish-grey colour from species that closely resemble Quaternary genera, such as *Aegopinella*, *Cepaea*, Clausiliidae, *Discus*, *Isognomostoma*, *Monachoides* and *Trochulus*, plus *Bithynia*, *Lymnaea*, *Stagnicola*, *Radix*, *Gyraulus*, *Planorbarius*, *Planorbis* and *Valvata*. These seem to have been redeposited from the upper part of the Upper Freshwater Molasse (UFM), possibly the early Tortonian (Rahn and Selbekk 2007). There are also more heavily recrystallised fragments with a black/dark grey colour, which come from similar terrestrial and freshwater genera to those listed above, but are significantly different from the species seen in the Quaternary, indicating that they come from an older part of the UFM, possibly the Langhian.

3.1.3 The Sedimentary environment linked with the Hasli Formation

3.1.3.1 Accumulation of the Hasli Formation and sedimentary cycles

Within the Hasli Formation, the constant presence of varying quantities of aquatic and marsh molluscs, together with a dominant component of non-marsh terrestrial molluscs that include many from forest and shade-loving species, is consistent with accumulation taking place within the floodplain of a lowland meandering river (Figures 4a and 4b). This is entirely in keeping with the nature of the sediments, which are predominantly silts and fine sands deposited by flood waters. The up to c.6.2 m of fine sediments at Hasli suggests that for a prolonged period the fluvial regime was associated with regular episodes of significant flooding. Despite the strong representation of forest species within the molluscan assemblages, showing that the surrounding area was largely wooded, the upper parts of the drainage basin lay within the Alps where the vegetation cover was much poorer and there was notable seasonal melting. This would have encouraged significant surface run-off, which would in turn have led to notable fluctuations in discharge and to regular flood events (Butzer 1982, Chap. 8), with the intensity of flooding being largely determined by precipitation and melting (Wetter et al. 2011).

There are significant vertical variations within the nature of the HF sediments that are reflected in the molluscan faunas (Figures 4a and 4b). The sandy facies at the base of the HF at Hochwacht and Amselboden, for example, is associated with poor faunas that suggest seasonal flow and rapid accumulation at the margin of an active channel. Beneath these sands at both sites are c.0.2 m of very sandy fine to medium gravel with low frequencies of rather corroded mollusc shells, which seem to represent the bed deposits of the meandering river that generated the flood sediments of the HF. This evidence also indicates that these two sites lay nearer to the river than Hasli and Steig, showing that it used to flow to the south-west of the Irchel Plateau.

When the molluscan faunas from the 2018/19 profile at Hasli are compared with the lithology of the sediments, it appears that the sequence can be divided into four stratigraphic units, labelled ‘Parts’ 1, 2, 3 and 4 in Tables 1 and 6a. These units seem to represent four upward-fining sedimentary cycles, with sandier deposits at the start of each

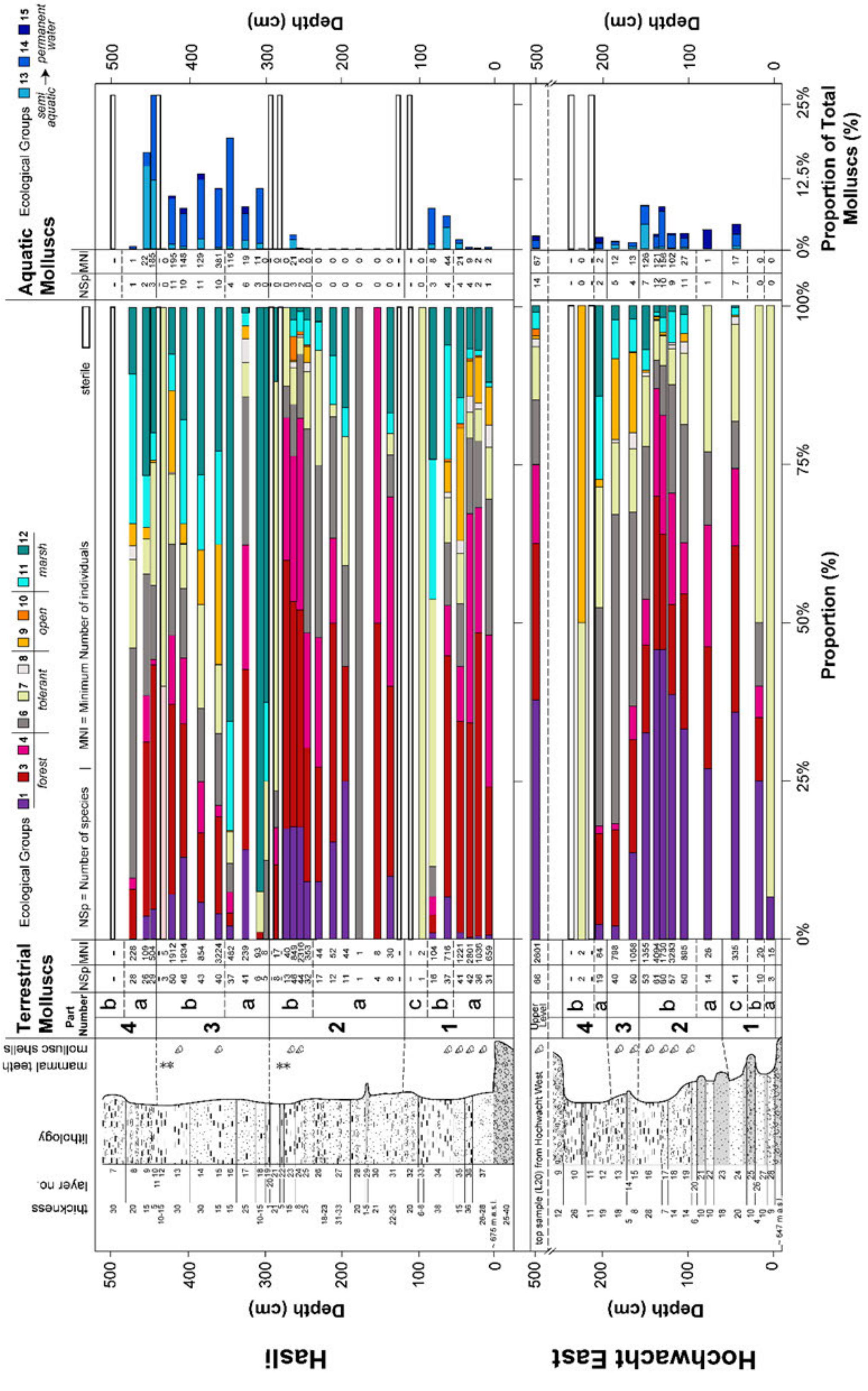

Figure 4: Composition of the molluscan faunas in the Hasli and Hochwacht East profiles, showing variations in forest, tolerant, open ground and marsh species, as well as aquatic molluscs, in addition to molluscan frequencies and the number of species.

cycle indicative of rapid accumulation, succeeded by siltier sediments, and then by silts with clay and signs of pedogenesis as accumulation slowed at the end of each cycle. Cycles 2 and 3 ended with the formation of thin layers of humified lignite, showing a virtual cessation of sedimentation. Evidence for incipient soil formation at the end of each cycle includes the presence of frequent small Fe and Mn concretions caused by the mobilisation of Mn and Fe, and notably poorer molluscan preservation, with surface corrosion caused by leaching. Poor shell preservation is shown by sharp increases in the proportions of slug plates and fragments from large thick-shelled species (Figure 4). The changes in both the sediments and their associated molluscan faunas at the end of each cycle were rather rapid. These cycles appear to be strongly linked to variations in the intensity of flooding. There also appears to be a trend for fining-upwards through the sequence as a whole, with the sediments of Parts 1 and 2 at Hasli being significantly sandier than those of Parts 3 and 4. Interestingly, the thicknesses of the four Parts at Hasli are 1.20, 1.70, 1.45 and 1.85 m, which might suggest a certain periodicity.

The sequences at Steig and Hochwacht can similarly be subdivided into ‘Parts,’ based on evidence from the sediments and the molluscs, which also appear to reflect the influence of sedimentary cycles, although erosion at both sites has made such cycles more difficult to identify (Tables 2a, 2b, 3a, 3b, 4, 6a, 6b). Although all of the documented sequences through the HF include erosion surfaces, these are more frequent at Steig than at Hasli and even more so at Hochwacht and Amselboden. Erosional loss of sediment at the floodplain surface is likely to have been caused by major flood events, which explains why erosion seems to have been more frequent and severe at Hochwacht and Amselboden, as they lay nearer to the main channel. Molluscan assemblages and lithological evidence (Tables 1 to 4, 6a, 6b) has been used to correlate the sequences between Steig West and Steig East and between Hochwacht East and West with a fairly high degree of confidence (Figures 5 and 6). By contrast, the effects of erosion together with differences in the nature of the sediments between the sequences at Hasli, Steig and Hochwacht has made correlation between these sites more problematic, so although there are malacological and sedimentological grounds to attempt such correlations, these must remain tentative.

At both Hasli and Hochwacht the transition from Parts 1 to 2 is marked by a significant decline in molluscan frequencies, while at both sites forest species increase during Part 2 and there is a clear tendency for marsh snails to decline during the upper levels of Part 2 (Figures 4a and 4b). At Hasli and Steig the transition from Parts 1 to 2 coincides with a horizon strongly influenced by pedogenetic processes, as well as a rise in the proportion of forest species during Part 2. At all three sites Part 3 is marked by significant increases in the proportions of open ground and marsh molluscs, a decline in the proportion of forest species and by notably better shell preservation due to the reduced influence of soil processes (Figures 4a and 4b). There were also significant increases in aquatic molluscs at Hasli and Steig West. All three sites show a dramatic decline in molluscan numbers at the start of Part 4a, while shell preservation is considerably worse. Part 4b saw the disappearance of mollusc shells and a much greater impact from soil processes at all three sites, including Hochwacht, where the burial of the HF by the Hochwacht-Schotter demonstrates that this was not caused by soil processes during a later period.

At Steig West, by far the most important episode of erosion seems to have occurred at the start of Part 4b, where marked incision was associated with the formation of a channel

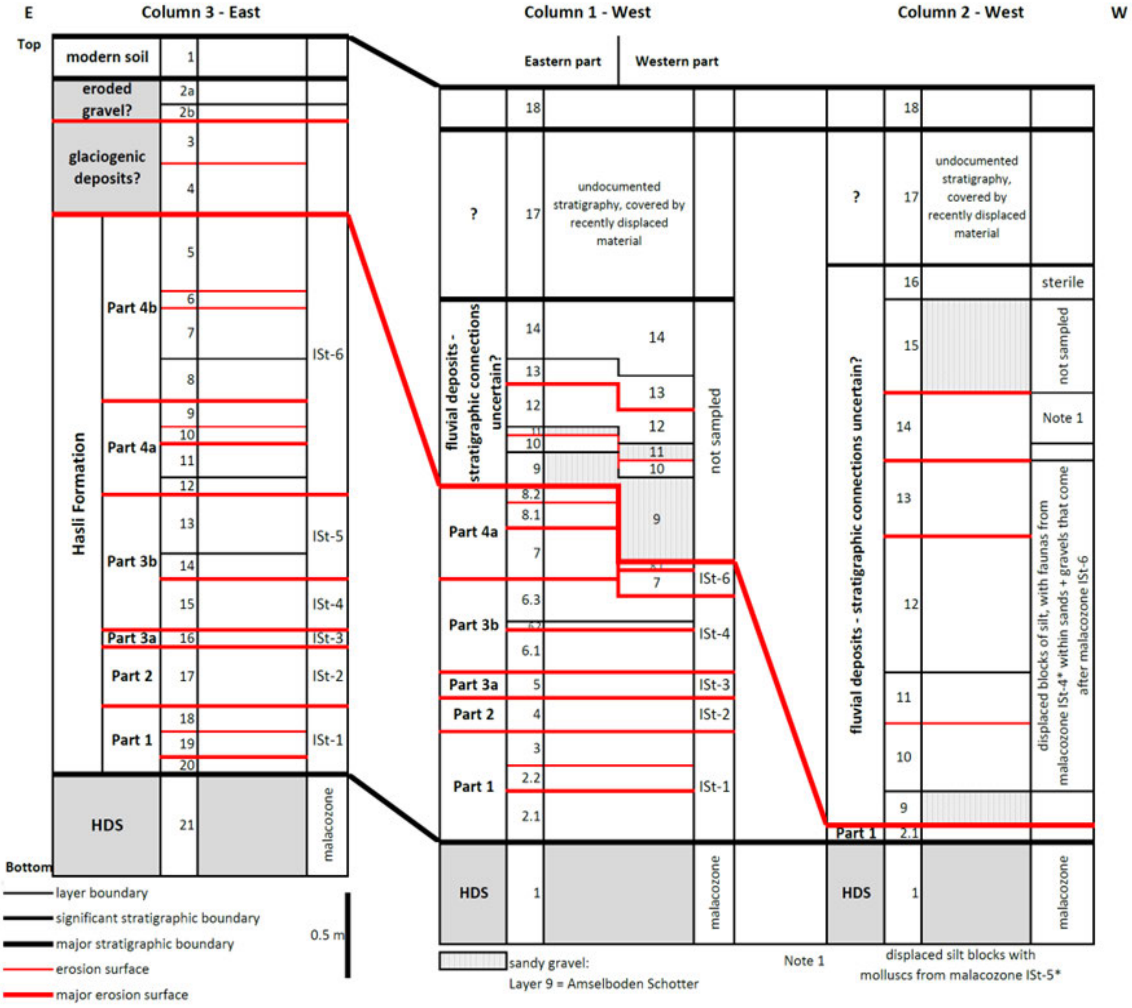

Figure 5: Irchel Steig 2018-2020: correlations between the two sample columns based on lithostratigraphy and malacozones

c.11 m wide by >3 m deep (4 m wide at its deepest part), eroded into the HF sediments, which subsequently became infilled by sandy gravel and angular blocks of silty HF material collapsed from the banks. The infill is interrupted by at least three further erosional events, which can perhaps also be observed within the flood-plain sediments at Steig East if the correlation between the two profiles is correct (Figure 5). The morphology of this small channel (moderate width: depth ratio) and the nature of the infill suggests that it may have been an overflow for the main river channel (that was originally located not far to the south-west), which only functioned during episodes of severe flooding. This would explain why both the erosional events and subsequent accumulation appear to have been rather rapid, with angular blocks of HF sediment collapsed from the banks of this channel and deposited with little or no rounding.

At Hochwacht, the nature of the sediments and their associated molluscan faunas is rather similar in East and West (Tables 3a, 3b, 6b), but the thicknesses of the four units have been significantly affected by erosional events that led to a lowering of the floodplain surface near the active channel (Figure 6). The most important lowering occurred at the base of Part 3, soon after increases in aquatic and marsh molluscs at the end of Part 2 heralded the start of notably damper conditions (Figure 4).

At Amselboden the upper part of the Hasli Formation has been truncated by later erosion. There is no evidence for the increase in open ground molluscs coupled with damper conditions seen in Part 3 at the other sites, meaning that the equivalents of Parts 3 and 4 are probably missing (Tables 4, 6b).

3.1.3.2 Lateral variation within the floodplain deposits

Variations in the faunal diversity and species representation between both the four study sites and the columns taken at Steig and Hochwacht are due to modest lateral differences in the local floodplain environment, as well as to taphonomic processes linked with sedimentation within a complex floodplain setting. Differences within the floodplain environment seem to have been largely due to proximity to the active channel, as well as to variations in drainage conditions at the floodplain surface.

Comparing the assemblages from Hasli sampled by Bräm in 1955, Bolliger and Kälin in 1994/95 and NAGRA in 2018/19, there are some notable differences in species representation despite the overall faunas being very similar. The Bräm samples include 4 species not found in the 2018/19 column, while the new samples have 10 taxa not present in Bräm (Tables 5 and 6a). Unlike the 2018/19 sequence that was sampled in its entirety, Bräm only seems to have sampled the two levels where faunal remains were most abundant (cf. Sections 3.1.2, 3.16). Of the species present in both sequences, *Cochlostoma salomoni* is rare in the Bräm material but rather frequent in the 2018/19 column, while *Trochulus filicinus* is abundant in the Bräm samples but only moderately common in the profile (Figure 7). These differences are due to lateral variation within the HF, caused by the complexities often linked with floodplain sedimentary environments. The 2018/19 profile, like the samples from the 'upper level' in 1994/95, were taken at the NW edge of HF sediments exposed by a major landslip at Hasli in the early 1950's, while the Bräm samples may have been taken up to 40 m away given the width of the exposure. Indeed, the sample from the 'lower level' in 1994 was taken c.20 m further to the SE than the lower level (equivalent to Part 2) in the 2018/19 profile, and the assemblages are somewhat different in their representation of both terrestrial and aquatic species.

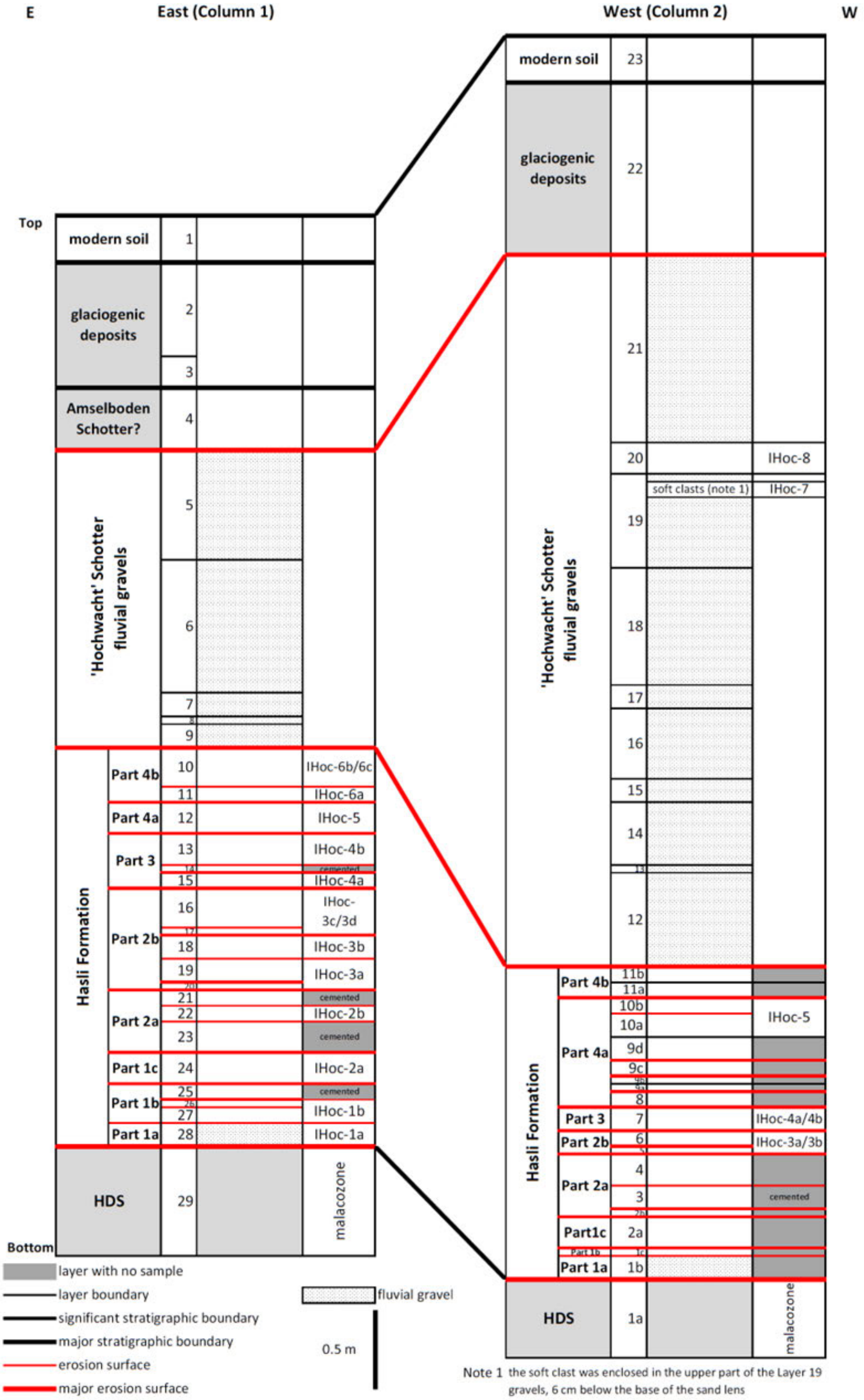

Figure 6: Irchel Hochwacht 2019-2021: correlations between the two sample columns based on lithostratigraphy and malacozones

At Steig, there are significantly more shells from aquatic and marsh species in the Steig West profile than at Steig East, showing that the former probably lay nearer to the active channel. By contrast, there are greater frequencies of forest and shade-loving molluscs in the eastern profile, while the number of terrestrial species is notably higher (50 as opposed to 44). At Hochwacht there were far fewer samples taken at Hochwacht West than at Hochwacht East and only the aquatic molluscs were fully counted. Although there are no significant differences in the representation of aquatic molluscs between the columns, Hochwacht West seems to have fewer marsh molluscs but notably more from open ground and tolerant species than the equivalent layers at Hochwacht East.

3.1.3.3 Taphonomic processes affecting accumulation of the molluscs

Although the great majority of molluscs identified from the Irchel sites are from terrestrial species (95.3%), the constant presence of aquatic shells is in agreement with the alluvial nature of the Hasli Formation sediments (Figures 4a and 4b). Shells from terrestrial species tend to be either washed into rivers by run-off flow or carried into the channel by retreating flood-waters, thus reflecting the vegetation that grows nearer to the edge of the active channel. This explains why assemblages can include species indicative of both dense mature forest and poorly vegetated open areas. There is also evidence for shell material entering the flood plain by mass movement or more severe surface run-off, with the clearest example being Layer 17 from Hasli, where an influx of forest molluscs together with a few small stones, coincides with a sharp fall in marsh snails. Aquatic shells may accumulate within a river channel either more or less *in situ*, or be carried down-stream to be deposited in places where the current slackens. This is particularly true for shells that do not float well, like bivalves. Alternatively, aquatic shells that can float may be deposited on the floodplain surface by retreating flood waters, especially if they float well like some gastropod species (*Valvata* spp., Planorbid spp.). Aquatic material like ostracod valves and *Chara* oospores may also be transported and deposited.

Within the Irchel sequences, sandy sediments with poor molluscan assemblages, such as the samples from Hasli Part 2a, appear to reflect rapid accumulation linked with fairly energetic flood waters fairly near to the main channel (Tables 1 and 6a). The same seems to be the case for sandy sediments in Part 1 at Steig West and Steig East, Hochwacht East Parts 1 and 2a, and Part 1 at Amselboden, which although they have rather poor molluscan assemblages, include rare opercula from *Bithynia tentaculata* that cannot float (Tables 2b, 3a, 3b, 4, 6a and 6b; Figures 4a and 4b). By contrast, sandy sediments containing much richer assemblages, such as those from Hasli Part 1 and Hochwacht East Parts 2b and 3 may have been generated by a mix of flooding and run-off flow from nearby woodland, which would explain their rich woodland faunas. More silty and clayey sediments associated with rich molluscan faunas, such as those of Hasli Parts 2b, 3 and 4a, Steig Part 3b and Amselboden Part 2, indicate slower sedimentation with an element of decantation in shallow standing water fed by seasonal flooding.

The other set of taphonomic processes that greatly influenced the molluscan assemblages within the HF deposits, were post-depositional. The shells of Hasli Parts 1, 2a and much of 2b, Steig Parts 1 and 2, Hochwacht Parts 1, 2a and much of 2b and Amselboden Part 1, for example, were significantly affected by surface corrosion. This was due to seasonal drying out at the floodplain surface that allowed pedological processes such as leaching, as well as drying out and pedological processes in the upper levels of Parts 1, 2, 3 and 4, caused by less intensive flooding activity, which led to the partial or complete dissolution of much of the shell material. At Hochwacht East pedological processes and a fluctuating water table led to the presence of shells encrusted with oxides of Fe or Mn, and shells filled with secondary precipitated calcite or iron oxide. By contrast, much of Hasli Part 3, Steig Part 3 and Hochwacht East Part 3 had much better preservation due to considerably wetter conditions. In Hochwacht West Part 3, some of the shells are exceptionally well preserved, although many of them are filled with secondary calcite, which suggests permanently waterlogged conditions with percolating ground-water.

3.1.4 The Local Terrestrial palaeoenvironment

A great majority of the shells identified from the Hasli Formation at all four sites come from non-marsh terrestrial species, of which most are from forest, shade-loving, or ecologically tolerant species that live in a wide variety of habitats including woodland (Figures 4a and 4b; Tables 5, 6a and 6b). Molluscs typical of open-ground form only a limited proportion of most assemblages. The terrestrial molluscs thus give an image of an floodplain environment with rather dense, fairly damp, mature, mainly deciduous woodland with large trees and a rich understory of tall herbs and young trees, with increasing proportions of marsh species nearer to the main channel. The molluscan sequences from the study sites appear to reflect biosuccessional processes within the floodplain forest, as well as changes in the floodplain environment linked with flooding activity and fluctuations in the water table.

In the molluscan faunas from the 2018/19 sequence at Irchel Hasli, the gradual arrival of new forest and shade-loving taxa during Parts 1, 2 and 3 is linked with biosuccessional development. This shows the fairly rapid progression from moderately open, rather damp, mixed coniferous and deciduous forest during Part 1, to rather dense, fairly moist, mature, mainly deciduous woodland with large trees and a rich understory of tall herbs and young trees during Parts 2 and 3 (Figure 4, Table 6a). This is in good agreement with pollen data from Part 2 (Layers 23, 20), which gives an image of mixed coniferous and deciduous woodland with tree species like *Pinus*, *Picea* and low frequencies of *Acer*, *Alnus*, *Betula*, cf. *Castanea*, *Corylus*, *Fagus*, *Quercus* and *Tilia*, typical of a warmer climate (Thew et al. 2024). Modest decreases in forest and shade-loving mollusc taxa during Part 3, a sharp rise in open ground molluscs at the start of Part 3b, and a much more marked decline in forest molluscs during Part 4a, point to some opening out of the forest and fewer large mature trees. This is paralleled by increases in marsh and aquatic molluscs which show that conditions became notably damper during Part 3a, and even more so during Parts 3b and 4a. The poorly preserved pollen from Part 3 (Layers 19, 12, 11) points to more open, largely coniferous woodland dominated by *Picea* and *Pinus*, with some *Abies* and *Quercus*, possibly suggesting somewhat cooler conditions. Interestingly, the sequence shows clear differences between the frequencies of some of the forest species during Parts 1 to 3, notably *Trochulus filicinus* and *T. leucozonus* (Figure 7). This might reflect responses in the forest flora and fauna to altered local conditions within the floodplain (such as damper conditions during Part 3). When compared to Holocene molluscan sequences, such as that studied at Abri Unterkobel/Oberriet (SG; Thew 2022), it is evident that the sequence at Hasli must have taken thousands of years to accumulate, given the clear evidence for both biosuccessional development linked to evolution of the forest, and for significant differences in the suite of forest species between Parts 1, 2, 3 and 4a.

The faunas from Hochwacht and Amselboden show a much more rapid progression during Parts 1 and 2 to rather dense, relatively moist, mainly deciduous woodland, with large mature trees and a rich understory of tall herbs and young trees, as shown by the arrival of new forest and shade-loving species (Figure 4, Table 6b). At Hochwacht, like at Hasli, there are signs of a significant opening out of the forest linked with damper conditions during Part 3 of the sequence, signalled by decreases in the proportions of forest and shade-loving molluscs, a loss of some forest species, significant rises in open ground and tolerant species and a modest increase in marsh molluscs. The assemblage from the 1993 Graf sample from Hochwacht corresponds to Part 3 of the 2019 sequence (Malacozone IHoc-4). Pollen analysed from Hochwacht shows a significant proportion of *Fagus*, together with some *Picea* and *Fraxinus* and some herbaceous pollen, although the *Fagus* may largely represent modern contamination as it is especially common in the upper two samples (K. Bieri in Graf 1993, p.46). Curiously, the presence at Hochwacht, and to a lesser extent at Hasli, of three small aquatic gastropod species that usually live in permanent subterranean waters or in freshwater springs (*Bythiospeum rhenanum*, *Hauffenia*/*Islamia* sp., a Moitessieriid/Hydrobiid sp.), suggests that spring-fed streams may have been entering the floodplain from areas of higher ground nearby.

The faunas from Wilemerirchel include fairly high proportions of forest species, but few open ground and marsh molluscs, so appear to correlate best with the faunas of Parts 1 and 2 at Hasli and Hochwacht. The small assemblage from the 1993 Graf sample taken at Forenirchel seems to correlate best with the upper level of Part 2 at nearby Amselboden (Malacozone IA-3).

Like Hasli, the faunas from Steig West and East show the progressive arrival of forest and shade-loving species during Parts 1, 2 and 3, indicating forest development. Nevertheless, the local environment seems to have been significantly more open than at the other sites throughout the sequence, being characterised by fairly open woodland with an understory of abundant tall herbs. Like the other sites, there was a significant increase in open ground and marsh molluscs during Parts 3 and 4a (Table 6a). The differences between the sites in the rapidity with which new forest and shade-loving species arrived, as mature forest progressively developed, may have been related to the degree of dampness at the floodplain surface, with Steig appearing to be notably wetter.

3.1.5 Climatic implications of the Irchel faunas

The molluscan faunas from the Irchel sites all have a number of species typical of warm interglacial conditions (Tables 5, 6a, 6b). The modern distributions of the forest and shade-loving taxa include several that are still found today in Central Europe, as well as 6 with modern or palaeo-distributions that lie much further to the west, north-west and/or south-west of the Swiss Plateau, such as *Cochlostoma salomoni*, *Retinella (Lyrodiscus) elephantium* and *Spermodea lamellata*, 3 that lie to the south, including *Poiretia dilatata dilatata*, 14 that lie to the east or far to the east, such as *Acicula parcelineata*, *Archaegopis acutus*, *Clausilia stranzendorfensis*, *Macrogastra sessenheimensis*, *Monachoides vicinus*, *Serrulella* sp. and *Soosia diodonta*, plus 3 that lie to the south-east, including the Alpine region, such as *Trochulus filicinus* and *Trochulus leucozonus* (Figures 3, 7, 8, 10; Appendix 2; cf. Section 5.5). Importantly, all the taxa with modern or palaeo-distributions that lie far from the Swiss Plateau have never previously been identified from Swiss Quaternary deposits.

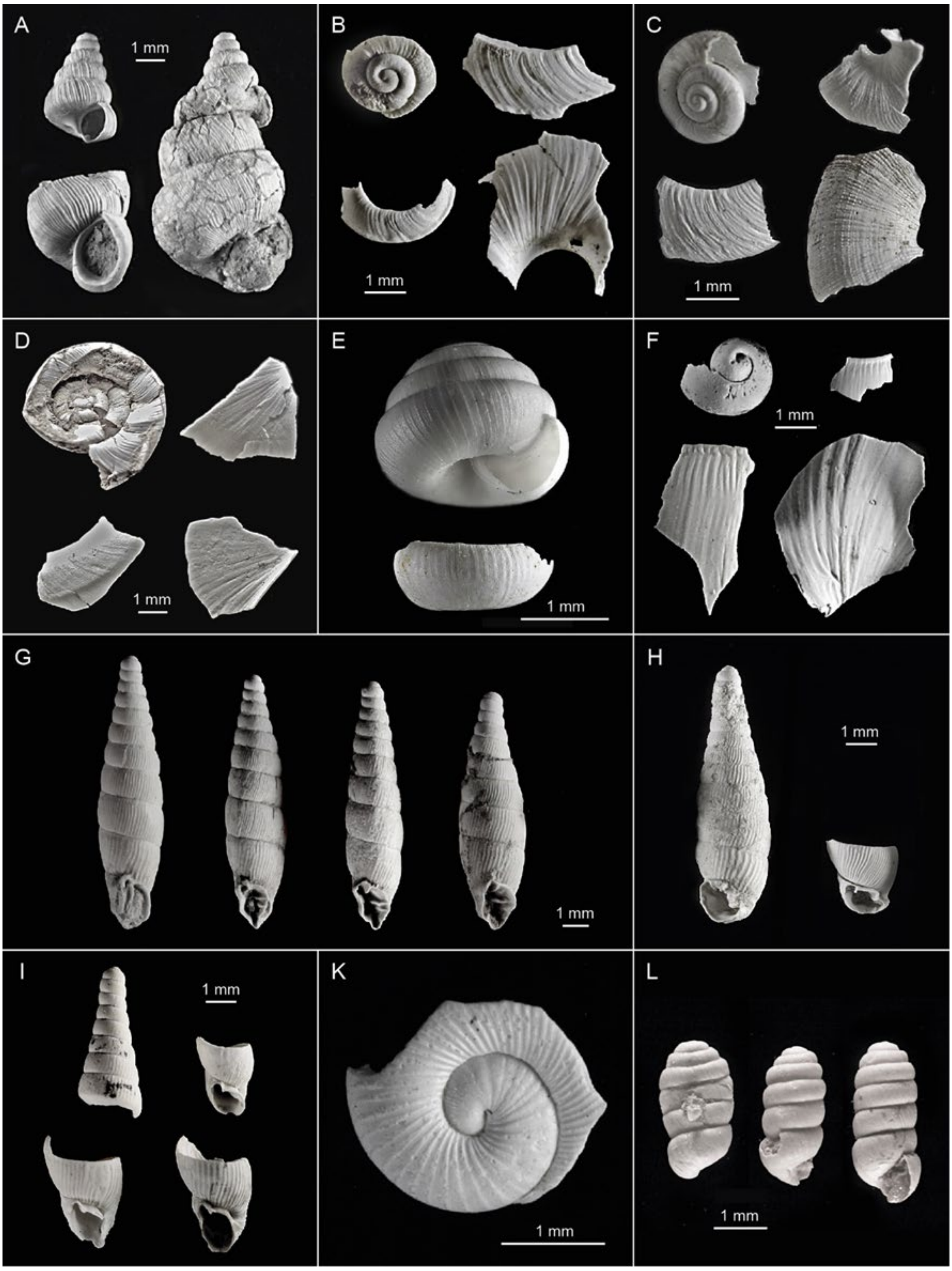

Figure 7: Photographs of several of the most important molluscan species from the Irchel Plateau: A. *Cochlostoma salomoni*, B. *Archaegopis acutus*, C. *Retinella elephantium*, D. *Monachoides vicinus*, E. *Spermodea lamellata**, F. *Poiretia dilatata dilatata*, G. *Clausilia stranzendorfensis*, H. *Macrogastra sessenheimensis*, I. *Neostyriaca corynodes ornatula*° + J. (top right) *Neostyriaca dehmi*, K. *Oxychilus steiningeri*, L. *Columella columella*. *Holocene shell from UK; °*N. corynodes ornatula* shells from Hungerbol (TDS).

This evidence clearly indicates that at the time when the Hasli Formation was forming the climate was significantly warmer than today, with the species possessing modern or palaeo-distributions that lie to the south or far to the east indicating higher summer temperatures, and the taxa with modern or palaeo-distributions that lie far to the west signifying considerably milder winters (cf. Limondin-Lozouet and Preece 2014). This is in good agreement with global surface palaeotemperature reconstructions and notably lower mean values for $\delta^{18}O$ in the MIS curve, which indicate a significantly warmer climate during the older Early Pleistocene before c.1.8 Ma (Lisiecki and Raymo 2005, Snyder 2016, Fig.1). The calcareous nodules present in both the HL and the Ebni silts are an indicator of circulating groundwater and a fluctuating near-surface water-table during a period of warm interglacial climate (cf. Preece et al. 2007, p.1249-1252).

As mentioned above (cf. Section 3.1.3.1), there are indications from both the sediments and the molluscs that the HF at Irchel Hasli is made up of four fining-upwards sedimentary cycles that appear to be linked to variations in flooding activity, with more intense flooding at the beginning of each cycle and greatly reduced flooding at the end. The repeated nature of these cycles and a certain periodicity in their length within the Hasli sequence, might suggest that climatic fluctuations were the most likely cause. Alternatively, this may represent a cycle of channel infilling followed by sudden avulsion, if changes in the base-level were involved, or be due to lateral movement of the channel within the floodplain, as larger particles tend to accumulate nearest to the active channel during flooding, or perhaps be caused by a combination of processes.

A recent study of a lowland valley in central Switzerland with a gravelly meandering river fed by an Alpine catchment (the Aar east of Lake Brienz), has shown a steady build-up of 2.25 m of relatively fine sediments across the floodplain since the mid-12th century AD (Schulte et al. 2015). Climate seems to have been the main factor governing sedimentary accumulation. Siltier deposits caused by moderate flooding were often linked with warmer periods that were also quite moist, whereas intervals of warmer and drier climate were associated with minimal flooding and little sedimentation. Sandier more detritic deposits and increased rates of sedimentation were caused by more severe flooding activity that was most frequently linked with intervals of cooler and wetter climate, such as the Little Ice Age. Major flooding events could also occur during warmer periods, especially if these came after long intervals of cooler climate that had encouraged water storage within Alpine glaciers. A nearby sequence through the Lütschine Delta at Lake Brienz has revealed gradual accumulation over the last 3,700 years of 5.5-6 m of silts, sands and gravels interrupted by peaty layers. Peak sedimentation coincided with colder and wetter periods such as the Löbben, Göschen I, Göschen II and the Little Ice Age, while least sedimentation occurred during the Late Bronze Age warm period, the Roman Climate Optimum and the Medieval Warm Period (Schulte et al. 2008, 2009). Wirth et al. (2013) have similarly shown that the Little Ice Age and earlier periods of cooler climate saw increased flooding and alluviation in the central Alpine region, while Wetter et al. (2020) have also documented more intense flooding by the River Limmat at Zürich during the Little Ice Age. This evidence is in keeping with work by Magny (2001, 2004), showing that across much of Central Europe intervals of cooler and wetter climate were associated with higher lake-levels, while warmer and drier periods coincided with lower levels. A good example is Lake Neuchâtel, where from the later Preboreal onwards the lowest levels consistently coincided with warmer periods, such as the Late Bronze Age (c.1050-850 BC), while higher lake-levels were associated with cooler intervals such as the Little Ice Age (Thew 2009). From these studies it may be inferred that the start of all four sedimentary cycles documented for the HF at Hasli may have coincided with somewhat cooler and wetter conditions, while the end of each cycle may have been warmer and drier. Nevertheless, it is also possible that some important flooding may have occurred during intervals with a warm and rather moist climate.

Apart from these cyclical fluctuations, there is also evidence from both the molluscs and the sediments for longer term changes in local conditions that may have been linked to more important climatic variations. The upper levels of Parts 2 and 4, for example, seem to have been notably warmer and drier due to the diversity of their forest faunas and strong evidence for pedogenesis. By contrast, the molluscan evidence from Hasli, Steig and Hochwacht suggests that Part 3 from all three sites was notably cooler and wetter, which allowed the shells to be better preserved and led to increases in open ground, tolerant and marsh molluscs, while forest and shade-loving taxa declined, including the loss of some interglacial forest species at Hochwacht. More importantly, Part 3 at Hochwacht also saw the appearance of the cold-tolerant pioneer species *Columella columella* (Figure 7), which today lives in the Alps above 1000 m (Turner et al. 1998), suggesting a fall in average summer temperatures of at least 2°C (cf. Rist et al. 2020), although most forest species continued at all three sites. Part 4a also appears to have been cooler and damper, and saw the disappearance of forest species from all three sites. The limited pollen evidence may also point to somewhat cooler and damper conditions during Part 3 at Hasli (cf. Section 3.1.4). Moreover, in the small mammal assemblage in the upper levels from Part 3 at Hasli, the bulk of the fauna indicates open marshy ground surrounded by fairly open woodland, in keeping with the molluscan evidence for some opening out of the landscape. More importantly, the presence of *Lemmus* sp. points to cooler conditions, as it is typically found in moist, relatively open habitats in areas with a rather cold climate (Cuenca-Bescós and Pérez Urrest, pers. comm.). Such a scenario might resemble what occurred in Central Europe during the Little Ice Age, or during the stadial periods MIS 5d and 5b of the Early Würm, which in the MIS curve have $\delta^{18}O$ values that are similar to the coolest periods during the older Early Pleistocene before 1.8 My (Lisiecki and Raymo 2005). During MIS 5d and 5b there was an opening out of the landscape in northern Switzerland, but although some thermophile trees and bushes seem to have disappeared (*Buxus*, *Carpinus*, *Hedera*, *Ilex* and *Taxus*), many of the principal thermophilous species survived (*Abies*, *Corylus*, *Quercus*, *Tilia*, *Ulmus*; Welten 1988, diags. 19, 20, Niederweningen), possibly replicating the situation during Part 3 at the Irchel sites. The only likely cold periods during the proposed time-frame of the Hasli Formation were MIS 72 at 1.965-1.945 and MIS 68 at 1.875-1.86 My. *Columella columella* was also present in older Early Pleistocene deposits at Stranzendorf in north-eastern Austria (levels D/E, K/L, L/M and M/N) in loessic layers that both predate and are contemporary with the Olduvai Subchron (Kovanda et al 1995, Frank and Rabeder 1997c), as well as in Late Tiglian levels in the Zuurland-2 Core in The Netherlands (Meijer 1988). This species may therefore have been fairly widespread during episodes of cooler climate during the older Early Pleistocene.

3.1.6 Sampling and the small mammal remains in the Hasli Formation

Sieving of the samples taken at Hasli in 2018/19 has demonstrated that the ‘upper level’ with small mammal remains coincides with Layers 12 and 13 in the profile (Table 1), while the ‘lower level’ with small mammals coincides with Layers 22 and 23, making the stratigraphic position of these remains much clearer. Layer 23 also includes a small fragment from the tooth of a larger mammal. Similarly, in addition to molluscs and small mammals, the Bräm material includes unidentifiable bone fragments from a much larger mammal that show significant iron staining so may have come from either level.

The detailed study of the molluscan assemblages from the 2018/19 profile at Irchel Hasli, shows that the large samples taken in 1994/95to recover small mammal remains from the 'upper level', included sediment from Layers 10, 11, 12, and 13. Similarly, the large 30 kg sample taken from the 'lower level' in 2018 seems to have comprised material from Layer 23 and the upper part of 24. This clearly demonstrates that large bulk samples tend to have less stratigraphic precision than the smaller bulk samples taken for molluscan analysis, although they have the major advantage of providing much greater volumes of sediment to process for scarce biological material like small mammal remains.

All of the identifiable small mammal material discussed in Bolliger et al. (1996), together with new tooth fragments recovered from Hasli between 2017 and 2019 that were reviewed by Cuenca-Bescós and Urresti (pers. comm.) and Fejfar (pers. comm.), come from the upper faunal level, which is referred to as Layer 12 in the 2018/19 profile. Bolliger et al. (1996) placed the Hasli material within small mammal zone MN17 of the European chronology, which corresponds to an age of 2.6-1.8 My. Since then, new publications concerning the age of various key small mammal species, such as the synthesis by Maul and Markova (2007), has allowed the age for Layer 12 to be narrowed down to the later part of MN17, between c.2.0 and 1.8 My, notably due to the presence of *Mimomys pliocaenicus*, which became extinct in Central Europe around 1.8 My, and *Pliomys episcopalis/simplicior*, which first appeared in Central Europe during the Olduvai Subchron after 1.934 My.

3.1.7 The 'Upper Channel' deposits at Hochwacht

At Hochwacht the Hasli Formation is succeeded by a series of fluvial gravels with fairly regular, gently inclined bedding, which are 1.9 m thick at Hoch East, but reach over 4.5 m at Hoch West. In their upper part at Hoch West the gravels include several silty soft clasts and 0.05-0.20 m above these a large lens of finely-bedded silts and fine sands, c.2.5 m wide by up to 0.4 m thick, which lies c.1.2 m below the summit of the gravels. These are the deposits that represent the 'upper channel.'

The largest of the soft clasts (0.37 x 0.11 m) and the lens of silt and fine sand both yielded rich molluscan faunas which show that bordering the river was a floodplain covered by dense largely deciduous woodland with large mature trees and a rich understory of young trees, bushes and tall herbs, and very little open ground (Table 6b, Figure 4). Both faunas have marsh molluscs indicative of damp conditions in parts of the floodplain, as well as up to three miniscule aquatic prosobranch species that attest to the existence of springs entering the floodplain nearby. Two of these minute prosobranchs have never before been found in Switzerland, apart from in the HF, and may represent extinct endemic taxa. The soft clast has no aquatic molluscs apart from these minute snails, showing that it represents flood silts that accumulated in a floodplain setting. The sand lens, by contrast, has a fairly varied aquatic fauna indicative of gently moving water with a relatively rich aquatic vegetation. The gravels and the silty-sandy lens seem therefore to have accumulated within a gravelly meandering river that was bounded by silty banks from which soft clasts sometimes entered the channel. The molluscan assemblages cannot have been formed of redeposited shells as they are too fragile to survive much transport.

The assemblages from both the soft clast and the silty-sandy lens have a number of taxa typical of notably warm interglacial conditions, including the same species as the HF (Table 6b; Figure 3; cf. Section 3.1.5). There are also 5 new terrestrial and 1 aquatic species present in the lens that seem to be absent from the HF, of which the new terrestrial taxa are all typical of warm interglacial periods. These include 2 that are new for Switzerland: *Oxychilus steiningeri* (Figure 7), which has only previously been found in middle Early Pleistocene contexts at Deutsch-Altenburg in north-eastern Austria so may have been an East-Central European species, and *Aegopis* sp., which is likely to be one of the taxa that still live today in southern or south-eastern Europe. Another, *Causa holosericea*, is a Southern and East-Central European species present today in south-eastern Switzerland, which has never before been found in Pleistocene sediments north of the Alps. The East-Central European marker taxon, *Clausilia pumila*, is present at Albishorn-Bürglen 1, Hungerbol and Sous-Terre, but has also not been found in the HF. The marker species, *Euomphalia strigella*, is absent from the HF, A-B 2, A-B 1 and Hungerbol, and only reappeared at early Middle Pleistocene Ecoteaux (cf. Section 6.1.1) before subsequently becoming a regular part of Swiss interglacial faunas. The presence of new species with modern or palaeodistributions that lie significantly to the west, south and east of Switzerland suggests that the soft clasts and sand lens represent a period that was equally warm as during the HF or slightly warmer.

Also present is *Cepaea nemoralis*, only previously found in the HF at Wilemerirchel, which originates from South-Western Europe but seems to have regularly extended its distribution into Central Europe during warm periods. It became common in Central and Eastern Europe (including Austria) during the later Holocene as a result of human activities, but has never previously been found in Pleistocene deposits in Switzerland. Internal slug plates from *Milax/Tandonia* sp., also only found in the HF at Wilemerirchel, is a group with distributions that originally lay mostly to the south-west, south and south-east of Switzerland, although several of them greatly expanded their presence across Europe during the later Holocene as a result of human activities. The most likely is the shade-loving species *Tandonia rustica*, which seems to have been a regular part of Swiss interglacial faunas since the Middle Pleistocene.

Biostratigraphically, the molluscan faunas recovered from the silty soft clast and silty-sandy lens are very similar to those of the HF and include most of the major biostratigraphical marker species (figure 3), showing that these faunas are of a very similar age and must represent the same chronostratigraphic period. Nevertheless, the presence within the lens of six new terrestrial species not found until now in the HF seems to suggest that the upper channel deposits are slightly younger.

The molluscs present within the soft clast and the silty-sandy lens indicate that the surrounding gravels must also have been deposited during an interglacial period by a meandering river, which is in keeping with their gently inclined bedding. Similar bedded gravels that form the base of the HDS sequence at Albishorn-Bürglen 2 (cf. Graf 2019) also have molluscs present in sandy-silty layers and in silty soft clasts, which accumulated within a gravelly meandering river bordered by a forested floodplain during a warm interglacial (cf. Section 3.3.1). The fluvial gravels at Hochwacht have been named the *Hochwacht-Schotter* because of their important biological content, although further fieldwork and a better documentation of their bedding structures is required to reliably separate them from the subsequent massively-bedded braided-type fluvioglacial gravels of the Forenirchel-Schotter.

The layers of fine-medium sandy gravel and sand at the base of the Hasli Formation at Hochwacht and Amselboden suggest that the channel deposits of the lowland meandering river that generated the flood silts and fine sands of the HF are likely to have been predominantly gravelly. This is hardly surprising given that most rivers flowing from the Alpine Massif today have gravelly meandering channels. It thus seems likely that the Hochwacht-Schotter was deposited by the same meandering river that deposited the HF, which continued to flow without interruption. The over 3 m of bedded gravels that accumulated between the end of the HF and deposition of the gravels with the soft clasts and the silty-sandy lens, nevertheless implies a period of significant aggradation after the HF, together with a modest shifting of the channel towards the north-east. Such aggradation may have been linked with an interval of somewhat cooler and wetter conditions (cf. Section 3.1.5), although this was not severe enough to greatly affect the forest, cause the local molluscan fauna to become impoverished or discourage new molluscan species from arriving. By contrast, the soft clasts and the silty-sandy lens in the upper part of these gravels suggest a time of greater fluvial stability, in keeping with their molluscan faunas that indicate a return to truly warm interglacial conditions and a densely forested floodplain.

3.2 Irchel Ebni, ZH

At Irchel Ebni the base of the sequence consists of >5 m of partially cemented sandy fine to coarse gravels (the 'Langacher-Schotter') that are succeeded by finely bedded fine to medium gravels, then by up to 0.8 m of heavily cemented sands with calcareous nodules, then by up to 1.6 m of grey flood silts with nodules intercalated with bands and lenses of sand and fine gravel (cf. Section 3.1.1). The molluscs are from a column of 5 samples taken by NAGRA in 2017 (Table 5), of which the lowest was taken in lightish grey marly-silt, while the upper 4 samples were taken in partially decalcified grey marly-silt. As these deposits lie beneath the thick Irchel-Schotter, they are significantly older than all of the Irchel sites mentioned above that are linked with the Hasli Formation.

Altogether the remains from a minimum of 180 individuals were identified, coming from just 3 terrestrial mollusc species (see Table 5), with no aquatic molluscs seen. The assemblages are dominated by slug plates (*Limax/Deroceras* sp.), together with two marsh snails, none of which are of biostratigraphical or climatic significance.

It is difficult to say much about the local terrestrial environment contemporary with the accumulation of the Ebni silts due to the extremely selective preservation of the molluscs. A poor pollen assemblage includes *Pinus* plus some *Fagus*, *Picea* and herbaceous plants, possibly suggesting a local environment with mixed coniferous-deciduous woodland during a period of warm climate (K. Bieri in Graf 1993, p.46). Despite the absence of aquatic molluscs, the specimens from two marsh taxa together with the presence of ostracod valves and *Chara* oospores all point to sedimentation in a marshy area within a floodplain subject to significant flooding, not far from the active channel of a meandering river. The ostracods come from two species (*Candona angulata*, *Cytherissa lacustris*) that are typical of fairly calm, rather mineral-rich waters (W Geiger and D. Danielopol in

Graf 1993, p.36), conditions which would also have suited the *Chara*. The rather abundant slug plates also suggest that significant surface run-off may have been taking place.

Although there is no biological evidence to help date the Ebni silts, palaeomagnetic data suggests that the Ebni silts coincided with an episode of normal polarity (Scheidt et al. 2023). This might possibly represent the Feni (Réunion) Subchron from 2.155 to 2.120 (Raffi et al. 2020), as the likely date of the overlying Hasli Formation appears to include the Olduvai Subchron (cf. Section 5.8.1).

3.3 Albishorn-Bürglen, ZH

3.3.1 Albishorn-Bürglen 2: molluscan faunas from the fluvial gravels below the Bürglen Till

A trial sample was taken by NAGRA in 2017 from a layer of silty-sand within the lower part of the fluvial gravels named the *Albisboden-Schotter* (Graf 2019), which form the base of the HDS complex at Albishorn-Bürglen, overlying Upper Freshwater Molasse. Although the assemblage was rather small and poorly preserved, it included specimens of the extinct species *Cochlostoma salomoni* and the eastern European taxon *Urticicola umbrosus*, which made this fauna comparable with those from the Irchel sites (Figures 3, 7, Appendix 2). This encouraged a more systematic investigation in 2019, using two columns that attempted to sample all of the finer layers present within the gravels. Profile 1 began at the basal contact with the Molasse and worked upwards, while Profile 2 started at the upper contact with overlying fluvioglacial gravels and worked downwards. A total of 12.9 m was investigated, which included at least five fine-grained layers as well as two levels with soft-clasts. As the gravels are around 17 m thick at this location (Gubler pers. comm.), it seems likely that up to 4 m remained undocumented and unsampled, although nearby these gravels are up to 20+ m thick (Gubler 2009, p.35). A detailed description of the profiles with sampling details for Albishorn-Bürglen 2 is given in Tables 7a to 7c, while the results of the molluscan analysis are presented in Table 8. Profile 1 is the same sequence that Graf sampled for a petrological, mineralogical and palaeomagnetic study of these gravels (Graf 2019, Profile Albis 1).

Altogether, from 13 of the 15 samples taken within the gravels, a minimum of 6,054 individuals have been identified that include 5,985 terrestrial molluscs (98.9%) from 58 species, together with just 69 aquatic molluscs (1.1%) from 10 taxa. Preservation is variable, with the best conserved shells being found in the siltiest sediments, especially the soft clasts sampled in the upper levels of the gravels.

Graf (2019) interpreted the Albisboden-Schotter as being fluvioglacial gravels of Alpine origin that were linked to the Linth-Rhine Glacier system. Nevertheless, the presence of molluscan species typical of warm interglacials (Table 8) shows that these gravels were not deposited by a cold-climate braided river, but were probably formed within a gravelly meandering channel. The impressive thickness and coarseness of the gravels can be explained by their proximity to the Alps, the Alpine character of the drainage basin, the source of the clastic material and the climatic context. There are erratic boulders up to 2.5 m across at the base of the Albisboden-Schotter, while the gravels appear to have accumulated within a valley a 2-3 km wide by at least 60 m deep eroded into the Molasse

(Gubler 2009, p.35), suggesting that a large part of this unit was originally deposited as fluvioglacial gravels by meltwater from the Linth-Rhine or Reuss Glaciers. This, together with the molluscan faunas, suggests that a warm interglacial period followed immediately after an interval of notably cold climate. As much of the drainage basin lay within the Alps, it seems likely that significant melting of stored glacial ice during the warm period may have released considerable volumes of meltwater that caused incision and rapid reworking of large quantities of poorly consolidated fluvioglacial gravel.

The local environment shown by the terrestrial molluscs towards the base of the gravels (Samples P1E-6 to P1E-1 and ALB-17-P1) is of rather damp fairly open mixed deciduous-coniferous forest, with an understory of tall herbs and young trees. By the upper part of this unit the forest had evolved into denser, largely deciduous woodland with more large mature trees and a richer understory, although patches of open ground were still present, possibly at the river banks (Samples 2-7 to 2-1). The poor aquatic fauna suggests that flow in much of the river flow was probably rather energetic, in keeping with the gravelly nature of the sediments. Nevertheless, the species include *Bithynia tentaculata*, *Planorbarius corneus*, *Planorbis carinatus* and *Stagnicola palustris/corvus*, showing that the meandering channel had stretches of quieter water where aquatic plants could flourish. Specimens from two miniscule gastropods that normally live in subterranean karstic habitats, indicate that there were freshwater springs entering the floodplain within the river valley.

Taphonomic processes had a major influence on the accumulation of the molluscan faunas. The poorest assemblages are found in the sandy layers that accumulated within the active channel (Samples 1E-6, 1E-1, 2-7). Assemblages with moderate numbers of molluscs accumulated within the silty-sandy infill of a small depression (4-5 m across) within the active channel, which seems to represent an interval of calmer flow (Samples 1E-4, 1E-3, 1E-2, ALB-17 P1). Fairly frequent molluscs were found in a compact silty layer with clay, some fine gravel and scattered stones, which may have been caused by the mass movement of sediment from near the river bank into the deeper part of the active channel (Samples 2-6, 2-5, 2-4). The most abundant assemblages were found in soft clasts from the upper levels of the gravels that seem to represent floodplain silts that have been eroded from the river bank (Sample 2-3, 2-2, 2-1).

Among the molluscs are several important biostratigraphical marker species, including *Clausilia stranzendorfensis* and *Cochlostoma salomoni*, which demonstrate that these gravels date from the older Early Pleistocene and are of a similar age to the faunas from the Hasli Formation studied at the Irchel sites that also belong to the HDS complex (Figures 3, 7; cf. Section 5.8.2). The presence of *Orcula dolium* and *Macrogastra densestriata* is interesting, as they are both missing from the Irchel sites. Species with modern or palaeo-distributions that lie far to the west, south and east of Switzerland show that the climate was significantly warmer than today.

Graf (2019) and Gubler (2009, pers. comm.) seem to have included within the Albisboden-Schotter some 2-6 m of gravels with large boulders that in places succeed the interglacial fluvial gravels, but these are clearly fluvioglacial, cold climate deposits that evidently had a very different depositional context.

3.3.2 Albishorn-Bürglen 1: molluscan faunas from organic overbank deposits above the Bürglen Till

The molluscs from Albishorn-Bürglen 1 come from five samples taken in 1993 and 2016 within a discontinuous layer of up to 0.9 m of grey-brown fairly organic sandy-silts/silts with bands of blackish-brown silty lignite and grey tufaceous silt, which become more organic and less tufaceous towards the summit. These overlie 0.5 m of diffusely laminated grey sandy-silt. A detailed description of the Albishorn-Bürglen 1 profile, with sampling details, is given in Table 7d. The sequence lies c.25 m and 150 m to the SE of two profiles that Graf sampled for petrological, mineralogical and palaeomagnetic analyses (Graf 2019: Albis 2, Albis 3). This silty unit overlies 2-6 m of fluvioglacial gravels with large boulders, followed by 9-12 m of basal moraine called the *Bürglen-Till*. The silts are covered by 24-30 m of the *Albiswald-Schotter*, a complex of largely cemented fluvioglacial gravels with intercalated layers of glacial till. The glacial sediments were deposited by the Linth-Rhine Glacier system during two separate glacial periods (Gubler 2009, pers. comm., Graf 2019). All of the deposits above the Albishorn-Bürglen 2 gravels seem to represent the **third sub-unit of the HDS in northern Switzerland**, as outlined in Graf 2019 (fig.16, p.21-23). This sequence is capped by 2-9 m of basal moraine and gravels that probably date from the Middle Pleistocene (Gubler 2009, p.35).

Of the six samples taken between 1993 and 2017, five had residues that could be resorted. Altogether a minimum of 241 individuals could be identified, including 100 terrestrial molluscs (41.5%) from 33 species and 141 aquatic molluscs (58.5%) from 10 taxa (Table 8). Although rather fragmented, the excellent preservation of the shell material and the sediment still adhering to the shells, show that all molluscs come from the bands of tufaceous silt. Two other samples taken in 2016, c.30 m to the NW (very near Graf 2019 profile Albis 2), in brownish-grey rather organic sandy-silts, have no molluscs due to an absence of tufaceous bands and decalcification of the remaining sediment.

The presence of a significant number of interglacial species (*Aegopinella ressmanni*, *A. pura*, *Cochlodina fimbriata*, *Discus rotundatus*, *Isognomostoma isognomostomos*, *Macrogastra attenuata*, *M. plicatula*, *Monachoides incarnatus*, *M. vicinus*, *Oxychilus cellarius* and *Trochulus edentulus*; Figure 7, Appendix 2) shows that the silts of Albishorn-Bürglen 1 represent a second warm interglacial period within this HDS sequence. Nevertheless, the loss since Albishorn-Bürglen 2 of all species with modern or palaeo-distributions that lay far to the west and to the south, and most of the taxa with distributions that lay far to the east, is likely to have been due to an intervening period with much colder conditions (Figure 3). Moreover, the faunas include few of the biostratigraphical markers present at Albishorn-Bürglen 2 and the Irchel sites, but instead have four new taxa (*Cochlodina fimbriata*, *Macrogastra attenuata*, *M. plicatula*, *Monachoides incarnatus*), of which all but *M. incarnatus* are also present among the Tiefere Deckenschotter (TDS) faunas at Hungerbol (cf. Section 4.1; Figures 8 and 10). There are also two fragments from a still unidentified terrestrial species that was not present in the earlier sites and is also absent from Hungerbol. The only early marker taxa that continue to be present are *Clausilia pumila*, *Monachoides vicinus* and *Neostyriaca corynodes ornatula*, all of which are also found at Hungerbol. The faunas from Albishorn-Bürglen 1 are thus clearly significantly younger than those from Albishorn-Bürglen 2 and the Irchel sites, but rather similar to those from Hungerbol 2.

The assemblages accumulated within a floodplain near the margin of a large, lowland meandering river, as shown by the relatively high proportion of aquatic shells (60.0%), but a total absence of any bivalve species. Fairly regular but moderate flooding events brought in silt, aquatic shells and other aquatic remains like *Chara*, Trichoptera tubes, fish bones and fish otoliths. The relatively high proportion of terrestrial marsh species and a significant number of aquatic molluscs normally associated with slow moving water and rich aquatic vegetation (*Planorbarius corneus*, *Planorbis carinatus*, *P. planorbis*, *Lymnaea stagnalis*), indicate that the nearby section of river had a gentle current, allowing both aquatic and marsh plants to flourish. The organic and tufaceous nature of the flood silts indicates that sedimentation rates may have been relatively low due to only moderate flooding, which suggests that this interglacial may have been characterised by a warm and fairly dry climate. The local terrestrial environment seems to have consisted of fairly damp, rather dense, largely deciduous woodland with mature trees and a fairly rich understory of tall herbs and young trees, with very little open ground.

Pollen from the same profile at Albishorn-Bürglen 1 includes tree species typical of a warm interglacial (*Abies*, *Carpinus*, *Corylus*, *Quercus*, *Taxus*, *Tilia*, *Ulmus*) and shows largely deciduous woodland with a strong coniferous component, in good agreement with the molluscs. It appears from the pollen sequence that the earlier part of this interglacial is probably missing, due to the absence of a pioneer phase like the Preboreal-Boreal of the Holocene. By contrast, the later part seems to be well represented and there are signs of a loss of thermophile tree species and an opening out of the forest in the upper part of the profile that might be due to a cooling climate. This is not shown by the molluscs, but this may be due to the less precise sampling.

3.4 **Boppelsen-Cholholz Ost, ZH** (2673 664/1258 893)

This site from the HDS complex was excavated and sampled by NAGRA in 2017. Although large quantities of sediment from two profiles were sieved, no molluscan material could be recovered. While some of the silty deposits were decalcified (Layer 1.10), others that reacted to HCl were sterile and had no biological material. The few shell fragments in Sample 2 (Table 8) were redeposited from the underlying Molasse.

One of the main reasons for sampling this site was due to the discovery by A. Jayet in 1948 of a fairly rich assemblage of mollusc shells in gravels around 3 m thick that overlie over 6 m of HDS gravels and sands (Jayet 1949). The gravels with the shells had a matrix of brown tufaceous sandy-silt with charcoal fragments. A reanalysis of this material has shown that it does not date from the Late Glacial as Jayet believed, but rather dates from the early Boreal, due to the species present and the excellent preservation of the shells. A Holocene age has been confirmed by AAR Dating (cf. Section 6.4.3, Table 33).

3.5 **Eichbrunnen, Freienwil, AG** (est. 2666 050/1261 450, c.580 m asl)

In his monograph from 1912 concerning the Deckenschotter deposits of northern Switzerland, R. Frei referred to (p.24-26) mollusc shells he had discovered within a HDS sequence in a gravel quarry at Eichbrunnen, just east of Freienwil, at the edge of the Dürn-Gländ Plateau (Figure 1). Graf (1993, p.80-82) returned to the same location in 1990/91, although the quarry had long been abandoned and the base of the sequence was partially covered by collapsed material. The sequence documented by Frei and Graf begins (from the base) with >5 m of grey horizontally-bedded fluvioglacial gravel, with boulders up to 0.8 m and occasional lenses of silty-sand up to 0.2 m thick. The upper 0.1-0.15 m is heavily cemented by secondary calcite, below which the matrix is weathered reddish-brown, is decalcified and has horizontal bands blackened by Mn (Graf 1993, p.82). These represent Graf's *Basale Dürn-Schotter*. There follows a discontinuous layer of truncated lenses up to 0.6 m thick of grey-brown laminated silt/sandy-silt, with frequent small calcareous nodules and mollusc shells. These silts were covered in places by up to 0.4 m of sandy fine-medium gravel stained reddish-brown by Fe and blackened by Mn. Above a clear erosion surface, the sequence is completed by up to 5 m of horizontally-bedded fluvioglacial gravels, with a layer of angular blocks up to 0.8 m near the base and lenses of silty-sand up to 0.15 m thick. The summit of the gravels is heavily cemented, below which the matrix is weathered reddish-brown and is decalcified. These gravels correspond to Graf's *Blockfazies* and *Südliche Dürn-Schotter* (1993, p.87-88).

The updated modern equivalents of the mollusc species identified by L. Rollier are:

Ena sp.
Clausilia cf. *dubia*
Cochlostoma cf. *henricae*
Cochlostoma obscurum
Oxychilus cf. *cellarius*
Cochlicopa lubrica
Cochlicopa lubricella
Trochulus cf. *hispidus*
Pupilla muscorum
Vallonia enniensis

When compared with the taxa identified from the Hasli Formation (HF) during this study, *Ena* sp. is probably *Ena montana*, while *Clausilia dubia*, *Oxychilus cellarius*, *Cochlicopa lubrica*, *C. lubricella* and *Pupilla muscorum* are all present in the HF. *Trochulus* cf. *hispidus* is missing from the HF, but is a common taxon that was found at Hungerbol. The species identified by Rollier as *Vallonia tenuilimbata* (Sandberger 1880) is a synonym of *V. enniensis*, but the shells at Freienwil are more likely to be *V. pulchella* and/or *V. costata*, as both are fairly common in the HF. Most important are the records for *Cochlostoma obscurum* and *C.* cf. *henricae*. *C. obscurum* is a species that lives today in NE France and the Pyrenees, which has never been recorded living or fossil in Switzerland. It closely resembles the extinct taxon *Cochlostoma salomoni* (first described by Geyer in 1914, two years after Frei's text), which is present in the HF and at Albishorn-Bürglen 2. The probable presence of *C. salomoni* at Freienwil confirms the importance of this species as a biostratigraphical marker for warm interglacial EP1 sediments within HDS deposits in Switzerland (cf. Section 5.5.1). *Cochlostoma henricae* has never been found in Early Pleistocene deposits in Switzerland or elsewhere, but its former presence is not impossible as it lives today in central Austria and north-eastern Italy, in the same areas where several of the marker species for the HF can currently be found (cf. Section 5.5.1). It is very unfortunate that this precious shell material seems to have been lost, as a comprehensive search among the elements of the Frei collection lodged at the ETHZ in Zürich failed to find them and there is no sign of them either in the PIMUZ in Zürich.

When Graf returned to this site, he was able to rediscover and resample the silty lenses where Frei had recovered the shells, but despite processing c.10 kg of sediment no molluscs could be found (Graf 1993). This may well be due to leaching by soil processes during the 80 years since the sediments were first exposed in the wall of the gravel quarry.

4 Molluscan faunas from the Tiefere (Lower) Deckenschotter

4.1 Hungerbol, near Schienen, DE

4.1.1 Site stratigraphy and an overview of the molluscan faunas

In 2016 four large bulk samples were taken in two units of silty-sand (Hungerbol 2 and Hungerbol 1) re-exposed by a new land-slip at the site of Hungerbol, which is part of the Tiefere Deckenschotter (TDS) complex. The 'Hungerbol 2' samples came from a lower series of grey silty-sands and sandy-silts up to 2.8 m thick ('lower silts'), while 'Hungerbol 1' represents an upper body of olive-grey to yellow-brown silty-sands and sandy-silts up to 2.2 m thick ('upper silts'), with the two silty units being separated by up to 0.8 m of fluvial gravels. The sampling locations were chosen because they had visible concentrations of mollusc shells. Two samples were taken from both silt units, although residues from only three of the four samples were available for resorting by the author. In 2019 the sequence was redocumented and a much more complete sequence of 12 samples was taken from the lower silts, and 5 from the upper silts. A detailed description of the documented profile and the samples taken in 2019 is given in Table 9, together with a correlation to the sequence documented and sampled in 2016-18, plus the positions of the original bulk samples and those taken for palaeomagnetism and pollen.

Altogether the remains from a minimum of 19,064 individuals have been identified from Hungerbol, including 18,449 terrestrial molluscs (96.8%) coming from 61 species, and 615 aquatic molluscs (3.2%) from 16 taxa (Table 10). Hungerbol 2 has 60 terrestrial and 16 aquatic taxa, while Hungerbol 1 has 21 terrestrial and 2 aquatic species. Molluscan frequencies in the samples from 2017 increased by a factor of between 20 and 35 and the number of species rose by 40-100% when the samples were thoroughly re-sorted for this study. The molluscan sequence in the lower silts has been divided into 4 parts, based on both faunal and lithostratigraphic changes, with Part 4 being the fluvial gravel that separates Hungerbol 2 from Hungerbol 1.

Like the sites at Irchel and Albishorn-Bürglen, the Hungerbol assemblages included fairly frequent shell material that has redeposited from the underlying Upper Freshwater Molasse (UFM). These include slightly recrystallised brown/pale brown/pale brownish-grey fragments from species that closely resemble Quaternary taxa, which were probably eroded from the upper strata of the UFM, with c.70% belonging from aquatic species and 30% from terrestrial taxa. There were also fairly numerous black/dark grey or sometimes whitish fragments with significant recrystallisation, which resemble existing genera but are clearly from pre-Quaternary species that seem to have been eroded from much older strata within the UFM, with aquatic taxa again being much more common.

4.1.2 Local terrestrial and aquatic environments and layer formation

At the base of the sequence, beneath the lower silts of Hungerbol 2, were 1.2 m of sandy-gravels, called the *Hungerbol-Schotter*, which to the west of the documented exposure can reach up to 4 m thick (Graf 2009a). These gravels are finely bedded and rather well-sorted, with frequent clast imbrication. They have a progressive transition from gravels to gravelly-sands to silts (Layers 27 to 23), and include interglacial mollusc species within the gravelly-sands (Layer 24). This evidence indicates that the basal gravels represent the bed deposits of a fairly large lowland meandering river with a sand and gravel bed.

At the start of the period represented by the lower silts (Part 1, Table 10), the local terrestrial environment seems to have consisted of fairly damp, moderately open woodland with mature trees and a dense understory of tall herbs and young trees, as well as small patches of open ground with low herbaceous vegetation. The woodland seems to have been largely deciduous with a coniferous element. The forest became somewhat denser and more diverse during Parts 2 and 3 of these silts, with significantly more large, mature trees, although small patches of open ground remained, probably at the margins of the river channel. The forest also became damper during Parts 2 and 3.1, before becoming somewhat drier again during Part 3.3.

Small mammal remains recovered from Part 2 of the silts of Hungerbol 2 are restricted to two unidentified species of rootless Lagurid (Fejfar, pers. comm.). Although their precise identification is uncertain, steppe lemmings typically live in rather dry, open habitats that allow them to dig burrows and have herbaceous plants to feed on. Fejfar has suggested that they may indicate a dry, open, forestless steppic landscape, but given the unambiguous evidence for well-established, largely deciduous floodplain forest in the local area, such an interpretation is untenable. Among the molluscs there are also species typical of open conditions, and it seems much more likely that both these and the Lagurids were taking advantage of more localised habitats, such as dry sandy banks linked with the river channel.

In the basal, sandy levels of the lower silts (Part 1), the aquatic molluscs indicate that accumulation was taking place near the margin of a large, slow-flowing, meandering river. Sand-grain impressions on some of the shells are in keeping with the sandy nature of the deposits. The fragmented nature and rather variable proportions of aquatic shells (8.4 to 66.7%), low ratio of *Bithynia tentaculata* shells: opercula and virtual absence of small bivalves (*Pisidium* spp.), shows that the aquatic molluscs were deposited in the part of the channel only normally occupied by seasonal flow. Regular flooding brought in silt and fine sand, as well as aquatic shells, fish bones, ostracods and *Chara* oospores. The species present include several typical of moving water (*Pisidium amnicum*, *Theodoxus danubialis*, *Unio crassus*), and others that require a fairly rich aquatic vegetation (*Lymnaea stagnalis*, *Planorbarius corneus*, *Planorbis carinatus*). The terrestrial shells, worm granules and small mammal bones would have been washed in by retreating floodwaters and surface run-off from the adjoining floodplain. The end of Part 1 is marked by a sharp decrease in molluscan numbers due to drying out that seems to have been caused by a reduction in flood activity and probably a fall in water-levels, allowing pedogenetic processes like leaching to take place, although some flood silts continued to accumulate.

After a probable rise in water-levels at the start of Part 2, the shells in Sample 2o show a return to accumulation resulting from seasonal flow near the margin of a slow-flowing river, although an absence of aquatic molluscs from Samples 12 and 11 shows that in places few aquatic shells were deposited. In Sample 10, by contrast, a notable rise in water-levels saw a sharp increase in the frequency of aquatic shells, which also included significant numbers of bivalves, in addition to a high ratio of *Bithynia tentaculata* shells: opercula. This, plus the presence of *Lymnaea stagnalis*, *Stagnicola palustris/corvus*, *Planorbis planorbis*, *P. carinatus* and *Segmentina nitida*, indicates accumulation in rather calm water with a rich aquatic vegetation, in keeping with the silty nature of Layers 19 and 18 that suggests sedimentation largely by decantation. Nevertheless, fragments of *Unio crassus* continued to be present, suggesting a sheltered marshy embayment with more or less permanent water at the edge of the active channel. At the end of Part 2, a sharp decline in molluscan numbers suggests a renewed fall in water-levels, which led to drying out and significant leaching, although flood silts continued to accumulate.

Parts 3.1 and 3.3, separated by up to 0.15 m of mostly fine gravel (Part 3.2), seem to be flood silts that accumulated on the floodplain surface near to the active channel. As the faunas in the two samples are rather similar, they clearly belong to the same stratigraphic unit. The thin sandy gravel that separates these silts might represent a major flood event as there is an erosion surface at the base of this layer.

After a clear erosion surface, the up to 0.9 m of gravels of Layer 13 seem to have been deposited by the same meandering channel, as they are fairly finely bedded, clast-supported, have sandy bands and frequent imbricated clasts, but have variable sorting. These gravels appear to have accumulated rather rapidly after a significant rise in water-levels. The surface of the gravels is irregular and shows evidence of rilling erosion up to 0.25 m deep caused by run-off water, which implies a sharp fall in water-levels and a possible sedimentary hiatus.

At the western side of the Hungerbol exposure the upper silts of Hungerbol 1 are largely decalcified and have no molluscs. In the eastern profile where shells are preserved, the few aquatic molluscs, together with large numbers of the marsh taxon *Succinea oblonga*, typical of poorly vegetated paludal habitats, indicate that the assemblage accumulated in a marshy area within the floodplain, near to the margin of the same lowland meandering river. Regular flooding brought silt, while the terrestrial shells, worm granules, wood fragments and small mammal remains accumulated as a result of entrainment by retreating floodwaters and surface run-off. Pollen from *Nymphaea* (water lily; Thew et al. 2024, M. Knipping pers. comm.) suggests that the nearby river still had reaches with fairly deep, slow-flowing water with aquatic plants.

The non-marsh terrestrial molluscs from the upper silts of Hungerbol 1 indicate that the local environment was still characterised by damp, well-established woodland with mature trees, although notable decreases in the proportions and number of species associated with forest and shaded conditions shows that the woodland was significantly more open and less diverse. Rises in the percentages of tolerant and open ground molluscs indicate that there was a dense understory of tall herbs together with larger patches of open ground with a low herbaceous vegetation. Pollen from *Pinus*, plus *Quercus*, *Corylus*, *Taxus*, *Ostrya*-type, *Betula* and *Picea* in the silts of Hungerbol 1 (4.60-4.65 m, M. Knipping pers. comm.) suggest that a variety of tree species continued to be present, although some grains may have been redeposited.

Succeeding the upper silts of Hungerbol 1 are a series of probable slope deposits (Layers 8 to 5) with no signs of fluvial influence. These signs of slope instability suggest that the local vegetation cover may have become much less dense.

4.1.3 Climatic implications

The presence within the silts of Hungerbol 2 of a number of species typical of warm conditions clearly indicates that they accumulated during a period of warm interglacial climate (Table 10). The high species diversity (60 terrestrial taxa) is also typical of interglacials, while being compatible with the faunas from the Irchel sites. As the gravels that underlie the lower silts seem likely to have been deposited by a meandering river, the base of the sequence seems to already have been associated with temperate conditions. The Hungerbol 2 faunas, like those from Albishorn-Bürglen 1, retain a few of the eastern taxa that were already present in the Irchel sites and Albishorn-Bürglen 2, like *Macrogastra densestriata*, *Monachoides vicinus* and *Trochulus filicinus* (Figures 8 and 10; cf. Section 5.5.2), which suggests that the climate is likely to have been rather warm, with somewhat higher summer temperatures than today.

The fluctuations in the intensity of flooding and in the water-levels that led to the sedimentological and faunal changes in the Hungerbol 2 silts described above, may have been caused by modest changes in the climate, as postulated for the Irchel sites (cf. Section 3.1.5). As the catchment area for the river that flowed at Hungerbol was largely mountainous (probably the Alpine Rhine), variations in flood activity and overall water-levels are likely to have been largely dictated by precipitation and glacial melting in the Alps. Studies of alluvial sediments in the Aar Valley east of Lake Brienz and in the Lütschine Delta at Lake Brienz, both also fed by Alpine catchments (Schulte et al. 2009, 2015), has shown that more intensive flooding activity tended to be associated with cooler and wetter periods, although some floods were also linked with warm and moist conditions, while warmer and drier intervals led to greatly reduced flooding and incipient soil development. The probable falls in the water-levels at the end of Parts 1 and 2, might therefore represent episodes of warmer drier climate, while higher water-levels during Parts 1 and 2, as well as more modest levels during Part 3, may have coincided with somewhat wetter conditions with either a cooler and damper or a warm and moist climate.

The notably higher water-levels during the deposition of the gravels of Layer 13 suggest considerably cooler and damper conditions, while the fall in levels during the accumulation of the upper silts of Hungerbol 1 indicate more mild conditions. Even so, the molluscan faunas of Hungerbol 1 have just 21 terrestrial species and none of the interglacial forest and shade-loving taxa present in Hungerbol 2, while the fauna includes the cold-tolerant pioneer species *Columella columella*, all of which points to a major climatic cooling since the time of the lower silts. Nevertheless, the presence of several woodland taxa, including *Clausilia bidentata*, a Western European species that does not tolerate very cold winters (cf. Welter-Schultes 2012), indicates that the upper silts of Hungerbol 1 accumulated during a mild interstadial early on in the succeeding glacial period. The short hiatus between the gravels of Layer 13 and the silts of Hungerbol 1, may therefore represent an episode of cold and dry climate.

A subsequent major lowering of water-levels followed by the accumulation of up to 3 m of slope deposits (Layers 8 to 5) may indicate that the climate had become much colder and possibly drier, explaining the slope instability linked with a probable impoverishment of the vegetation cover. The imbricated (dipping upslope) inclination of some of the clasts in Layer 6 is typical of slow mass-movement caused by gelifluction in cold climate situations (van Steijn 2011), which points to intense winter freezing of superficial deposits in the ‘active layer’ followed by summer thawing. Spring-summer thawing would also have encouraged cold ground water to circulate, helping to explain why the upper silts were almost completely decalcified at the western side of the Hungerbol exposure (calcium carbonate is more soluble at lower temperatures) and why there was such intense Fe and Mn staining in the gravels of Layer 13.

There then follows up to 5.5 m of fluvioglacial gravels with boulders up to 1.2 m, capped by up to 0.6 m of glacial diamicton, which Graf (2009a) has called the *Bannholz-Schotter*. These deposits point to truly cold, full glacial conditions.

4.1.4 Biostratigraphy and the age of the Hungerbol faunas

Like Albishorn-Bürglen 1, the faunas of Hungerbol 2 lack all of the major molluscan biostratigraphic marker species seen in the Hasli Formation at Irchel and at Albishorn-Bürglen 2, which seem to be typical for the older Early Pleistocene (see Figures 3, 8 and 10). Nevertheless, some species from this earlier period continued to be present, such as *Helicopsis striata*, *Macrogastra densestriata*, *Monachoides vicinus*, *Neostyriaca corynodes ornatula*, *Perforatella bidentata* and *Trochulus filicinus*, as well as *Clausilia pumila* that was present in the upper channel deposits at Hochwacht. Of these taxa, *Helicopsis striata*, *Macrogastra densestriata*, *Monachoides vicinus* and *Trochulus filicinus* all seem to have disappeared from Switzerland after Hungerbol 2.

Equally important are the species that are absent from the Irchel sites and Albishorn-Bürglen 2, but which subsequently became a regular part of Swiss interglacial faunas, such as *Cochlodina fimbriata*, *M. attenuata* and *M. plicatula*, which were already present at Albishorn-Bürglen 1, and *Clausilia cruciata* and *Platyla polita*, which appeared for the first time in Hungerbol 2. In addition, there is the earliest Swiss appearances of *Aegopis klemmi* and the aquatic gastropod *Theodoxus danubialis*, which might suggest that at this time there was a link between the Hochrhein and the Danube system, although this aquatic species was also able to jump from one river system to another without a direct connection (cf. Section 5.5.3).

The Hungerbol 2 faunas are rather similar to those of Albishorn-Bürglen 1, but as the latter site comes from the upper levels of a HDS terrace, while Hungerbol 2 is situated near the base of a TDS complex, it must morphostratigraphically be significantly younger. It is also clear that Hungerbol 2 is significantly older than Middle Pleistocene sites like Ecoteaux, Sous-Terre and Montfleury, which lack early marker species like *Helicopsis striata*, *Macrogastra densestriata*, *Monachoides vicinus* and *Trochulus filicinus* and have new biostratigraphic markers that only seem to have appeared in Switzerland during the Middle Pleistocene (cf. Section 5.6.2; Figures 8 and 10). AAR Dating also shows that *Bithynia* opercula from the lower silts of Hungerbol 2 are considerably older than those from Ecoteaux that appear to date from MIS 15 (cf. Section 6.1.1). Taken together, the evidence clearly indicates that Hungerbol 2 still belongs within the Early Pleistocene, but is considerably younger than the Irchel sites and also more recent than Albishorn-Bürglen 1, suggesting that Hungerbol 2 may date from EP3.

Although the two species of rootless Lagurid found in the silts of Hungerbol 2 cannot be firmly unidentified, O. Fejfar (pers. comm.) states that these early forms largely disappeared from Central Europe at the Early/Late Biharian transition, equivalent to the end of EP2, based on sites from Slovakia and Hungary. A more comprehensive survey of European small mammal faunas by Maul and Markova (2007), however, has shown that although steppe lemmings declined significantly in Central Europe after EP2, *Lagurus arankae* continued to be present until the first part of EP3 in Austria, disappearing only during the Jaramillo Subchron, while *Prolagurus pannonicus* continued until the end of EP3, before being replaced by the more modern *Lagurus transiens* during the early Middle Pleistocene. *L. arankae* first appeared in Central Europe during the Olduvai Subchron, while *Prolagurus ternopolitanus* appeared during the Olduvai Subchron and was replaced by *P. pannonicus* early in the Eburonian. As the two Lagurids present at Hungerbol 2 are rather likely to be *Lagurus arankae* and *Prolagurus pannonicus*, this would suggest a date between 1.8/1.7 and 1.1/1.0 My.

Despite the clear differences between the faunas from the lower silts of Hungerbol 2 and those from the upper silts of Hungerbol 1, it appears from the stratigraphic evidence that there was not much of a time gap between these two deposits. This is in good agreement with the evidence from AAR Dating, which shows no detectable age difference between the values from Hungerbol 2 and Hungerbol 1. From the stratigraphic and molluscan evidence, it appears that while the gravels and lower silts of Hungerbol 2 represent a warm interglacial, this was followed by a climatic deterioration at the start of a cold glacial period. Conditions improved fairly soon afterwards, however, so despite an absence of interglacial species and the presence of the cold-tolerant pioneer *Columella columella*, the upper silts of Hungerbol 1 seem to have accumulated during a fairly mild interstadial within the early part of this glacial period.

There is *Ostrya*-type pollen in the silts of Hungerbol 1 (Knipping pers. comm.), which became rare in Central Europe after the end of the Early Pleistocene (Hahne et al. 2008).

4.2 Iberig, AG

A 2.55 kg sample was taken in 2018 by NAGRA in silty-sands that form part of a fine-grained channel infill within the massive complex of braided gravels that make up the *Iberig-Schotter* of the TDS complex at Iberig, AG (cf. Preusser et al. 2011, p.286). When this sample was sieved it proved to be totally sterile, with no biological material of any kind (Table 10). The sample reacted to HCl, showing that the absence of shells was not due to post-depositional leaching, but instead indicates accumulation within a cold-climate braided river channel. During periods with cold glacial conditions, glacier-fed rivers tend to flow in braided channels, producing massive, poorly-sorted gravel deposits with more or less horizontal bedding, sometimes with steeply inclined internal bedding structures produced by migrating gravel bars and interrupted by small channels that may be infilled with finer silts and sands. If sampled, these channel fills tend to be sterile or have very little molluscan material, especially if the deposits formed close to the glacier front (cf. Briggs et al. 1990).

5 Dating the Deckenschotter complexes and other Quaternary deposits

5.1 The Early Pleistocene chronology of Switzerland and the adjoining area of southern Germany

The Pleistocene chronology of Switzerland, like that of much of Central, Western and Northern Europe is heavily influenced by which deposits survived the destructive effects of successive glacial advances. Deposits that can be assigned to one or more warm periods have often been preserved in topographical depressions beneath glacial deposits or as sedimentological 'refugia' beyond the reach of advancing ice sheets. Due to the fragmentary nature of surviving deposits, constructing a coherent Quaternary chronology for Switzerland has proved extremely difficult, so to some extent it is lagging behind what is known about interglacial and glacial sequences in countries like France, the UK, The Netherlands, Germany, Italy and Austria. As part of an attempt to construct an aminostratigraphy for Switzerland, in order to help date the deposits from the Höhere and Tiefere Deckenschotter complexes in northern Switzerland (Section 5.7), the shell material from a number of interglacial sites scattered across the Swiss Plateau has been reanalysed. The biostratigraphic and AAR Dating results of this re-examination have been of considerable interest as they have suggested unexpected ages for several of the interglacial sites older than the Eemian (cf. Penkman et al. 2024). Ecoteaux, for example, might be the first site from the Cromerian period that is known from Switzerland (cf. Section 6.1.1), while the Genevan sites of Sous-Terre and Montfleury may date from MIS 11 (cf. Sections 6.1.2, 6.1.3).

In a recent attempt at defining a Quaternary chronology for Switzerland by Preusser et al. (2011, fig.19; revised in Graf and Burkhalter 2016, fig.1), there are numerous gaps, especially for the warm periods. This is typical for the Alpine region, where fixed points in a chronology tend to be defined by the main glacial units, as their deposits are often the most likely to survive. Although the old model of Würm (Weichselian), Riss (Saalian), Mindel (Elsterian) and Günz has been largely superseded by a more sophisticated system based on Marine Isotope Stages (Lisiecki and Raymo 2005), there is no escaping the strong geomorphological and stratigraphical imprint left by major glaciations. Thus MIS 12 and MIS 6, two of the coldest and most prolonged glacial periods in the MIS curve, correspond to two of the most important Middle Pleistocene glaciations in Central Europe, which greatly influenced the survival of earlier Quaternary sediments across large parts of Switzerland. In the Geneva area, for example, the so-called '*Alluvion ancienne*' may date from MIS 6, while the basal moraine that directly overlies the Molasse and underlies sites at Sous-Terre, Montfleury, Petit Saconnex and WHO, may correspond to MIS 12 (cf. Sections 6.1.2, 6.1.3). A major problem for the Swiss chronology is that older deposits like the Höhere and Tiefere Deckenschotter complexes are detached from this younger glacial framework. Fortunately, south of the Alps the great majority of the Italian peninsula was unaffected by glaciation, so the terms Early, Middle and Late Villafranchian, Epivillafranchian and Galerian, define megafaunal units that reflect evolution in tandem with climatic and environmental changes (see Figure 10; Rook and Martínez-Navarro 2010). Similarly, in the European small mammal chronology, the Villanyian is succeeded by the Biharian and then the Toringian. The timing of the limits between these periods reflects important faunal changes that were often in response to

Period (CH = Switzerland)		**Species**	**Time of disappearance from Swiss Quaternary deposits (see Section 5.5)**	**Geographical distribution relative to CH**
Late Pleistocene	present in much of CH	*Clausilia bidentata*	Now only present in south-western Switzerland; but previously widespread during the Early to Middle Pleistocene and the Eemian	NW, W
		Ruthenica filograna	Now only present in the extreme north-eastern part of Switzerland; a typical interglacial marker species for other areas, present EP1 to the Eemian	E
	Eemian Interglacial all of Swiss Plateau	*Aegopinella ressmanni*	Never before found in CH; a typical interglacial marker species; present EP1 to the Eemian; it disappeared from Swiss faunas after the Eemian	E
		Aegopis verticillus	Never before found in CH; a typical interglacial marker species; present at Sous-Terre (MIS 11) and the Eemian; possibly absent during MIS 7, it disappeared from Swiss faunas after the Eemian	E
		Discus perspectivus	A typical interglacial marker species, present EP1 to the Eemian; disppeared from CH after the Eemian	E
		Pagodulina pagodula	A marker species for the Eemian; present at Ecoteaux (MIS 15), then at Niederweningen, Thalgut and Zell (MIS 5e); it disappeared from Swiss faunas	E, S, SW
	Eemian Interglacial locally present in CH	*Acicula lineolata*	Never before found in CH north of the Alps; present at Ecoteaux (MIS 15) and Zell (MIS 5e); now only present south of the Alps in SE Switzerland	E, SE
		Aegopinella nitidula	A possible marker species for the Eemian, but may also be present in earlier deposits; absent from Swiss faunas after the Eemian	NW, W
		Platyla dupuyi	Present during the Holocene in the Geneva basin though missing from CH today; during the Eemian more widespread in western Switzerland	W, SW
		Trochulus caelatus	Present today only in the Birs Valley (central part of the Swiss Jura); during the Eemian more widespread in the Jura Mountains of north-western CH	endemic
Middle Pleistocene		*Urticicola umbrosus*	Never before found in CH; seems to have disappeared from Swiss faunas after EP1, then reappeared during MIS 7 (Nuolen and Ried), and then disappeared for good after MIS 7	E, NE
		Clausilia pumila	Never before found in CH; first seen in the upper channel at Hochwacht, also present at Albishorn-Bürglen 1 and Hungerbol; it may have diappeared from Swiss faunas after MIS 11 (Sous-Terre), although it seems to have become regionally extinct only after MIS 7	E, NE
		Perforatella bidentata	Present during the Early to early Middle Pleistocene, it may have diappeared from Swiss faunas after MIS 11 (Montfleury), although it seems to have become regionally extinct only after MIS 7	E, NE
		Aegopis klemmi †	Never before found in CH; it may have disappeared from Swiss faunas after MIS 11 (Sous-Terre); it became extinct in all of Europe after MIS 9	(E), SE
		Zonitoides sepultus †	Never before found in CH; it may have disappeared from Swiss faunas after MIS 11 (Sous-Terre); it became extinct in all of Europe after MIS 9	slightly NW, N, E
		Clausilia rugosa antiquitatis †	Never before found in CH; it seems to have disappeared from CH and become extinct across all of Europe after MIS 11 (Sous-Terre)	
		Pisidium clessini †	Never before found in CH; it may have disappeared from Swiss faunas after MIS 15-13 (Ecoteaux), when it became regionally extinct in Central Europe; it survived for longer in Western Europe before finally going extinct after MIS 7	W
Early Pleistocene or later		*Neostyriaca corynodes ornatula* †	Never before found in CH; it may have disappeared from Swiss faunas after EP3 (Hungerbol), although it became extinct in all of Europe after MIS 13	E
		Theodoxus danubialis	Never before found in CH; it may have disappeared from Swiss faunas after EP3 (Hungerbol), although it was regionally present until the end of MIS 13	E
		Azeca goodalli	Never before found in CH; it may have disappeared from Swiss faunas after EP1, but became regionally extinct in west-central Europe (southern Germany, eastern France) only after MIS 11	NW, W, SW
middle-late Early Pleistocene (EP2: 1.78-1.22 - EP3: 1.22-0.78)		*Helicopsis striata*	Never before found in CH; it disappeared from CH and became regionally extinct after EP3 (Hungerbol)	E, NE, SE
		Macrogastra densestriata	Never before found in CH; it disappeared from CH and became regionally extinct after EP3 (Hungerbol)	E
		Monachoides vicinus	Never before found in CH; it disappeared from CH and became regionally extinct after EP3 (Hungerbol)	E
		Retinella (Lyrodiscus) elephantium †	Never before found in CH; it seems to have disappeared from CH after EP1, but may have reappeared during subsequent warm interglacials like MIS 11; it finally became extinct in western Europe after MIS 11	W, SW
		Trochulus filicinus	Never before found in CH; it seems to have disappeared from CH and become regionally extinct after EP3 (Hungerbol)	SE
		Causa holosericea	Never before been recorded from pre-Holocene deposits in CH; during EP1 it may have been present in much of CH, but subsequently might have become largely restricted to the southern and south-eastern parts of CH after EP1 or possibly after EP2.	S, SE, E
		Ciliella ciliata	Never before found in CH north of the Alps; it may well have disappeared from the Swiss Plateau after EP1 or possibly after EP2.	S, SW, SE
		Oxychilus clarus	Never before before found in CH north of the Alps; during EP1 it may have been present in much of CH, but subsequently became restricted to the south-eastern part of the country after EP1 or possibly after EP2.	S, SE
older Early Pleistocene (EP1; 2.6 -1.78 My)		*Acicula parcelineata*	Never before found in CH; seems to have disappeared from CH after the end of EP1	E
		Aegopis sp.	Never before found in CH; seems to have disappeared from CH after the end of EP1	S, SE?
		Poiretia dilatata dilatata	Never before found in CH; seems to have disappeared from CH after the end of EP1	S
		Serrulella sp.†	Never before found in CH; seems to have become extinct in CH after the end of EP1, but survived in Austria and northern Italy until the end EP3	S, E
		Soosia diodonta	Never before found in CH; seems to have disappeared from CH after the end of EP1, although it may have reappeared during later warm periods?	SE
		Spermodea lamellata	Never before found in CH; seems to have disappeared from CH after the end of EP1	NW, W
		Trochulus leucozonus	Never before found in CH; seems to have disappeared from CH after the end of EP1	SE
		Archaegopis (Retinella) acutus †	Never before found in CH; seems to have become extinct in CH after EP1, but survived in Austria until the end of EP2	E, SE
		Clausilia stranzendorfensis †	Never before found in CH; this major biostratigraphical marker became extinct in all of Europe after EP1, c.1.8 My	E
		Cochlostoma salomoni †	Never before found in CH; this major biostratigraphical marker became extinct in all of Europe after EP1, c.1.8 My	W, SW
		Macrogastra sessenheimensis †	Never before found in CH; seems to have become extinct in CH after EP1, but survived in Austria until the middle of EP2	E
		Neostyriaca dehmi †	Never before found in CH; seems to have become extinct in in all of Europe after EP1, c.1.8 My	
		Oxychilus steiningeri †	Never before found in CH; seems to have become extinct in CH after EP1, but survived in Austria until the end of EP2	E
		Triptychia new sp.†	Never before found in CH; most taxa of this major biostratigraphical marker genus became extinct across Central Europe at the end of the Pliocene, but one species survived in CH until the end of EP1, c.1.8 My	S, E
		Hauffenia/Islamia sp.†?	Never before found in CH; this unidentified possible endemic may have become extinct after EP1	endemic?
		Moitessieriid/Hydrobiid sp.†	Never before found in CH; this unidentified possible endemic may have become extinct after EP1	endemic?

Period	**Species**	**Time of first appearance in Quaternary deposits of the Swiss Plateau (see Section 5.6)**
Late Pleistocene	*Daudebardia brevipes*	First seen at Flurlingen and Niederweningen (MIS 5e); only present now in northernmost Switzerland
	Daudebardia rufa	First seen at Niederweningen (MIS 5e); only present now in the far north-west of Switzerland
later Middle Pleistocene	*Pomatias elegans*	First seen at Grandson (MIS 7); absent from Les Tuileries and Giez (MIS 5e)
	Semilimax semilimax	First seen at Nuolen and Ried (MIS 7), Niederweningen and Zell (MIS 5e); absent from Sous-Terre and Montfleury
	Cepaea sylvatica	First seen at Sous-Terre (MIS 11), also seen at Les Tuileries and Giez (MIS 5e)
	Cochlostoma septemspirale	First seen at Sous-Terre (MIS 11 - form with fine ribbing); absent from Les Tuileries and Giez (MIS 5e)
	Helicodonta obvoluta	First seen at Sous-Terre (MIS 11)
	Sphyradium doliolum	First seen at Sous-Terre (MIS 11)
early Middle Pleistocene	*Acicula lineata*	First seen at Ecoteaux (MIS 15); then at Niederweningen and Bürgerspital (MIS 5e)
middle-late Early Pleistocene (EP2/EP3)	*Clausilia cruciata*	First seen at Hungerbol (EP3); absent from Irchel sites, Albishorn-Bürglen 2 and Albishorn-Bürglen 1
	Platyla polita	First seen at Hungerbol (EP3); absent from Irchel sites, Albishorn-Bürglen 2 and Albishorn-Bürglen 1
	Cochlodina fimbriata	First seen at Albishorn-Bürglen 1 (EP2) and Hungerbol (EP3); absent from Irchel sites and Albishorn-Bürglen 2
	Macrogastra attenuata	First seen at Albishorn-Bürglen 1 (EP2) and Hungerbol (EP3); absent from Irchel sites and Albishorn-Bürglen 2
	Macrogastra plicatula	First seen at Albishorn-Bürglen 1 (EP2) and Hungerbol (EP3); absent from Irchel sites and Albishorn-Bürglen 2
	Monachoides incarnatus	First seen at Albishorn-Bürglen 1 (EP2); absent from Irchel sites and Albishorn-Bürglen 2; also missing from Hungerbol
older Early Pleistocene (EP1)	*Euomphalia strigella*	First seen in the first seen in the upper channel at Hochwacht (late EP1), then reappeared at Ecoteaux (MIS 15); also present at Sous-Terre and Montfleury (MIS 11)

Figure 8: Molluscan biostratigraphic marker species for Swiss Quaternary deposits

major climatic shifts that may also have affected Switzerland. The Early Villafranchian, like the Lower Villanyian, ends at c.2.6 My, which coincides with the start of the Early Pleistocene and the Gauss to Matuyama Chron boundary. The Middle Villafranchian ends at c.1.8 My, like the Upper Villanyian/Biharian transition, and the Late Villafranchian ends at c.1.2 My (Petronio et al. 2011). Moreover, 1.8 My is the Gelasian to Calabrian Stage boundary, 1.78 My marks the end of the Olduvai Subchron, while in the North-West European Chronology 1.76 My corresponds to the transition from the Tiglian to the Eburonian cold stage, and after the Waalian warm stage 1.22 My marks the start of the Menapian cold stage. Importantly, 1.2 My also coincides with a major change in the frequency and nature of glacial/interglacial cycles, with longer and more intense glacial stages having a stronger influence on terrestrial plant and animal populations (Clark et al. 2006, Head and Gibbard 2015, Westerhoff et al. 2020, Cohen and Gibbard 2022).

The dates of 1.78 and 1.2 My thus seem to provide valid points for the division of the Early Pleistocene in Europe. To simplify the following discussion, the Early Pleistocene has been divided into three parts, with the older Early Pleistocene (EP1) from 2.6 until 1.78 My, the middle Early Pleistocene (EP2) from 1.78 until 1.2 My, and the later Early Pleistocene (EP3) from 1.2 to 0.77 My, which marks the start of the early Middle Pleistocene. The Jaramillo Subchron thus lies within the lower part of EP3.

The Irchel sites and Albishorn-Bürglen 2 both correspond to the Höhere Deckenschotter (HDS) complex. Apart from the site at Freienwil, AG, these are the only HDS locations where fine sediments have been discovered with preserved biological remains. Similarly, for the Tiefere Deckenschotter (TDS), Hungerbol, DE and Iberig, AG are the only sites with fine sediments known to have biological remains. Unfortunately, no samples of either the fine sediments or the mollusc shells from Iberig were retained for analysis (Graf pers. comm.), and the relevant levels are only accessible by coring. The TDS unteres Niveau (lower level) has not been studied during this research, due to a lack of deposits with molluscs or other biological remains (cf. Graf 1993, Graf 2009a).

The comprehensive work by Graf studying Deckenschotter deposits in Switzerland and neighbouring areas of southern Germany (Graf 1993, 2009a, 2019), has shown that the HDS can *grosso modo* be divided into three sub-units (Graf 2019, fig.16, p.21-23).

- The **first sub-unit** began with fluvioglacial gravels, followed by silts with calcareous nodules and rare biological material. Examples include the *Langacher-Schotter* followed by bedded gravels and sands, then silts with calcareous nodules at Irchel Ebni, at the base of the Irchel Plateau, ZH, and the *Hinterhau-Schotter* followed by a well-developed palaeosol at Heitersberg, AG (Graf 2019, p.16-19). Other examples of the gravels include the *Basale Kristallinschotter* at Bowald, AG (p.76-78), and the *Basale Dürnschotter*, from the Dürn-Gländ Plateau, AG (p.87-88). These coarse, massively-bedded basal gravels represent cold climate fluvioglacial deposits, while the succeeding bedded gravels and sands, flood silts and palaeosols, seem to correspond to warm interglacial conditions.
- The **second sub-unit** again began with coarse gravels, followed in places by bedded gravels and sands, then flood silts, sometimes with biological remains. Examples include the *Irchel-Schotter* succeeded by the *Steig-Schotter*, then the thick flood deposits with calcareous nodules and abundant biological material that form the Hasli Formation of the Irchel Plateau, ZH, the *Basale Egg-Schotter* followed by bedded

gravels and sands, then flood silts at Egghalden, ZH (Graf 1993, p.55-56; 2019, fig.16), the gravels of the *Südliche Dürn-Schotter*, followed by flood silts with shells at Freienwil, AG (Graf 1993, p.80-82) and pollen at Tromsberg, AG, from the Dürn-Gländ Plateau, and possibly the massive lower gravels overlain by up to 1.25 m of flood silts with calcareous nodules at Roggenfeld, from the Mandach Plateau, AG (Graf 1993, p.88-92). Other examples of the gravels include the *Dolomitschotter* and possibly the *Westliche Bowald-Schotter* at Bowald (p.76-78) and the *Rüsler-Schotter* at Heitersberg, AG (Graf 2019, p.16-19). These strata again represent cold-climate fluvioglacial gravels, that were followed by interglacial flood silts probably linked with meandering rivers. The sands and gravels of the *Albisboden-Schotter*, ZH, were placed by Graf (2019, fig.16) in the first sub-unit due to the petrography of the clasts, but the presence of interglacial molluscs with distinctive marker species shows that they were deposited by a meandering river during a fairly prolonged warm period, and may well have been contemporary with the Hasli Formation (cf. Section 3.3.1). The presence of large boulders at the base of these fluvial deposits suggests, however, that the river reworked earlier fluvioglacial gravels that may have corresponded to the first sub-unit.

- The **third sub-unit** includes a mixture of fluvioglacial gravels and glaciogenic deposits, often basal till. In some locations HDS sequences are dominated by deposits from this sub-unit, such as at the Uetliberg, ZH and Wildstock, ZH (Graf 2019, fig.16). Other examples include the *Mittlere Dolomit-Schotter* and *Östliche Bowald-Schotter* followed by the *Obere Dolomit-Schotter und Moräne* of the Egg Plateau, ZH (Graf 1993, p.50-66), possibly the upper gravels with moraine of the Mandach Plateau, AG (p. 90-91), fluvioglacial gravels and the Bürglen Till followed by the *Albiswald-Schotter* at Albishorn-Bürglen, ZH (Graf 2019, p.8-9, 23) and possibly the fluvioglacial gravels of the *Forenirchel-Schotter* at the Irchel Plateau, ZH. In some locations this sub-unit includes a body of silt and sand that has been affected by pedological processes and may have biological remains. Examples include the up to 1.4 m of overbank organic and tufaceous silts and fine sands at Albishorn-Bürglen 1, c.0.8 m of clayey-silts and silty fine sands with calcareous nodules in the Uetliberg sequence (Graf 2019, p.12-15), and up to 2.6 m of bedded silts, sands and gravels with calcareous nodules at Cholholz, and up to 1.1 m of bedded sands at Boppelsen and Riese in the Wildstock outcrop (Graf 1993, p.66-69). Molluscs from the Albishorn-Bürglen 1 silts show that they accumulated in the floodplain of a meandering river during a warm interglacial. This sub-unit clearly starts with cold period deposits linked with a significant glacial advance, then saw an interval of warm interglacial climate associated with meandering rivers, before new cold period sediments point to a second notable glacial advance.

In the southern part of Baden-Württemberg (B-W), the chronology for the south-western German Alpine Foreland is equally lacking in detail as that for Switzerland (Ellwanger et al. 2011), with a similar paucity of well-dated sites and deposits with biological material. Like most of northern Switzerland, much of this region is connected to the Rhine system so shares a common history influenced by falling base-levels in the Upper Rhine Graben. As there is little evidence for post-depositional tectonic activity that may have influenced the altitude of Deckenschotter and river terrace deposits in this area, it should be possible to correlate surviving morphostratigraphic units across the whole region. The only exception might be HDS deposits in the area east of the Bodensee if this was connected to the Danube system during the older Early Pleistocene (Graf 2009a).

The chronology for southern B-W includes the *Älteste*, *Ältere* and *Jüngere Deckenschotter* complexes, of which the first has been correlated with the HDS of Switzerland and is attributed to EP1, the second is thought to date from EP2, and the third corresponds to the TDS of Switzerland and is attributed to EP3. Among the scarce dating information available is a reversed palaeomagnetic signal in several horizons of silty glacial till intercalated within the upper part of the *Heiligenberg-Schotter* at Altheiligenberg, north of the Bodensee, which correlates with the *Ältere Deckenschotter* of EP2. Nearby at Lichtenegg/Höchsten, there are glaciolacustrine and lacustrine sediments associated with reversed polarity, succeeded by sands capped by a thick interglacial palaeosol, then by basal till and fluvioglacial gravels, and finally by thick *Jüngere Deckenschotter* gravels, all of which seem to date from EP3 (Bibus et al. 1996b, Doppler et al. 2011, p.338-339, Ellwanger et al. 2011, p.313-314, Rolf et al. 2012).

The Alpine Foreland of southern Bavaria is connected to the drainage system of the Danube, so there is no inherent reason to assume that morphostratigraphical correlations exist between Early Pleistocene fluvial deposits in this region and the area of northern Switzerland and south-western Germany drained by the Rhine system. Nevertheless, some degree of contemporaneity may well exist as climate is one of the primary factors influencing the behaviour of fluvial systems. One of the difficulties in comparing morphostratigraphical units between southern B-W and southern Bavaria is that both regions link their units to the old chronostratigraphic system of Donau, Günz, Mindel, Riss and Würm, but use these temporal divisions in different ways. Thus, Günz is considered to correspond to EP2 in B-W, but to the early Middle Pleistocene in Bavaria, while Mindel is attributed to EP3 in B-W, but is linked with MIS 12 in Bavaria (Ellwanger et al. 2011, p.314, ab.2). To avoid confusion, none of these older chronostratigraphical terms will be used in the following discussion.

In Bavaria and parts of eastern B-W drained by the Danube, the morphostratigraphic units include a high level *Älteste Deckenschotter* and a *Höhere-Ältere Deckenschotter* that are attributed to EP1. There is no unit thought to belong to EP2, but a *Tiefere-Ältere Deckenschotter* is believed to correspond to EP3, while a *Jüngere Deckenschotter* appears to date from the early Middle Pleistocene (Doppler et al. 2011, Tab.3). The dating of several of these units is based upon the key region of the Iller-Lech-Platte. The site of Uhlenberg is located within the southern, somewhat higher part of the Zusamplatte, with small mammal and molluscan remains being found in sandy flood silts that overlie gravels up to 526-529 m asl which correspond to the *Höhere-Ältere Deckenschotter*. The small mammals (Ellwanger et al. 1994) and molluscs (Dehm 1979, Rähle 1995) show that these silts correspond to warm interglacial conditions during the Late Tiglian (late MN17), while normal palaeomagnetic polarity suggests they probably belong to the Olduvai Subchron at the end of EP1 (and possibly earlier, as the basal 0.85 m of the silts plus the underlying gravels were not studied). Overlying the Tiglian level are 1.0-2.0 m of decalcified sandy-silts with reversed polarity that include the '*Uhlenberg-Schieferkohle*' and seem to correspond to EP2/EP3 (Doppler and Jerz 1995; Strattner and Rolf 1995, figs.13-14; Bludau 1995). Similar Late Tiglian molluscan faunas have been found at the sites of Buch and Fischach in sandy-silts above *Höhere-Ältere Deckenschotter* gravels up to c.530+ m asl, and in silty-sands at Fürbch and Hörlis that overly older gravels with surfaces at 600-610 m asl that correspond to the *Älteste Deckenschotter* (Geyer 1914, Schröder and Dehm 1951, Münzing and Ohmert 1974, Rähle and Bibus 1992, Rähle

1995). Further to the south-west within the Iller-Lech-Platte are the older gravels of the Staudenplatte, which rise to c.645 m asl and again correspond to the *Älteste Deckenschotter* (Doppler and Jerz 1995, p.17-19). These gravels are thought to date from early EP1. The overlying slope and loessic deposits at Markt Wald all have normal polarity and seem to date from the Middle Pleistocene (Strattner and Rolf 1995, p.92).

In the northern part of the Zussamplatte are a series of sites with molluscan faunas that were found in sandy lenses within finely bedded sandy gravels with a surface at c.495-507 m asl (Brennberg, Fuchsberg, Kirchberg, Lauterbrunn, Osterbuch, Welden; Löscher et al. 1978, Münzing and Aktas 1987). The molluscan faunas lack all Tiglian marker species so are clearly younger, but nevertheless have typical interglacial taxa as well as aquatic molluscs that seem to have accumulated more or less in situ. As these interglacial gravels lie 20-30 m lower than the Höhere-Ältere Deckenschotter and overlie several metres of massively bedded fluvioglacial gravel, the underlying gravels may correspond to the *Tiefere-Ältere Deckenschotter*. Palaeomagnetic work has been undertaken at Lauterbrunn and on similar deposits at Roβhaupten. The profile at Lauterbrunn shows that the bedded gravels with shells have normal polarity, while the succeeding flood silts have reversed polarity (fig.20, Strattner and Rolf 1995). At Roβhaupten, a profile with flood silts has reversed polarity, but neither the base of the silts nor the underlying bedded gravels were studied (fig.20, Strattner and Rolf 1995). Tillmans et al. (1986) did study the base of these silts, but the palaeomagnetic signal is unclear. It thus appears that the bedded gravels with interglacial molluscs are associated with normal polarity, while the overlying flood silts have reversed polarity. As these gravels are clearly younger than the Late Tiglian sediments at Uhlenberg that seem to correspond to the Olduvai Subchron, it seems possible that they correspond to the Jaramillo Subchron. In this case the underlying sterile, probable Tiefere-Ältere Deckenschotter gravels might represent the cold phase during the early part of the Jaramillo Subchron during EP3.

To summarise, the Iller-Lech-Platte appears to have gravels that represent the *Älteste Deckenschotter*, which may date from early EP1, the *Höhere-Ältere Deckenschotter*, which predates the Olduvai Subchron during the later part of EP1, and the *Tiefere-Ältere Deckenschotter*, which seems to date from the early part of EP3. A cosmogenic date of $2.35^{+1.08}_{-0.88}$ My for the Höhere-Ältere Deckenschotter at the Bohener Feld, 60 km to the SW, supports an EP1 age for this unit (Häuselmann et al. 2007a). There appear to be no Deckenschotter gravels that correspond to EP2.

Around 50 km to the SW, at Unterpfauzenwald, near Steinental, within the Iller-Riss-Platte, the *Tiefere-Ältere Deckenschotter* is capped by a well-developed palaeosol. This is succeeded by two units of glacial till that are separated by an interglacial peat that is attributed to the Bavelian (EP3) because the pollen includes the extinct genera *Ostrya* and *Tsuga* that disappeared or became rare after the end of the Early Pleistocene. The glacial tills seem to correspond to *Jüngere Deckenschotter* gravels in the same area that may date from later EP3 (Ellwanger et al. 2011, p.312). Some 15 km to the NE, *Jüngere Deckenschotter* gravels at Gronenbacher Feld, near Memmingen, have yielded a cosmogenic date of $0.68^{+0.23}_{-0.24}$ My (Hauselmann et al. 2007a), but given the error margins this may still be compatible with an age during late EP3. Further to the East there are glacial tills at the margins of the Salzach and Inn Glaciers that appear to correlate with the *Tiefere-Ältere Deckenschotter* so may also date from EP3 (Fiebig et al. 2011, p.168).

5.2 Terrace formation and incision in the Alpine region

Beyond the limits of glacial ice, terraces in much of North-Western, Northern and Central Europe are features most commonly found in river valleys, with aggradation and gravel deposition during cold periods, followed by incision and the accumulation of finer sediments during interglacials, although in some areas the greatest incision seems to have been at the start of cold periods (Antoine et al. 2003). Good examples of terrace systems have been documented for river valleys across much of Europe (Bridgland et al. 2006, Cordier et al. 2006, 2009, 2011, Antoine et al. 2015). Within areas affected by glaciation, however, much of the incision seems rather to have been caused by glacial ice. 'Over-deepened valleys', for example, are common in inner-Alpine settings that were spatially confined and through which large volumes of ice used to flow, as well as in lowland situations where valley glaciers merged, there was a marked break of slope or there was an ablation area. The severity of erosion seems to have been largely dependent on the volume of ice flow, the degree of spatial confinement, gradient, and on the nature of the bedrock, with valleys up to 1000 m deep known from both Switzerland and Austria (Preusser et al. 2010, van Husen 2011, Buechi et al. 2017). In the foreland of the Swiss Alps many over-deepened valleys follow pre-existing weaknesses in molassic bedrock, while studies of their infills suggest that due to later scouring these often represent only the last two or three major periods of glaciation, together with remnants from earlier glacials (Preusser et al. 2010, Burschil et al. 2018). In the Glatt Valley, for example, the greater part of the infill dates from MIS 2 and 6, while vestiges can be tentatively correlated with MIS 8, 10 and possibly 12 (Buechi et al. 2018). In lowland situations where the relief is fairly subdued and there is no spatial confinement, it seems to be the volume of the ice that largely dictates the erosive force of glacial flow. This explains why in areas of the Swiss Plateau that have been significantly affected by past glacial activity, sedimentary sequences often resemble those from Alpine valleys, being dominated by glaciogenic deposits from the last few glacial periods, together with pockets of interglacial and earlier glacial sediments. A good example is the Seeland-Mittelland area between Olten, Neuchâtel, Bern and Murten, where the bedrock is largely covered by basal till dating from MIS 6 or MIS 2 (Pugin 1991). Earlier sediments are only conserved in scattered pockets at the margins of deeper troughs, or in topographical depressions such as that found at Ecoteaux, VD (Pugin 1991, Pugin et al. 1993). In areas less often affected by glaciation, the erosive action of rivers during interglacial periods becomes more important (cf. Fiebig et al. 2011, p.169), and the basal fills of valleys often retain evidence of multiphase fluvial and glacial erosion (Preusser et al. 2010).

There are two episodes of major incision included in the Quaternary chronology for Switzerland presented by Preusser et al. (2011, fig.19). The first is between the HDS and the TDS, while the second is between the TDS and the deposits of the Hochterrasse, of which the earliest may date from the Möhlin Glaciation (MIS 12). They attribute the first incision to subsidence in the Upper Rhine Graben (URG) together with possible uplift in the Alpine Massif. The URG seems to have become more active during the final phase of the Late Pliocene after c.2.9/2.8 M, while the older Early Pleistocene seems to have been a time of particularly rapid subsidence (Kemma and Westerhoff 2007, Knipping 2008, Weidenfeller and Knipping 2008, Ziegler and Fraefel 2009, Gabriel et al. 2013). For the second incision, they propose that subsidence within the URG may have been added to by capture of the Alpine Rhine by the Rhine system, as the Alpine Rhine was a tributary of the upper Danube for part of the Early Pleistocene (Preusser 2008). For much of this period, however, the upper part of the Alpine Rhine system used to flow north-westwards through the Walensee gap to join the Rhine (Graf 1993, p.101-104), while capture of the remainder of the Alpine Rhine may well have occurred somewhat earlier, between 2.1 and 1.2 My (Villenger 2003, Müller et al. 2002, Kuhlemann and Rahn 2013), making it more of a contributary factor for the first incision. Moreover, there is little evidence for differential uplift or other significant tectonic activity in most of the northern Alpine region during the Pleistocene (Graf 2009a, Ziegler and Fraefel 2009, van Husen 2011).

Apart from the possibility of modest fluvial reorganisation, the tectonic argument fails to explain why both episodes of incision seem to have been fairly rapid rather than incremental, and few intermediate deposits have been documented. A more probable scenario for rapid incision may therefore be that of glacial scouring coupled with subsidence within the URG, which would have lowered the base-level and led to pronounced fluvial incision along the Hochrhein and its tributaries after glacial retreat.

The timing of these two episodes of major incision may thus have been linked to notable increases in glacial activity. A possibility for the first incision is MIS 34-32, as this appears to have marked the start of more significant glacial activity across much of north-western Europe (cf. Section 5.3), although some incision may already have occurred during MIS 36. It is possible, for example, that MIS 34-32 may have coincided with the notable glacial incision seen at the base of the TDS complex at Iberig (cf. Preusser et al. 2011, p.286). Similarly, Graf's work at the Schiener Berg west of the Bodensee (2009a, fig.12), shows that incision of c.50 m may have occurred in three or four episodes, linked with the successive units of glaciogenic and fluvioglacial deposits that constitute the TDS (cf. Section 5.8.3). A strong candidate for the second incision is MIS 16, as this period appears to have seen a great intensification of glacial activity across much of north-western and Central Europe, although in many areas evidence for this has been lost due to glacial scouring during MIS 12 (cf. Section 5.3). Kuhlemann and Rahn (2013) similarly concluded that MIS 16 and 12 represent the most likely periods for major glacial deepening in the Alpine foreland. An examination of the sequence from the type locality for the Möhlin Glaciation at Möhlinerfeld, for example, shows that there are glacial tills and fluvioglacial gravels deposited by two different glaciations, separated by a well-developed interglacial palaeosol, and then a third fluvioglacial gravel (Graf 2009b, p.153, tab.13; Preusser et al. 2011, p.287). This sequence has been interpreted as representing advances during MIS 12, 10 and 6, but as glacial ice may not have reached as far as Möhlinerfeld during MIS 10, it is possible that these deposits instead represent MIS 16, 12 and 6, with initial deepening during MIS 16. If correct, there may have been significant glacial activity across much of lowland Switzerland during MIS 16, such as that shown by the possible MIS 16 glaciogenic deposits at Ecoteaux (cf. Section 6.1.1).

5.3 Evidence for Early and early Middle Pleistocene glaciations in Europe

All of the Early Pleistocene sites discussed in this study, including those at Irchel, Albishorn-Bürglen and Hungerbol, have deposits linked with glacial activity, such as fluvioglacial gravels and basal tills. Although the Quaternary landscape of North-Western, Northern and Central Europe has been greatly influenced by glacial activity (cf. Section 5.1), there have only been between 10 and 15 cold periods over the last 2.6 My during which ice build-up would have been sufficiently great to generate significant glacial activity across the Swiss Plateau and adjoining areas of Europe (cf. Ehlers et al. 2011a, Preusser et al. 2011). The number of such glacial periods can to some extent be estimated from the curve for Marine Oxygen Isotope stages constructed by Lisiecki and Raymo (2005). Despite this curve being based on $\delta^{18}O$ data that comes from the floors of the world's oceans (two thirds from the Atlantic), it has been shown repeatedly to be a reliable indicator of climatic variations across the European landmass (cf. Head and Gibbard 2015). The most extensive glaciation in much of Europe, for example, occurred during what is known as the Möhlin Glaciation in Switzerland (cf. Section 5.3; Preusser et al. 2011), which corresponds to when $\delta^{18}O$ values reached their peak during MIS 12.

A standard approach to constructing a Quaternary chronology seems to involve an attempt to survey and examine the available deposits across a given area, often at a national scale, and then determine how many colder and warmer periods these sediments might represent and the order in which they accumulated. For an Alpine area like Switzerland, however, the deposits from the majority of warm intervals and many of the glacial periods have been lost to later erosion, while beyond the limits of past ice fronts interglacial deposits may be better preserved but cold period sediments become more difficult to identify. This has meant that important sequences have often been located in transitional areas between the limits of the most extensive ice advances and ice fronts that are closer to the Alps, where a mix of glacial and interglacial deposits can be found, but this leaves the complex problem of how to correlate fragmented depositional records from different areas. A potential solution is to use the MIS curve as a framework into which the various cold and warm period deposits may be inserted, aided by scientific dating techniques. This might involve taking the sequence of identified glacial deposits from a particular area and attempting to correlate them with the 10 to 15 periods that may have seen significant glaciation in Central Europe. Interglacial sediments could then be slotted in between these glacial periods, using biostratigraphic indicators to try to correlate them with deposits possessing similar biological remains in sequences that may have better dating evidence.

The MIS curve for the Pleistocene can be divided into several sections, which makes correlating cold and warm period deposits somewhat easier. From 2.6 until c.1.2 My, the periodicity of the glacial-interglacial cycles was c.41 ky, with the great majority of the colder periods being of low intensity and unlikely to generate much more than localised increases in glacial ice within mountainous areas such as the Alps. After 1.2 My, the cycles increased their periodicity to c.100 ky and were of significantly greater amplitude. Between 1.2 and 0.68 My, $\delta^{18}O$ values for the colder periods increased progressively, as glacial intervals became notably more intense, while between 0.68 My and the LGM, the Middle and Late Pleistocene were characterised by full-blown glaciations associated with major ice advances across much of North-Western, Northern and Central Europe.

Evidence for early to middle Early Pleistocene Glaciations between 2.6 and 1.2 My

In the North Atlantic SW of Ireland, a detailed record shows peaks in ice rafted debris (IRD), linked with an expansion of the British-Irish Ice Sheet, during EP1 at 2.6-2.45 My, corelating with MIS 100, 98 and 96, 2.35-2.15 My, which may correspond to MIS 92?, MIS 86? and MIS 82, and 2.10-1.95 My, which equates to MIS 78-76 and possibly MIS 72. There is much less evidence for IRD during the Olduvai Subchron, but during EP2 there are two strong signals between 1.75 and 1.65 My that may correspond to MIS 60 and MIS 58, above which the record is truncated (Thierens et al. 2012). Rea et al. (2018) found evidence in the central North Sea for scouring caused by marine-terminating ice sheets flowing from surrounding land-masses during EP1 between 2.6 and 1.78 My. They could identify notable glacial scour events that correspond to MIS 100, 98, and 96 (2.53 to 2.44 My), less significant scouring during MIS 92 (2.40 to 2.36 My), important scouring between MIS 82 and 72 (~2.15 to 1.94 My), and more minor scouring between MIS 70 and 64 (1.91 to 1.78 My). The two most notable EP1 sea-level low-stands associated with major scouring occurred during MIS 82 and 78. There is also evidence for ice-rafting over the Hebrides Shelf after 2.6 My and west of Norway that may correspond to MIS 82, 78-76, 72 and 52-50 (Graham et al. 2011, Thierens et al. 2012), while buried iceberg scours have an age between 2.6 and 1.7 My (Ehlers et al. 2011a). The Svalbard shelf shows initial glacial expansion after 2.3 My followed by further glacial expansion between 1.6 and 1.3 My (Sejrup et al. 2005). In the palaeo-Adriatic, there were significantly lower water temperatures and stronger seasonality after c.1.8 My (Crippa et al. 2016, 2018, 2019). Oceanic records from the Atlantic show a period of cooler conditions after 1.75 My, which became notably colder between MIS 54 and 50 (McClymont et al. 2013).

In Europe north of 43/45°N, as well as in other areas of the Northern Hemisphere, evidence for glacial activity in the terrestrial domain during the older and middle Early Pleistocene is scarce, due to the destructive force of later glaciations. One of the most complete records for Early Pleistocene glaciation has been compiled in Iceland, where glacial tills and interglacial sediments have been preserved between datable basaltic lava flows and sub-glacially formed volcanic hyaloclastites. During EP1 there is evidence for significant glacial activity at 2.6-2.45, 2.35-2.25 and 2.15-2.05 My, which equates to MIS 100, 98 and 96, MIS 92 and 86, plus MIS 82 and 78-76, but there seems to have been no notable activity during the Olduvai Subchron. EP2 saw significant glacial activity at c.1.7-1.65, 1.55-1.5, c.1.4, and 1.3-1.25 My, which may correspond to MIS 58, 52-50, 46 and 38 (Geirsdóttir 2011). A core from the southern North Sea shows clear vegetational responses to truly cold conditions in the land areas drained by the Rhine-Meuse and Baltic paleo river systems during the earlier part of EP1, which seem to equate to MIS 98, 96 and to a lesser extent MIS 94 (Donders et al. 2018). In The Netherlands and the UK, the oldest deposits with evidence of cold conditions are shallow marine sediments dating from the Praetiglian, which may correspond to MIS 100, 98 and 96. Subsequently, there are signs of a rather cold climate in marine beds in the UK during the ‘Baventian', which seems to date from c.2.2 My and includes an episode of normal polarity at Easton Bavents. These are followed by the marine beds of the ‘Weybourne Crag’ that at Sidestrand clearly represent a much warmer climate and have normal polarity (Preece et al. 2020). If both normal events coincide with the Feni (Réunion) Subchron, this might suggest that the cold episode corresponds to MIS 82 (2.15 My) while the warm interval represents MIS 81 (2.13 My). Contemporary deposits belonging to the Tiglian in The Netherlands and Belgium include notable cold episodes that may correspond to MIS 82 and 78-76, as well as another that might represent MIS 72 or 68. Subsequent episodes of cold climate during the Eburonian cold stage may correspond to MIS 62, 60, 58 and 52-50 (cf. Drees 2005, Laban and van der Meer 2011, Westerhoff et al. 2020). In the UK, there are terrace deposits linked with the ancestral Thames that contain clasts and glacially abraded sand that seem to derive from a fluvioglacial input caused by glacial activity in north-central Wales (Lee et al. 2012). The oldest terrace (Nettlebed Terrace) appears to date from shortly after 2.2 My (Preece et al. 2020) so might correspond to MIS 82, while subsequent terraces may possibly correlate with MIS 78-76, 72 or 68, 58 and/or 52-50

(Pawley et al. 2010, Lee et al. 2011). In SW Germany fluvioglacial gravels of the *Älteste Deckenschotter* appear to date from EP1, while there are *Ältere Deckenschotter* gravels with reversed polarity that may date from EP2. In SE Germany the *Älteste Deckenschotter* gravels seem to date from the first part of EP1, while the *Höhere-Ältere Deckenschotter* comes from later in EP1 before the Olduvai Subchron (cf. Section 5.1). In eastern North America, extensive tills have been dated to MIS 100, 98 and 96, while others seem to correspond to MIS 82, 78-76, 58 and possibly MIS 52-50 (cf. Thierens et al. 2012). Finally, Tzedakis et al. (2015) have noted a clear vegetational response to notably colder conditions in the Iberian Peninsula during MIS 38.

To summarise, EP1 saw significant glacial activity that might correlate with MIS 100, 98 and 96, plus MIS 82 and 78-76. There also appears to have been moderate activity during MIS 92, 86, 72 and possibly 68. EP2 may have seen fairly notable glacial activity during MIS 58 and 52-50, as well as moderate activity during MIS 62, 60, 46 and 38. Given that the colder periods during the older to middle Early Pleistocene were of short duration, while $\delta^{18}O$ values remained rather low, especially during EP1, it is unsurprising that the strongest evidence for glaciation seems to coincide with colder periods that had the highest $\delta^{18}O$ values and lasted for longer.

Evidence for final Early Pleistocene Glaciations between 1.2 and 0.77 My

In the Northern Hemisphere the later Early Pleistocene saw a considerable increase in the intensity and frequency of glacial activity after c.1.2 My, which seems to have been due to the change from 41k to 100k glacial/interglacial cycles. In the Nordic Seas, large-scale shelf-edge glaciation seems to have begun at c.1.1 My, during MIS 34-32, while in the North Sea Basin a sub-glacial till was formed by a major expansion of the Scandinavian Ice Sheet (SIS) from Norway during MIS 34-32. There are also clear signs (glacial outwash, diamicton) for the expansion of the British Ice Sheet into the North Sea during MIS 34-32, 30, 24-22 and 20. In the North Atlantic SW of Ireland, a detailed record after c.1.0 My shows peaks in IRD linked with westwards the expansion of the British-Irish Ice Sheet (BIIS) during MIS 24-22 and 20. There is also a general increase in the magnitude and duration of ice-rafting events around the margins of Svalbard, Norway and the Barents Sea during MIS 24-22 and 20 (Head and Gibbard 2015). At the same time terrestrial glaciers seem to have entered the North Sea from several directions, generating a subglacial till in the central North Sea that dates from c.0.9 My (MIS 24-22), and creating ‘tunnel valleys’ due to the existence of grounded ice in the North Sea Basin at this time (Graham et al. 2011, Lee et al. 2012, Thierens et al. 2012). A dramatic increase in the global volume of sea ice, especially in the Northern Hemisphere, saw sea-levels c.70 m below the present during MIS 34-32 and MIS 30, c.120 m lower during MIS 24-22 and c.90 m below during MIS 20 (Head and Gibbard 2015).

In Iceland there was glacial activity during EP3 at 1.15-1.10, 1.05-1.00 and 0.90-0.85 My, which can be correlated with MIS 34-32, 30, and 24-22 (Geirsdóttir 2011). The record from the proto-Thames includes terraces with glacial material that may correspond to MIS 34-32, 30, 24-22 and possibly 20. In the Bay of Biscay, the earliest significant input from a terrestrial European ice sheet began around 0.95 My during MIS 24-22 and reoccurred during MIS 20 (Böse et al. 2012). The late Menapian Hattem Bed Complex in The Netherlands, and its equivalent in NW Germany, provides the earliest indicator for glacial activity during MIS 34-32, while there is further evidence for glacial activity during the Linge Glaciation, which correlates to MIS 30, the Dorst Glaciation, during MIS 24-22 and Cromerian Glacial A that corresponds to MIS 20 (Ehlers et al. 2011b, Laban and van der Meer 2011). At Lichtenegg/Höchsten in south-western Germany there are glaciogenic deposits with reversed polarity capped by a well-developed interglacial palaeosol, then by basal till and gravels that represent an early advance by the Rhine Glacier, followed by thick *Jüngere Deckenschotter* gravels, all of which seem to date from EP3 (cf. Section 5.1). At Unterpfauzenwald in south-central Germany, *Tiefere-Ältere Deckenschotter* gravels that appear to date from the first part of EP3 are capped by a well-developed palaeosol, and then by two units of glacial till deposited by the Rhine Glacier that are separated by an interglacial peat pollen-dated to EP3 (cf. Section 5.1). In SE Germany there are glacial tills near the margins of the Salzach and Inn Glaciers that seem also correspond to EP3. In Austria, the Langenloiser Schotter might represent MIS 34-32 as it has reversed polarity and predates several other gravel units that have been attributed to MIS 24-22 (van Husen and Reitner 2011). In the Italian Alps and the Dolomites, the earliest notable southward advances by valley glaciers date from MIS 24-22, while this period saw a major increase in glaciogenic sedimentation in the Po River Basin (Muttoni et al. 2003). In Poland, the Narewian Glaciation seems to equate to MIS 34-32, while a further glaciation linked with MIS 24-22 may have been fairly extensive in parts of SE Poland (Marks 2011). The first widespread glaciation in European Russia, the Likovo Glaciation, also seems to correspond to MIS 24-22, while in northern Eurasia MIS 24-22 and 20 saw notable rises in the thickness and coarseness of loessic deposits. In North America, the earliest widespread lowland glaciations also took place during MIS 24-22 and 20 (Ehlers et al. 2011a, Velichko et al. 2011, Head and Gibbard 2015).

To summarise, MIS 34-32 saw important glacial activity that seems to have been more severe than during any previous Early Pleistocene cold period in the Northern Hemisphere and MIS 30 also witnessed significant glacial expansion, while MIS 36 may have seen more localised glacial activity. MIS 24-22 is known as the '*0.9 My super cooling event*' (Head and Gibbard 2015, p.31-32), because it represents a major increase in the intensity, duration and lateral extent of glaciation in many parts of Europe and North America, and was associated with the highest δ^{18}O values in the MIS curve since the start of the Pleistocene and record low temperatures. Indeed, during MIS 24-22 the whole of Fennoscandia was covered by an ice sheet that spilled across the Baltic and into North-Eastern Europe (Batchelor et al. 2019). MIS 20 also seems to have been a fairly severe glacial event, although it was fairly short-lived and thus allowed less time for glacial ice to accumulate (Head and Gibbard 2015).

Evidence for early Middle Pleistocene Glaciations between 0.77 and 0.42 My

In the North Atlantic SW of Ireland and in the southern North Sea there are peaks in IRD that provide evidence for significant ice-rafting during MIS 18 and 16, while in the central North Sea a proximal ice sheet caused scouring during MIS 16. MIS 12 saw the most extensive Pleistocene glaciation in the area, covering most of the North Sea Basin by linking up ice sheets from Norway, Denmark, Scotland and northern England. This caused a redirection of the European drainage network towards the south-west that led to the breaching of the Straits of Dover and the creation of the English Channel. The Nordic Seas also saw major shelf-edge glacial activity during MIS 12. In the Bay of Biscay there were significant inputs from terrestrial ice sheets during MIS 16 and 12. (Graham et al. 2011, Lee et al. 2011, Böse et al. 2012, Lee et al. 2012, Thierens et al. 2012).

In Iceland, glacial activity has been dated to 0.75, 0.65, 0.45, 0.2 and 0.5 My, which equates to MIS 18, 16, 12, 6 and 4-2 (Geirsdóttir 2011). In North-Eastern Europe, the Don Glaciation, which was one of the most important glaciations in the East European Plain, has been reliably correlated with MIS 16. It affected NE Germany, Poland (the Sanian 1), the Czech Republic, Latvia, Lithuania and western Russia, and seems to largely represent a south-eastwards expansion of the Scandinavian Ice Sheet across the Baltic Sea. In European Russia this was preceded by the Setun' Glaciation during MIS 18. During MIS 12 the ice sheets in Eastern Europe (the Sanian 2 in Poland) were less extensive than during MIS 16 in some areas but more widespread in others, like the Baltic States. In Denmark the earliest evidence for glacial tills seems to date from MIS 18 or 16, while the thickest and most extensive tills correspond to MIS 12, and include material of Norwegian, Swedish and Baltic origin (Guobytė and Satkūnas 2011, Houmark-Nielsen 2011, Kalm et al. 2011, Marks 2011, Nývlt et al. 2011, Velichko et al. 2011, Zelčs et al. 2011). In the UK the record from the proto-Thames includes terraces with glacial material that can be correlated with MIS 18, 16 and 12. There is possible evidence for lowland glaciation in the Cotswold Hills during MIS 18 or 16, although it was MIS 12 (the Anglian Glaciation) that saw the most extensive ice cover in the British Isles (Gibbard and Clark 2011, Lee et al. 2011, Lee et al. 2012). In The Netherlands there is evidence for cold conditions during MIS 18 and glacial activity during MIS 16 (the Weerdinge Member), but by far the most extensive glaciation up until that point occurred during MIS 12 (Laban and van der Meer 2011). Similarly in northern Germany, after the Don Glaciation of MIS 16 in parts of the north-east, MIS 12 (the Elsterian) saw much of the north being covered by ice that extended to the south of Leipzig (Ehlers et al. 2011b, Böse et al. 2012). In Austria there is clear evidence for significant glacial activity during MIS 16 (Günz Glaciation), including basal till, terminal moraines and fluvioglacial gravels attributed to the *Ältere Deckenschotter*, but the most extensive ice advances occurred during MIS 12 (Mindel Glaciation), including morainic deposits and fluvioglacial gravels attributed to the *Jüngere Deckenschotter* (van Husen 2011, van Heusen and Reitner 2011). In Baden-Württemberg, the undated Steinhausen-Till from the Rhine Glacier that may correspond to MIS 16, is followed after an episode of notable incision by tills linked with the Hoβkirch Glaciation during MIS 12, when the Rhine Glacier extended some distance to the north of the Bodensee and was associated with the earliest known fluvioglacial gravels of the Hochterrasse in the Rhine Valley. In Bavaria, the chronology follows the Austrian model, so morainic deposits and fluvioglacial gravels assigned to the Günz Glaciation appear to correspond to MIS 16, while extensive Mindel glacial deposits and *Jüngere Deckenschotter* gravels with normal polarity seem to correlate with MIS 12 (Doppler et al. 2011, Ellwanger et al. 2011, Fiebig et al. 2011, Burschil et al. 2018, Preusser et al. 2021). The first major glaciations in the Pyrenees also date from MIS 16 and 12 (Calvet et al. 2011, Head and Gibbard 2015). Major ice sheets covered large parts of North America during MIS 16 and 12, generating the first Heinrich Events in the eastern North Atlantic (carbonate-rich IRD from the Hudson Strait area of eastern Arctic Canada; Ehlers et al. 2011a, Hodell et al. 2008, Naafs et al. 2013, Head and Gibbard 2015).

To summarise, while MIS 18 seems to have witnessed fairly significant glaciation in places, MIS 16 and to an even greater degree MIS 12 saw extensive lowland glaciation across large parts of northern, north-western and Central Europe. During MIS 14 glaciation seems to have been largely restricted to mountainous areas, with little or no evidence for lowland glaciers.

5.4 Basics of molluscan biostratigraphy

There are four types of faunal pattern that can be noted when constructing a molluscan biostratigraphy, such as that proposed for The Netherlands by Meijer (1986, 1991a).

C**limatic influence**: this is shown by the number of terrestrial and aquatic species and the presence of taxa that are either typical of warm interglacial conditions or are cold-tolerant pioneers. Assemblages that represent interstadials during periods of cold-climate lack the former but often have specimens of the latter. Examples include the site assemblages from Petit Saconnex, WHO, Fisibach, Baden, Bertigny/Pont-la-Ville, Sihlbrugg and Dättnau as well as the faunas from the silts of Hungerbol 1 and the upper level from Montfleury.

Biosuccessional position: all interglacial periods saw the progressive arrival of new forest and shade-loving species after initial warming, with the most climatically sensitive and/or ecologically demanding taxa arriving last, when the forest was at its most diverse. This is crucial when attempting to understand whether an assemblage corresponds to a particular interglacial period. Taking the Eemian as an example, Niederweningen has the richest site assemblage from this period known in Switzerland, but while some biostratigraphic marker species appear fairly early on (*Pagodulina pagodula*), others arrive somewhat later (*Acicula lineata*, *Aegopinella ressmanni*, *Discus perspectivus* and *Ruthenica filograna*), while certain taxa only appear during the 'climax phase' (*Aegopis vorticillus*, *Daudebardia brevipes* and *Daudebardia rufa*). At Les Tuileries, *D. perspectivus* only appears near the top of the conserved sequence, suggesting that the 'climax phase' of the Eemian is missing. The deposits at Zell sampled by Forcart and Jayet in the early 1940's include *Aegopinella ressmanni*, *D. perspectivus*, *P. pagodula* and *R. filograna*, indicating that the greater part of the Eemian is present but the 'climax phase' might be missing. All of these species are absent from layers sampled by Kälin at the same site, although *A. ressmanni* is present, showing that the new strata belong to an earlier phase of the Eemian. Similarly, the fauna from Bürgerspital, Basel represents the early to middle part of the Eemian, as only *A. ressmanni* and *Acicula lineata* are present.

Ecological context: the marker species *Pagodulina pagodula* arrived fairly on at Niederweningen, so its absence from sites like Les Tuileries and Bürgerspital may be due to ecological reasons. As *P. pagodula* is found under leaf-litter in moist woodland and among shaded calcareous rocks (Kerney et al. 1983, Welter-Schultes 2012), it is possible that some aspect of the local forest environment at Les Tuileries and Bürgerspital may not have encouraged colonisation by this taxon.

Stratigraphic order: it is important to establish during which interglacial periods key biostratigraphic marker species may have been present or absent, by studying their representation through time at a number of sites from the same region. Certain taxa may have been more or less continuously present over a notable time span that included a series of interglacials, before disappearing for good when they became regionally extinct, such as *Clausilia pumila*, or globally extinct, like *Clausilia rugosa antiquitatis* and *Neostyriaca corynodes ornatula* (Figure 10). Others appeared and then became more or less regularly present during interglacial periods up until the present day, such as *Clausilia cruciata* or *Macrogastra attenuata*. Still other taxa may only have been widely present during one or two interglacials, such as *Zonitoides sepultus*. Being able to discern patterns from incomplete and complex data sets is obviously made easier when there are sites with well dated assemblages that provide reliable points of comparison.

5.5 Molluscan biostratigraphical marker species that are absent from or rare among Holocene faunas in Switzerland

5.5.1 Marker species for Höhere Deckenschotter deposits

There are a number of biostratigraphical marker species worthy of detailed mention, several of which help to provide an approximate age for the deposits at Irchel, Albishorn-Bürglen and Hungerbol (Figure 8). Important marker taxa have also been found in the material from Middle and Late Pleistocene sites analysed for this study. Based on a review of published literature and a thorough survey of the molluscan material held by the main geological and zoological museums in Switzerland, only one of the Early-Middle Pleistocene marker species, *Perforatella bidentata*, has ever previously been recorded from Swiss Quaternary deposits. This is because, unlike much of Germany, Austria and France, the Early, Middle and Late Pleistocene molluscan faunas from Switzerland are poorly known. The following review of published records for the various biostratigraphical marker species in nearby countries from Western and Central Europe is intended to provide a temporal framework for when species first appeared, were present and disappeared, in order to better understand when they were likely to have been present among Swiss molluscan faunas. The combined records for the various species can then be used to estimate approximate ages for the site assemblages analysed during this study. The bibliographic references for all the sites mentioned are given in Appendix 3, along with the probable ages and how the sites are dated. All data concerning modern geographical distributions is taken from Turner et al. (1998) and Welter-Schultes (2012).

The following site abbreviations are used in the text below: IH = Irchel Hasli, IS = Irchel Steig, Wil = Wilemerirchel, Hoc = Irchel Hochwacht, Ams = Irchel Amselboden, A-B 2 = Albishorn-Bürglen 2, A-B 1 = Albishorn-Bürglen 1

Species with modern or past geographic distributions that lie to the East of Switzerland

Acicula parcelineata: found in Switzerland only at Hoc and A-B 2 (Figure 7). This is an Eastern European species with a modern geographical distribution that lies far to the east of Switzerland centred on the Carpathians, including the far east of the Czech Republic, Slovakia, the southernmost part of Poland, and further to the south-east. It has never been found as a fossil in Austria or Germany and only rarely in Holocene deposits in Slovakia, although its scarcity is understandable given its small size and fragility. Like the other species with modern or past distributions that lie far from northern Switzerland, this species seems likely to have disappeared from Switzerland at the end of EP1.

Aegopis sp.: found in Switzerland only at Hoc(upper). There are several fragments from the inner whorls of a moderately sized taxon that seems to correspond to a species of *Aegopis* (Appendix 2). They show fine, sharp, densely-spaced ribbing on the upper side, which after a fairly sharp angle at the periphery, slightly keeled on some fragments, continue on the underside as considerably blunter, less well-defined and more widely spaced ribs. The shell between the ribs is somewhat matt on the upper side, but rather shiny on the underside. The ribs continue into the umbilicus, which is wide and deep. The absence of a strong keel and spiral microsculpture rules out *A. klemmi* and *A. verticillus*, as well as *A. gemonensis*, which lives today in northern Italy, Slovenia and Croatia. *A. compressus*, which inhabits Slovenia and Croatia, is excluded because its shell lacks ribbing. Possibilities include *A. italicus*, which lives today in central Italy, and *A. croaticus*, which is present in southern Slovenia, Croatia and western Bosnia.

Archaegopis acutus: found in Switzerland only at IH, Wil, Ams, Hoc and A-B 2 (Figure 7). This is an extinct forest species that is mostly known from Early Pleistocene sequences in north-eastern Austria, so it may have had an Eastern or East-Central European distribution that may also have reached SE Europe. In Austria it has been found at Late Pliocene (MN16b) levels at Neudegg and at Deutsch-Altenburg in sediments dating from EP2 (2C1, 33, 37, 43) and late EP2 (4B), but nothing more recent. Given its absence from Albishorn-Bürglen 1 and Hungerbol, this species may have disappeared from Swiss faunas at the end of EP1, and can be considered as **a reliable biostratigraphic marker for Final Pliocene/Early Pleistocene faunas up until the end of EP2**[5].

Clausilia stranzendorfensis: found in Switzerland only at IH, IS, Wil, Ams, Forenirchel, Hoc and A-B 2 (Figure 7). This extinct forest species is so far known only from a few Late Pliocene/Early Pleistocene sequences in north-eastern Austria, so it may have had an East-Central European distribution. There seem to be two forms: one described by Nordsieck (1990) that is found in Late Pliocene (MN16b) sediments at Neudegg and at Stranzendorf (levels A); and another illustrated in Frank (2006) that is present at Neudegg and at Stranzendorf in deposits dating from the Late Pliocene (levels A and C) and EP1 (levels F, G, K, K/L, L), and in EP1 sediments at the nearby site of Unterparschenbrunn[6]. The second form is the one present at the Irchel sites. This species is absent from EP2 sites like Krems and Deutsch-Altenburg and has never been found in anything younger than EP1. In southern Germany the second form may also be present in EP1 deposits at Buch and Uhlenberg. It thus appears likely that *Clausilia stranzendorfensis* became extinct after EP1 and can be considered as **a reliable biostratigraphic marker for Final Pliocene/Earliest Pleistocene (EP1) faunas**.

Macrogastra sessenheimensis: found in Switzerland only at IH, IS, Wil, Ams, Forenirchel, Hoc and A-B 2 (Figure 7). This extinct forest species is known only from Late Pliocene/Early Pleistocene sequences and seems to have had an East-Central European distribution. In Austria it has been found in deposits dating from EP1 at Stranzendorf (level F), in EP2 levels at Krems (11 and possibly 12, 9, Kov-5, Kov-2, Kov-1, as Ložek 1978 and Kovanda et al. 1995 mention a small form of *Macrogastra* sp.). In southern Germany it is known from EP1 levels at Fischach and Uhlenberg. In France it has only been found in Late Pliocene (MN16b) deposits at Sessenheim in Alsace. As it is absent from both Albishorn-Bürglen 1 and Hungerbol, it may have disappeared from Swiss faunas at the end of EP1 or possibly during EP2. It seems to have become extinct during EP2. It can be considered as **a reliable biostratigraphic marker for Final Pliocene/Early Pleistocene (EP1- start of EP2) faunas older than c.1.4 My.**

Oxychilus steiningeri: found in Switzerland only at Hoc(upper). This extinct forest species has so far only been found in Early Pleistocene deposits in north-eastern Austria, so it may have had an East-Central European distribution. It was recorded at Deutsch-

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[5] The single shell recovered from MIS 11 layers in a deep core in the Vienna Basin is clearly redeposited according to Frank (in Salcher et al. 2017).

[6] In the form described by Nordsieck 1990 (figs.9-10), after the columellaris bifurcates towards the mouth edge the upper and lower folds are poorly developed, whereas in the new form illustrated in Frank 2006 (Plate XXXI, figs.7-10) both folds are well-developed, parallel and with a noticeable gap in between.

Altenburg in sediments dating from EP2 (45) and late EP2 (4B), but according to Frank (2006, p.439) it may also have been present in an EP1 context at Rottenburg in SW Germany (Rähle and Bibus 1992, p.334). Identification was possible thanks to a large fragment that included most of the first two whorls (Figure 7). The first whorl has a diameter of 1.7 mm, which is compatible with the diameters of 1.64 and 1.9 mm reported for the first whorl of two specimens from Deutsch-Altenburg (p.437).

Serrulella sp.: found in Switzerland only at Wil and Hoc (Appendix 2). The extinct species from this genus are similar to modern *Serrulina serrulata* (Diameter 2.6-3.2 mm) that lives in south-eastern Europe (E Romania, E. Bulgaria) and northern Turkey. *Serrulella truci* from Late Pliocene deposits at Fortuna-Garsdorf and Frechen, west-central Germany, *S. zanchettai* from Late Pliocene levels at Monte Serampoli, Toscana and *S. decemplicata* from Late Pliocene strata at Fossano and possibly Ceresole d'Alba, NW Italy, all have whorls that are flatter in profile and have finer, sharper ribbing than the fragments found at Wilemerirchel. *S. austriaca* (D 3.3 mm) found in Late Pliocene strata at Neudegg, Austria, has less flattened whorls than *S. truci*, but also has much weaker ribbing, unlike the Irchel fragments. *S. ultima* (D 3 mm), from EP2 (45) and late EP2 contexts at Deutsch-Altenburg (4B), Austria, has body whorls that are slightly curved in profile, with closely-spaced, pronounced but notably blunt ribbing, similar to the fragments at Wilemerirchel (estimated D 3-3.2 mm). Whorl fragments with analogous blunt ribbing recorded by Nordsieck (2021) as *Serrulella* sp. from Late Pliocene (level C) and EP1 strata (levels F and L) at Stranzendorf and EP2 deposits at Krems (level 9), may be *Serrulella ultima* or a similar ancestral species.[7] Specimens from EP3 contexts at Krems (levels 6 and 5) described by Ložek (1978) as "*Serrulina* aff. *serrulata*" and "?*Serrulina*" are probably *Serrulella* (Nordsieck 2021) and are also likely to be *S. ultima*. *S. ultima* has also been found in EP3 strata at Castell'Arquato, Emilia-Romagna, NW Italy, so seems to have been an East-Central European species that was certainly present from EP2 to EP3 and perhaps also from Late Pliocene to EP1. The shell fragments found at Wilemerirchel and Hochwacht may therefore be *S. ultima*, or possibly a rather similar ancestral species. *Serrulella* sp. seems likely to have disappeared from Switzerland at the end of EP1.

Soosia diodonta: found in Switzerland only at Wil. This Eastern European species has a modern distribution that lies far to the east of Switzerland, including Serbia, Romania and Bulgaria. In eastern Austria it is known in deposits dating from the Late Pliocene (MN16b) at Neudegg, the Late Pliocene (level C) and EP1 (level F) at Stranzendorf, EP2/3 at Gedersdorf, EP3 (level 7) at Krems, EP2 (43, 45) and late EP2 (4B) at Deutsch-Altenburg, early Middle Pleistocene at Hundsheim, an MIS 9 level in the Vienna Basin, and MIS 5e at Aigen/Hohlweg. In the Czech Republic it has been found at sites dating from EP3 at Stránská skála I, early Middle Pleistocene at Mladeč-Höhle and Zlatý Kůň-C718, late Middle Pleistocene at Sedlec-Prague, Tučin and Turold, and MIS 5e at Kobyla-Chlupáčova, Letky, Litoměřice II and Pavlov. In Slovakia it is known from sites dating from EP2/EP3 at Gombasek-Steinbasek, EP3 at Ivanovce-Skala, Jabloňov-Soroška, Plešivec and Slovenská skala, early Middle Pleistocene at Hradište, and MIS 5e at Bojnice-Kirkhof, Gánovce-Hrádok, Nové Mesto-Mnešice and Záskalie. In Poland it has

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[7] The records for Stranzendorf level C, Krems level 9 and Castell'Arquato are from Nordsieck 2007, 2021; new records for Stranzendorf levels F and L are given in Appendix 5; Krems 6 and 5 are from Ložek 1978, quoted in Frank 2006, p.326.

been found in EP 1 strata at Przymiłowice 3. In Hungary it is known from sites dating from EP2/3, Middle and Late Pleistocene. In southern and central Germany it has only been found in MIS 13 deposits at Adlerberg-Nördlingen. In The Netherlands it may have been present in EP1 strata at Maalbeek Pit and Russel-Tiglia-Egypte Pit, Tegelen. It has never been recorded from France. Present from the Late Pliocene onwards, *Soosia diodonta* seems to have expanded its range towards the west during warm periods on several occasions, so although it might have disappeared from Switzerland at the end of EP1, it may have reappeared during EP2 and possibly the early Middle Pleistocene.

Trochulus leucozonus: found in Switzerland only at IH, Wil, Ams, Hoc and A-B 2 (Appendix 2). This species lives today in the southern foothills of the Alps to the south-east of Switzerland, including north-eastern Italy, Slovenia and the southernmost part of central Austria. In Austria it has only ever been found in Late Pliocene and EP1 strata at Stranzendorf (levels C, F, K, L), at Krems in EP2 (9) and EP3 (7) levels[8], and Holocene deposits near the southern border of central Austria, while it seems never to have been found fossil in Germany, the Czech Republic or Slovakia. This evidence suggests that for much of the Early, Middle and Late Pleistocene its main distribution probably lay further to the south-east. As this taxon is missing from both Albishorn-Bürglen 1 and Hungerbol, it seems likely that *Trochulus leucozonus* disappeared from Switzerland at the end of EP1 at the same time as the other taxa with modern or past distributions that lie far from northern Switzerland, although this may have been during EP2.

Species with modern or past geographic distributions that lie to the South of Switzerland

Causa holosericea: found fossil only at Hoc(upper; Appendix 2). This is a Southern and East-Central European species, whose modern distribution includes the Alps of south-eastern France, southern Switzerland, northern Italy, western and south-eastern Austria and the Carpathians of the Czech Republic, Slovakia and southernmost Poland. In Austria this species has been found in deposits dating from the Late Pliocene at Neudegg,[9] MIS 11 or MIS 9 silts at Stratzing, MIS 11 and MIS 5e levels in the Vienna Basin, MIS 5e sediments at Krems/Hundssteig and Willendorf, and in a number of more recent contexts, but in no Early Pleistocene and very few Middle Pleistocene sites. In the Czech Republic it is known from an early Middle Pleistocene site at Dobrkovice II, a late Middle Pleistocene site at Turold, plus a few MIS 5e and later sites. In Slovakia it has been recorded from an EP3 site at Nové Mesto-Skalka, a Middle Pleistocene site at Dudlavá skala, plus a few MIS 5e and later sites. In SE Germany it has been found in MIS 13 levels at Breitenberghöhle-Göβweinstein. It has never previously been recorded from pre-Holocene deposits in Switzerland and was absent from all the other sites investigated during this study, including Albishorn-Bürglen 1 and Hungerbol. It thus appears that *Causa holosericea* may have been present in much of Switzerland during EP1, but subsequently became largely restricted to the southern and south-eastern parts of the country after EP1 or possibly after EP2.

Ciliella ciliata: found fossil in north-central Switzerland only at Wil and Hoc (Appendix 2). This species lives today in the Southern Alps of France, Switzerland and Italy, as well as the Apennines and parts of the Tuscan hills and the Eastern Pyrenees. It has never previously been found north of the Alps, so the shells from Hochwacht represent the

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[8] These are new records for the Early Pleistocene of Austria; cf. Appendix 5.

[9] A record from Stranzendorf [level C] is incorrect; cf. Appendix 5.

northernmost record for this species. Given its absence from both Hungerbol and Albishorn-Bürglen 1, it may have disappeared from the Swiss Plateau after EP1 or possibly during EP2.

Oxychilus clarus: found fossil in north-central Switzerland only at Ams and Hoc (Appendix 2). This species lives today in the Southern Alps of France, SE Switzerland, and Italy, parts of the Eastern Alps of western and eastern Austria and the SE corner of Germany, as well as the Apennines and the Eastern Pyrenees. Fossil finds of this species are extremely rare, so the records from the Hasli Formation may be the earliest known. In Italy it has been recorded from Early Würm deposits at Moncucco Torinese, Asti.

Poiretia dilatata dilatata: found in Switzerland only at Wil, Ams, Hoc and A-B 2 (Figure 7). This is a Southern European species that lives today in southern and east-central Italy (Bodon et al. 2010). Similar, but more slender and heavily ribbed forms from the Peloponnese and Crete named *P. d. peloponnesica* and *P. d. marginata* may well belong to one or two separate species (Welter-Schultes 2012, p.120). In Italy, *P. d. dilatata* has only been found in MIS 13 deposits at Valle Giumentina, Abruzzo, and MIS 5e strata at Boccabianca, Marche. Late Pliocene records of *Poiretia pseudoalgira* from Fossano and Tassarolo, Piemonte (published by Sacco 1884-1897; Esu and Ciangherotti 2004) and a probable EP1 record of *Poiretia senensis* from Balze di Caspreno, Pianella/Castelnuovo Berardenga, Toscana (Di Stefani 1880, p.28-29) may well correspond to *P. d. dilatata* according to their description, size and illustrated forms, as these have never been checked and were described at a time when Oleacinid taxonomy was far from clear. *Poiretia dilatata dilatata* can be considered as **reliable biostratigraphic marker for the older Early Pleistocene (EP1) when found at sites north of the Alps.**

Species with modern or past geographic distributions that lie to the West of Switzerland

Azeca goodalli (=*menkaena*): found in Switzerland only at IH, IS, Wil, Ams and Hoc. It is a Western European species whose modern distribution includes England, western France, northern Spain, Belgium, plus NW and central Germany. In Austria it has only been found in Late Pliocene (MN16b) levels at Stranzendorf (level A, Kov 5). In the Czech Republic it is known from the early Middle Pleistocene at Mladeč-Höhle and the Middle Pleistocene at Podsedice. In southern and central Germany it has been found in deep cores in the Upper Rhine Graben in strata dating from EP1 and EP2 near Viernheim, and MIS 11 at Ludwigshafen and Mannheim/Lindenhof, as well as in layers dating from the Late Pliocene (MN16b) at Bären- und Karlshöhle, Erpfingen, EP1 at Buch, Fischach, Hörlis, Rottenburg and Uhlenberg, EP3 at Osterbuch, MIS 17 at Kärlich, MIS 13 at Adlerberg-Nördlingen, Bietigheim-Bissingen, Bilzingsleben I, Breitenberghöhle-Göβweinstein, Bruheim-Gotha, Schmiechen-Blaubeuren and Weiβenburg 7, MIS 11 at Bilzingsleben II, Heilbronn, Hundersingen, Leilenkopf and Seebach, MIS 9 at Bad-Cannstatt/Stuttgart and Neumark-Sud, and MIS 5e at Neumark-Nord and Weimar-Ehringsdorf. In France it is known from deposits dating from the Late Pliocene (MN16b) in a deep core in the Upper Rhine Graben at l'Hôpital Civil, Strasbourg, EP1 at Agencourt/Nuits-Saint Georges, final EP3(MIS 21) at Grâce-Autoroute/Somme, a probable MIS 15-13 level in a core in the Upper Rhine Graben at Dingsheim, MIS 13 at Hangenbieten and Hanhoffen, MIS 11 at Arrest, Chelles, Hanhoffen, Le Celle, St Acheul and Vernon, MIS 9 at Chaignay and Soucy, MIS 7 at Achenheim, Biache-Saint-Vaast, Dijon and Menchecourt-Abbeville and MIS 5e at Chambolle, Mens and Vanvey.

Strangely, it has never been recorded from Quaternary deposits in The Netherlands. In southern England it is known in levels dating from MIS 11 at Barnham, Clacton-on-Sea, Hitchin, Barnfield Pit, Dierden's Pit and Southfleet Road/Swanscombe, Beeches Pit/West Stow and Woodston, MIS 9 at Purfleet and Stretton-on-Dunsmore, MIS 7 at Histon Rd/Cambridge, Marsworth, Stoke Goldington, Stutton, Sutton Cross and Whittlesey, and MIS 5e at Folkstone and Tattershall Thorpe. In Italy it has been found in deposits dating from EP2 in the Mugello Basin, Toscana, EP3 in the Stirone River Valley, Emilia-Romagna, and MIS 13 at Valle Giumentina, Abruzzo, but no later.
In Western Europe this Atlantic species was often present during interglacials. The absence of *Azeca goodalli* from deposits at Albishorn-Bürglen 1 and Hungerbol suggests that it might have disappeared from Swiss molluscan faunas after EP1, although it may have been present during EP2, EP3, MIS 13, MIS 11, or MIS 9 when it is known from southern Germany. After MIS 9 it seems unlikely to have reached Switzerland, despite repeatedly extending its range eastwards during interglacial periods.

Cochlostoma salomoni: found in Switzerland only at IH, IS, Wil, Ams, Forenirchel, Hoc, A-B 2 and probably Freienwil (Figure 7). This extinct Western European species is not known from Austria[10], the Czech Republic or Slovakia. In southern and central Germany it has been found in EP1 strata in deep cores in the Upper Rhine Graben near Philippsburg and Viernheim, and in EP1 deposits at Buch, Fischach, Frechen, Rottenburg and Uhlenberg.[11] In The Netherlands it has been found in Tiglian (EP1) deposits at Russel-Tiglia-Egypte Pit, Tegelen in Late Tiglian sediments in Core Zuurland-2, Brielle and in Tiglian levels from four other unpublished core sites (Meijer unpublished). In Fance, shells from Late Pliocene (MN16b) levels in a deep core in the Upper Rhine Graben at l'Hôpital Civil, Strasbourg, Alsace, may also belong to this species, but there are no other records, possibly due to a lack of suitable EP1 sites with shells. It thus appears, that *Cochlostoma salomoni* was a Western and West-Central European species that became extinct after EP1, so can be considered as a **reliable biostratigraphic marker for Final Pliocene/older Early Pleistocene (EP1) faunas**.

Pisidium clessini: found in Switzerland only at Ams and Ecoteaux (Appendix 2). This extinct West-Central European bivalve has also been reported from Italy, Russia and Romania (Ellis 1962), but only in older records that need to be checked. It has not been found in Austria, the Czech Republic or Slovakia, but is known from EP1 and early Middle Pleistocene deposits in Hungary, and MIS 11 at Szymanowo, in eastern Poland. In Germany it has been found in deposits dating from EP3 at Edersleben/Voigtstedt, and MIS 15-13 in the 'Mosbach Sands' at Wiesbaden and in deep cores in the Upper Rhine Graben near Mannheim-Ladenburg and at Biebesheim. In The Netherlands it is known from deposits dating from EP1, EP2 and EP3 in Core Zuurland-2, Brielle, EP1 at Maalbeek Pit and Russel-Tiglia-Egypte Pit, Tegelen, EP3 in Core 38H/148, Leerdam and Core Hendrik Ido, Ambacht, MIS 9 at Wageningen, and MIS 7 in Borehole Noorderhoeve-19E117. In Denmark it has been found in MIS 7 sediments at Copenhagen. In France it is only known from Late Pliocene (MN 16b) strata at Cuisery, Montagny-les-Beaune and Saint Bernard, and EP2/EP3 deposits in a deep core in the Upper Rhine Graben at Dernières Nouvelles, Strasbourg. In southern England it has been found in

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[10] Late Pliocene records from Neudegg and Stranzendorf [level C] are not *C. salomoni*; cf. Appendix 5.

[11] A single shell found in EP3 sediments at Lauterbrunn may have either been redeposited or correspond to *Cochlostoma scalarinum saueri*.

deposits dating from EP1 at Sidestrand, MIS 15 at Kessingland/Pakefield, Little Oakley, Sugworth and West Runton, MIS 13 at Ostend and Waverley Wood, MIS 11 at Clacton-on-Sea, East Hyde/Tillingham, Elveden, Barnfield Pit and Dierden's Pit/Swanscombe and Woodston, MIS 9 at Cudmore Grove, Hackney and Purfleet, and MIS 7 at Crayford, Ilford and West Thurrock. *Pisidium clessini* thus seems to have disappeared from Central Europe after MIS 15-13 and from Western Europe after MIS 7. Although only recorded from a single EP1 site at Irchel, it may also have been present during later periods in the Rhine and the Aar.

Retinella (*Lyrodiscus*) *elephantium* (formerly *skertchlyi*): found in Switzerland only at IH, Wil, Ams, Hoc and A-B 2. This extinct species seems to have had a Western and South-Western European distribution, as a closely related taxon still lives in the Canary Islands today (Alonso et al. 2013). In Austria it has only been found in Late Pliocene (MN16b) strata at Neudegg. In southern Germany it has been found in deposits dating from EP1 at Buch, Fischach, Hörlis, Rottenburg and Uhlenberg and EP3 at Osterbuch. In The Netherlands it may be present in EP1 deposits at Russel-Tiglia-Egypte Pit. In France it has been found in sediments dating from late EP3 (MIS 21) at Grâce-Autoroute/Somme, and MIS 11 at Arrest, Chelles, La Celle, Saint-Acheul, Saint Pierre les Elbeuf and Vernon, as well as Coupy. In southern England it is known from deposits dating from MIS 15/13 at Sun Hole/Cheddar, MIS 13 at Valdoe Quarry, and MIS 11 at Hitchin and Beeches Pit/West Stow. As most of the more Middle Pleistocene records for *Retinella elephantium* lie far to the west of Switzerland, its absence from Albishorn-Bürglen 1 and Hungerbol suggests that it probably disappeared from Swiss faunas at the end of EP1, although it may have disappeared during EP2 or even EP3. Its presence at Coupy, however, suggests that it might have reappeared in western Switzerland during MIS 11. It has not been found in any contexts younger than MIS 11, so seems to have finally become extinct in western Europe after this period. This species may be a **reliable biostratigraphic marker for Early Pleistocene (EP1 to EP3) faunas when found in Central European sites.**

Spermodea lamellata: found in Switzerland only at IH, Ams and Hoc (Figure 7). This Western European species lives today in western Spain and Portugal, much of Britain and Ireland, northern Holland, northern Germany, Denmark, south-western Scandinavia and northern Poland. In western France it has been found in deposits dating from MIS 11 at La Celle and MIS 5e at Caours. In The Netherlands it is only known from MIS 9 strata at Bélvèdere Pit and Holocene levels. In southern England it has been found in sediments dating from MIS 13 at Boxgrove, MIS 7 at Wretton and MIS 5e at Bobbitshole /Ipswich and Tattershall Castle. Until this study it had only been found at three sites in Central Europe: in EP1 levels at Gamsheim and La Wantzenau in eastern Alsace, and at Buch in south-central Germany, and each time with *Cochlostoma salomoni*. The discoveries at Buch and the Irchel sites represent by far the easternmost records for *Spermodea lamellata*. Its absence from Albishorn-Bürglen 1 and Hungerbol suggests that it disappeared from Switzerland at the end of EP1, at the same time as other species with distributions that lie far from Switzerland. As *Spermodea lamellata* seems to have first appeared during early EP1 (coming from the closely related Late Pliocene taxa *Spermodea puisseguri* and *S. demarcqui*; Geissert 1985, p.3), it can be considered as a **reliable biostratigraphic marker for older Early Pleistocene (EP1) faunas when found in Central European sites.**

Central European species or that may have been endemic to Switzerland

Hauffenia/*Islamia* sp.: found in Switzerland only at Hoc(upper). *Hauffenia* and *Islamia* are closely related genera of minute subterranean aquatic valvatoid Hydrobiid prosobranchs that also live in springs, so shells can enter streams and rivers. There are no other modern or Quaternary records of *Hauffenia* or *Islamia* in eastern, central and northern Switzerland, the nearest being *Islamia minuta consolationis*[12] that is found in western Switzerland in the systems of the Areuse (NE) and Doubs Rivers (NE, JU and neighbouring France; Turner et al. 1998[13]). The first two whorls of a single shell from the upper channel at Hochwacht are 0.6 mm across (Appendix 2), which is slightly smaller than the 0.65 mm for the first two whorls of *I. minuta consolationis*. There are other *Islamia* species in eastern France and northern Italy, but no records of either genus from Germany. The nearest *Hauffenia* are found in central-eastern Austria and northern Italy (Cossignani and Cossignani 2020, Glöer 2022b). In Italy records of *Islamia* sp.[14] go back to EP1 at Dunarobba, Umbria, and EP2-EP3 in the Tiberino Basin, Umbria, but there are no sub-fossil records for *Hauffenia* from Austria.

Moitessieriid/Hydrobiid sp.: found in Switzerland only at Hoc and A-B 2. This is a minute freshwater gastropod (4.5 whorls, 1.3 mm high x 0.5 mm wide, rounded whorls, deep sutures, 3rd and 4th whorls almost equal size, narrow umbilicus, sinuated peristome, mouth is ovate but the reflected lip takes a rounded triangular form) whose genus is uncertain (Appendix 2). It may be a *Moitessieria* or *Spiralix* sp. (Moitessieriidae), or possibly *Belgrandia*, *Istriana*, or *Palacanthiliopsis* sp. (Hydrobiidae) These tiny subterranean aquatic prosobranchs also live in springs, so shells can enter streams and rivers. Many species are endemic to the karstic systems of limited areas. As no similar species have been found anywhere nearby (Glöer 2022a, 2022b), it seems fairly likely that this minute prosobranch is extinct.

Neostyriaca dehmi: found in Switzerland only at Ams and Hoc (Figure 7). This extinct species has so far only been recorded from older Early Pleistocene deposits at the sites of Buch and Uhlenberg in central southern Germany (Nordsieck 2007, p.174-5). It thus appears to have been a Central European taxon, which may have become extinct in both Switzerland and the rest of Europe after EP1. Only two specimens have been securely identified, although other individuals may have been present as fragments. This species is notably smaller than *N. corynodes ornatula* (D = 1.8 compared to 2.4 mm) and has denser ribbing.

Triptychia new sp.: found in Switzerland only at Wil. The genus *Triptychia* has long been thought to have become extinct at the end of the Late Pliocene (Nordsieck 1972, 1982, Schnabel 2006), but fragments discovered at Wilemerirchel clearly belong to this genus due to their size and morphological features (Appendix 2). The remains include 11 large apices, 8 decollate apices, body whorl fragments with fairly closely spaced rather blunt ribs on the first whorls that bend leftwards at the suture, pronounced rather regular growth lines on the middle whorls and rather well-defined but fairly irregular growth lines on the final whorls. Also fragments with a columellar lamella and subcolumellar lamella that inside the mouth become two spiral lamellae that continue upwards for several whorls,

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[12] Name given for Doubs records by the INPN, which lists French fauna (https://inpn.mnhn.fr/).

[13] The most recent Swiss data is given by the CSCF (http://www.cscf.ch/).

[14] The shells have been identified as *Islamia minuta*, but this is far from certain.

typical of *Triptychia* spp. (Nordsieck 2015 p.86). The whorls are only slightly curved, while sutures are rather shallow, and the simple mouth edge is slightly thickened externally and probably deflected outward. The apices and fragments from the final whorls have a diameter that is estimated at c.7.5-8.5 mm. In its shape and microsculpture, it resembles *T. terveri* from the Early Pliocene (MN 14-15) of eastern France near Geneva and possibly *T. schlickumi*. The known Late Pliocene species are all Central European. They include *T. neudeggensis* from Neudegg, NE Austria, *T. geisserti*, from Sessenheim, Alsace and Elchesheim-Illingen, west Baden-Württemberg, *T. schlickumi*, from Cessey-sur-Tille, central-eastern France (Schnabel 2006), *T. emyphila*, from Fossano and San Giacomo/Ovada, NW Italy, and *T. mastodontofila*, from Ceresole d'Alba, RDB Quarry/Villafranca d'Asti, San Paolo and Molinetta, NW Italy. *Triptychia* sp. was also found at Hambach, west central Germany. The decollate apices at Wilemerirchel resemble a Late Pliocene decollate specimen of *Triptychia*, possibly *T. schlickumi*, found in a core at Hôpital Civil, Strasbourg, Alsace (Nordsieck 1974 p.36, Geissert et al. 1976 p.126, 129, Schnabel 2006 p.37).

Marker species that reappeared in later deposits in Switzerland

Clausilia pumila: found in Switzerland at Hoc(upper), A-B 1, Hungerbol and Sous-Terre (Appendix 2). This is an East-Central European species, whose modern geographical distribution includes eastern Germany, Denmark, east-central Austria, the Czech Republic, Slovakia, Poland and Hungary. In Austria it is present in EP1 sediments at Stranzendorf (levels G, I, K, K/L, L, L/M, M[15]), at Krems in strata dating from EP2 (Kov-5 to -1, 9, 8/2) and the early Middle Pleistocene (4/2, 4/1), at Deutsch-Altenburg in contexts dating from EP2 (30A, 2C1, 35, 37), late EP2 (4B), EP3 (4A) and the early Middle Pleistocene (28), in early Middle Pleistocene sediments at Hundsheim and several Late Pleistocene and Holocene sites. In the Czech Republic it is known from sites dating from EP1 at Ctiněves-Hýkovina, EP3 at Suchdol-Kozi hřbety and Únětice-Holý vrch, early Middle Pleistocene at Dolni Věstonice, Kokory, Mladeč-Höhle and Zlatý Kůň-C718, plus several Middle Pleistocene and MIS 5e sites. In Slovakia it has been found in EP3 sites at Bojnice-Úboče, Ivanovce-Skala and Plešivec, plus several Middle Pleistocene and MIS 5e sites. In Poland it is known from EP2 sediments at Kielniki, MIS 19/17 strata at Kozi Grzbiet and at MIS 5e sites. In Hungary it has been found in EP1, EP2, EP3, Middle and Late Pleistocene deposits. In southern and central Germany it is known from deep cores in the Upper Rhine Graben in strata dating from EP3 at Biblis, MIS 15-13 at Mannheim/Lindenhof, and MIS 11 at Ludwigshafen. Also in deposits dating from EP1 at Buch, Fischach, Frechen, Rottenburg and Uhlenberg, EP3 at Bottendorf, Fuchsberg, Kalbsrieth, Osterbuch, Wendelstein and Zeuchfeld, MIS 18 at Kärlich, MIS 17 at Diersheim, MIS 15-12 in the 'Mosbach Sands' at Wiesbaden and their equivalent at Herxheim, MIS 13 at Bietigheim-Bissingen, Schmiechen-Blaubeuren and Weiβenburg 7, early MIS 12 at Roβbach, Süβenborn and Uichteritz, MIS 11 at Bilzingsleben II, Heilbronn, Hundersingen, Kärlich, Leilenkopf, Lengefeld-Bad Kösen, Salzmünde, Seebach and Steinheim an der Murr, MIS 9 at Bad-Cannstatt/Stuttgart, Lengefeld-Bad Kösen, Neumark-Sud and Schöningen 12, MIS 8 at Lengefeld-Bad Kösen and Neumark-Sud, MIS 7 at Höchstadt, Rain and Weimar-Ehringsdorf, early MIS 6 at Mainz-Weisenau, MIS 5e at Bötzingen, Burgtonna, Bonau, Heilbronn-Böckingen, Königsaue, Neumark-Nord, Niederhummel, Oberheisesheim, Schöningen, Tönchesberg,

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[15] Work needs to be done to properly separate shells of *C. strauchiana* from *C. pumila*; cf. Appendix 5.

Wallertheim, Parkhöhle-Weimar and Weimar-Ehringsdorf and MIS 5c at Bad-Cannstatt/Stuttgart. In The Netherlands it has been found in strata dating from EP1 in Maalbeek Pit and Russel-Tiglia-Egypte Pit, Tegelen, EP3 at Bavel and Core Hendrik Ido, Ambacht, MIS 9 at Wageningen and MIS 5e at Bergen-Pompstation, Opgespoten-Oostenpolder, Zaanstreek. In France it is known from deposits dating from MIS 17 at Hanhoffen and La Wantzenau, in probable MIS 15-13 strata in deep cores in the Upper Rhine Graben at l'Hôpital Civil and Polygone, Strasbourg, Marckolsheim and Ohnheim, MIS 15-12 at Achenheim, Hangenbieten, Hanhoffen and Mothern, Alsace, MIS 11 at Hanhoffen, St Acheul and St Pierre les Elbeuf, MIS 9 at Soucy, MIS 9/7 at Lampertheim, MIS 7 at Achenheim, and MIS 5e at Mens and Saint-Pierre-de-Cherennes/Saint-Marcellin. In southern England it has been found in contexts dating from MIS 15 at Sugworth and West Runton, MIS 15/13 at Sun Hole/Cheddar, MIS 13 at Boxgrove and Valdoe Quarry, MIS 11 at Clacton-on-Sea, Hitchin, Barnfield Pit, Dierden's Pit and Southfleet Road/Swanscombe, Beeches Pit/West Stow and Woodston, MIS 9 at Purfleet, MIS 7 at Stutton, Whittlesey and Wretton, and MIS 5e at Deeping St James, Trafalgar Square/London, Tattershall Thorpe, and Woolpack Farm/Fenstanton.

It seems that *Clausilia pumila* originally appeared to the east of Switzerland during early EP1 (cf. Nordsieck 1990), before expending its range during EP1 to EP3. During subsequent interglacials it regularly expanded its geographical range significantly towards the west. Although it has so far only been found in late EP1, EP2, EP3 and MIS 11 deposits in Switzerland, it is highly likely that it was also present during other warm periods such as during the early Middle Pleistocene, MIS 9 and possibly MIS 7, although it seems to have been absent during MIS 5e.

Clausilia rugosa antiquitatis: found in Switzerland at IH, IS, Wil, Ams, Forenirchel, Hoc, A-B 2, Hungerbol and Sous-Terre (Appendix 2). This extinct subspecies seems to have had a Central European distribution. In Austria it has been found in EP2 strata at Radlbrunn and at Deutsch-Altenberg in contexts dating from EP2 (2D/E, 37, 38) and the early Middle Pleistocene (28). In southern and central Germany it has been found in deep cores in the Upper Rhine Graben in strata dating from EP2 near Viernheim, and MIS 11 at Ludwigshafen and Mannheim/Lindenhof; also in deposits dating from EP1 at Rottenburg and Uhlenberg, and MIS 15-13 in the 'Mosbach Sands' at Wiesbaden. In The Netherlands it has been found in EP1 deposits at Maalbeek Pit and Russel-Tiglia-Egypte Pit, Tegelen. In France it has been found in MIS 13 levels at Achenheim. Its appearance in the MIS 11 site at Sous-Terre is therefore remarkable, as it suggests that Switzerland was one of the last areas where this sub-species persisted.

Helicopsis striata: found in Switzerland only at IH, Wil, Hoc, Hungerbol 2 and an undated Middle Pleistocene interstadial in Hochterrasse sediments at Stadel, ZH. This is a Central and Eastern European species, whose discontinuous distribution includes central and SW Germany, parts of Poland, west-central Czech Republic, easternmost Austria, west Slovakia and then continues towards the east and south-east. In Austria it has been at Stranzendorf in deposits dating from the Late Pliocene (level C) and EP1 (most levels), EP1 at Unterparschenbrunn, EP2 at Radlbrunn, at Krems in strata dating from EP1 (15), EP2 (11, 10, 9, 8/2, 8/1), EP3 (7, 7/2, 5) and the early Middle Pleistocene (4/2, 3), in EP2/3 sediments at Gedersdorf, at Deutsch-Altenburg in contexts dating from EP2 (30A, 2C1, 2D/E, 22A, 37, 38), late EP2 (4B), EP 3 (4A) and the early Middle Pleistocene (28), Middle Pleistocene strata at Ebersbrunn, Edelstal and St. Margarethen, MIS 11 and MIS

9 levels in the Vienna Basin, at several MIS 5e sites and a number of Würmian sites. In the Czech Republic it is known from an EP3 site at Červený kopec, early Middle Pleistocene strata at Přezletice, plus several Middle Pleistocene and MIS 5e sites. In Slovakia it has been recorded at Middle Pleistocene and MIS 5e sites. In Hungary it has been found in EP1, EP2, EP3, Middle and Late Pleistocene contexts. In southern and central Germany it is known from deposits dating from EP3 at Bottendorf, Kalbsrieth, Wendelstein and Zeuchfeld, MIS 15-13 in the 'Mosbach Sands' at Wiesbaden and their equivalent at Herxheim, early MIS 12 at Süβenborn and Uichteritz, MIS 11 at Lengefeld-Bad Kösen, Neumark-Sud, Salzmünde, Seebach, Steinheim an der Murr and a deep core from the Upper Rhine Graben near Mannheim-Ladenburg, MIS 10 at Neumark-Sud, MIS 9 at Neumark-Sud and Schöningen 12, MIS 8 at Lengefeld-Bad Kösen and Neumark-Sud, MIS 7 at Weimar-Ehringsdorf, early MIS 6 at Mainz-Weisenau, MIS 5e at Burgtonna, Heilbronn-Böckingen, Neumark-Nord, Rottenburg, Wallertheim and Weimar-Ehringsdorf, and Early/Mid-Würm at sites such as Wallertheim and Wiesbaden. In The Netherlands it is only known from MIS 9 strata at Bélvèdere Pit. In France it has only been found in Rhine sands dating from MIS 15-12 at Achenheim, Hangenbieten and Mothern in Alsace, and MIS 9 and early MIS 6 levels at Achenheim, but no other dated deposits until Late Glacial contexts such as Conty (Limondin-Lozouet 2012).

It appears that *Helicopsis striata* may have disappeared from Swiss molluscan faunas after the Early Pleistocene, but then reappeared during the Middle Pleistocene. It seems to have been absent during the Late Pleistocene.

Macrogastra densestriata: found in Switzerland only at A-B 2 and Hungerbol 2. This is an East-Central European species that is today largely confined to the Alpine region of Austria and north-eastern Italy, but also extends into the extreme south-eastern corner of Germany and Slovenia. In Austria it is present in deposits dating from the end of the Late Pliocene (MN16b) at Neudegg, from EP1 at Stranzendorf (levels F, K), at Krems in strata dating from EP2 (12, Kov-5, Kov-2) and EP3 (7), at Deutsch-Altenburg in sediments dating from late EP2 (2C1, 4B) and EP3 (4A), as well as several Late Pleistocene sites. In the Czech Republic it is known from EP3 sites at Stránská skála I and Stránská skála II, the early Middle Pleistocene at Mladeč-Höhle and Zlatý Kůň-Höhle, plus some Middle Pleistocene and MIS 5e sites. In Slovakia it has been found at an EP2/EP3 site at Gombasek-Steinbasek and an EP3 site at Plešivec as well as a few Middle Pleistocene sites. In Poland it has been documented from MIS 19/17 sediments at Kozi Grzbiet. In Hungary it has been found in EP1, early Middle and Late Pleistocene deposits. In southern and central Germany it has been found in deposits dating from the Late Pliocene at Hambach (MN16a) and Fortuna-Garsdorf (MN16b), MIS 13 at Bietigheim-Bissingen, Bilzingsleben I, Breitenberghöhle-Göβweinstein and Weiβenburg 7, MIS 9 at Bilzingsleben III, Lengefeld-Bad Kösen, Neumark-Sud and Schöningen 12, and MIS 5e at Burgtonna, Neumark-Nord and Weimar-Ehringsdorf. In The Netherlands it is known only from EP1 deposits at Maalbeek Pit, Tegelen. In France it has been found in Late Pliocene (MN16b) deposits at Cessey-Sur-Tille and Sessenheim, but nothing more recent. In Italy it is known from EP2 sediments in the Steggio Basin, Veneto.

Macrogastra densestriata seems to have been present across much of Europe during the Late Pliocene, but disappeared from most of Western and Central Europe during EP1. From EP2 onwards it extended its distribution significantly further westwards during interglacial periods. It seems to have first appeared in Switzerland during late EP1, but may have disappeared after the Early Pleistocene. It might also have been present during the early Middle Pleistocene, but seems to have been absent since then.

Monachoides vicinus: found in Switzerland at IH, IS, Wil, Ams, Hoc, A-B 2, A-B 1 and Hungerbol 2 (Figure 7). This is an Eastern European species whose modern distribution includes Hungary, Slovakia, eastern Czech Republic, southern Poland and continues further east. In Austria it is known at Neudegg in Late Pliocene (MN16b) strata, at Stranzendorf in deposits dating from the Late Pliocene (level C) and EP1 (most levels), from EP1 at Unterparschenbrunn, and Deutsch-Altenburg in contexts dating from EP2 (30A, 2C1, 37, 38) and late EP2 (4B). Otherwise, it has only been found at a Late Pleistocene/Holocene site at Alberndorf in eastern Austria. In the Czech Republic it is known from sites dating from EP2/EP3 at Chlum, EP3 at Červený kopec, early Middle Pleistocene at Mladeč-Höhle, plus Middle Pleistocene, MIS 5e and Holocene sites. In Slovakia it has been recorded from EP3 sites at Ostrá hora, Plešivec and Slovenská skala, plus several Middle Pleistocene, MIS 5e and Holocene sites. In Poland it has been found in EP1 strata at Przymiłowice 3 and MIS 19/17 sediments at Kozi Grzbiet. In Hungary it is known from EP1, early Middle and Late Pleistocene deposits and in Ukraine from MIS 5e sediments at Kolodiiv. In southern Germany it has only been found in EP1 strata in a deep core from the Upper Rhine Graben near Viernheim and possibly EP1 deposits at Uhlenberg. It thus appears that *Monachoides vicinus* was not a part of Central European molluscan faunas after the Early Pleistocene. Given this evidence and its presence at Albishorn-Bürglen 1 and Hungerbol 2, it seems that this species disappeared from Switzerland after the end of EP3 and can be considered as **a reliable biostratigraphic marker for the Early Pleistocene in Switzerland, from EP1 until the end of EP3.**

Neostyriaca corynodes ornatula (formerly *schlickumi*): found in Switzerland at IH, IS, Wil, Ams, Hoc, A-B 2, A-B 1 and Hungerbol (Figure 7). This extinct East-Central European subspecies appears to have had a distribution largely located to the east of Switzerland. It has been found in Austria in deposits dating from EP1 at Stranzendorf (levels F, I, K, K/L, L, L/M, M), at Krems in strata from EP2 (9) and EP3 (7), at Deutsch-Altenberg in sediments dating from EP2 (30A, 2C1, 5A, 5B, 6, 22, 22A, 35, 37, 38), late EP2 (4B), EP3 (4A) and the early Middle Pleistocene (28), and in early Middle Pleistocene levels at Hundsheim. In southern and central Germany it has been found in deposits dating from EP1 at Buch, Fischach and Uhlenberg, EP3 at Osterbuch, EP3 and MIS 15-13 in a deep core in the Upper Rhine Graben near Viernheim, and MIS 15-12 in the 'Mosbach Sands' at Wiesbaden. In France it is known from MIS 13 deposits at Achenheim. *Neostyriaca corynodes ornatula* **appears to have become extinct at the end of the early Middle Pleistocene**, but as very few sites from this period are known from Switzerland, it is unclear whether it disappeared from Switzerland after the Early Pleistocene or the early Middle Pleistocene.

Perforatella bidentata: found in Switzerland at IH, IS, Wil, Hoc, A-B 2, A-B 1, Hungerbol and Montfleury. This is an East-Central and Eastern European species, whose modern distribution includes most of central and eastern Germany, central and eastern Austria, the Czech Republic, Slovakia, Poland, SE Fennoscandia, the Baltic republics, Belarus, Hungary, and then continues further to the east. In Austria it has been found in Late Pliocene (MN16b) strata at Neudegg, at Stranzendorf in sediments dating from the end of the Late Pliocene (Kov5, A, C) and EP1 (most levels), at Krems in strata dating from EP2 (10, Kov-2, Kov-1) and at Deutsch-Altenberg in contexts dating from EP2

(30A, 22A) and late EP2 (4B), but in no Middle Pleistocene contexts, in Late Pleistocene layers at Krems-Bäckersteig, Krems-Rehberg and Willendorf, but no Holocene sites. In the Czech Republic it is known from EP3 sites at Červený kopec, Suchdol-Kozi hřbety and Únětice-Holý vrch, the early Middle Pleistocene at Zlatý Kůň-C718, plus several Middle Pleistocene and MIS 5e sites. In Slovakia it has been recorded from an EP2/EP3 site at Gombasek-Steinbasek, the early Middle Pleistocene at Levice, and several Middle Pleistocene and MIS 5e sites. In Hungary it is known from EP1, EP2, EP3, Middle and Late Pleistocene deposits, being in the Bükk Mountains from EP2. In southern and central Germany it has been found in deep cores in the Upper Rhine Graben in strata dating from EP1-EP3, MIS 15-13, MIS 12, MIS 11 and Early Würm near Viernheim, EP3 at Biblis and Groβ-Rohrheim, MIS 15-13 near Mannheim-Ladenburg, MIS 11 near Philippsburg, Ludwigshafen and Mannheim-Lindenhof, and probable MIS 5e at Wolfskehlen. Also in deposits dating from EP1 at Buch, Fischach, Frechen, Rottenberg and Uhlenberg, EP3 at Brennberg, Fuchsberg, Kalbsrieth, Wendelstein and Zeuchfeld, MIS 19/17 at Edersleben/Voigtstedt, MIS 18 + 14 at Kärlich, MIS 17 at Diersheim, MIS 15-12 in the 'Mosbach Sands' at Wiesbaden, MIS 13 at Bietigheim-Bissingen, early MIS 12 at Roβbach, Süβenborn and Uichteritz, MIS 11 at Bilzingsleben II, Heilbronn, Leilenkopf, Lengefeld-Bad Kösen and Steinheim an der Murr, MIS 9 at Bad-Cannstatt/Stuttgart, Lengefeld-Bad Kösen and Neumark-Sud, MIS 7 at Rain, MIS 6 at Bötzingen, MIS 5e at Neumark-Nord, Parkhöhle-Weimar and Weimar-Ehringsdorf, and Early Würm at Mainz-Weisenau. In The Netherlands a large form (*P. belgrandi*) is known from deposits dating from EP1 at Maalbeek Pit and Russel-Tiglia-Egypte Pit, Tegelen, EP1, EP2 and EP3 in Core Zuurland-2, Brielle, and EP3 at Bavel, in Core Hendrik Ido, Ambacht and Core 40/351, Velp. The normal form has been found in levels dating from MIS 9 at Wageningen, MIS 7 + 5e in Core Zuurland-2, Brielle and MIS 5e in Borehole Noorderhoeve-19E117. In France, it is known from deposits dating from EP1 at Binges 5, final EP3 at Grâce-Autoroute/Somme, MIS 17 at Eschau, Hanhoffen and La Wantzenau, probable MIS 15-13 at Dingsheim and in strata in deep cores in the Upper Rhine Graben at l'Hôpital Civil, La Place des Halles and Polygone, Strasbourg, MIS 15-12 at Achenheim, Hangenbieten, Hanhoffen and Mothern, MIS 11 at Arrest, Hanhoffen, La Celle and St Acheul, MIS 9 at Achenheim and Soucy and MIS 5e at Mens. In southern England it is only known from MIS 15 strata at Sugworth.

Perforatella bidentata seems to have regularly expanded its geographical distribution south-westwards during interglacial periods, including EP1, EP2 and EP3, the earlier Middle Pleistocene, MIS 11, MIS 9, MIS 7 and MIS 5e. It thus seems likely that it was present in Switzerland during a number of interglacial periods, and in addition to MIS 11 may also been present during the early Middle Pleistocene, MIS 9 and MIS 7, although it appears to have been absent from Swiss faunas during the Eemian (MIS 5e).

Trochulus filicinus: found in Switzerland only at IH, IS, Wil, Ams, Forenirchel, Hoc, A-B 2 and Hungerbol 2 (Appendix 2). This species lives today in East-Central and South-Eastern Europe, including southern Austria, NE Italy and Slovenia, extending both east into Slovakia and Hungary and south-eastwards into the Balkans. In Austria it has been found in strata dating from the Late Pliocene and EP1 at Stranzendorf (levels C, F, K, L, L/M)[16], EP2 at Radlbrunn, EP3 at Krems (7/2), at Deutsch-Altenburg in contexts dating from EP2 (30A, 2C1, 37), late EP2 (4B) and EP 3 (4A), an Early Würm interstadial

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[16] These are new records for the Early Pleistocene of Austria; cf. Appendix 5.

deposit at Tropfsteinhöhle-Kugelstein, mixed Late Glacial/Holocene contexts at Lurgrotte and Groβe Badlhöhle, plus Holocene contexts in the south-eastern part of the country. It seems never to have been found fossil in Germany, the Czech Republic or Slovakia. This evidence suggests that for much of the Middle and Late Pleistocene its main distribution probably lay further to the south-east and/or east. It thus appears that *Trochulus filicinus* may have disappeared from Switzerland after the end of EP3 and can be considered as **a reliable biostratigraphic marker for the Early Pleistocene in Switzerland, from EP1 until the end of EP3.**

Urticicola umbrosus: found in Switzerland at IH, IS, Wil, Ams, Hoc, A-B 2, Nuolen and Ried (Appendix 2). This Central and Eastern European species has a modern distribution that includes SE Germany, Austria, the Czech Republic, Slovakia, southernmost Poland and then continues further east. In Austria it is known from Late Pliocene (MN16b) deposits at Neudegg, at Stranzendorf in strata dating from the Late Pliocene (C) and EP1 (levels J, K, L), at Deutsch-Altenburg in EP2 (30A) and EP3 (4A) contexts, at Krems in levels dating from EP3 (7/1) and the early Middle Pleistocene (4/1), and a number of sites from the Late Pleistocene and the Holocene, but surprisingly few from the Middle Pleistocene. In the Czech Republic it is known from an early Middle Pleistocene level at Únětice-Holý vrch, a Middle Pleistocene site at Podsedice, a few MIS 5e sites and some Holocene deposits. In Slovakia it has only been found at a single MIS 5e site and in a few Holocene contexts, while is only known from Late Pleistocene and Holocene sites in Hungary. In southern Germany it has been found in Late Pliocene (MN16b) strata at Bären- und Karlshöhle (Erpfingen), in EP1 sediments at Buch and Rottenburg, MIS 13 deposits at Weiβenburg 7, and MIS 11 at Bilzingsleben II, but nothing more recent, suggesting that the extent of its Holocene distribution may be fairly exceptional. As it was missing from Albishorn-Bürglen 1 and Hungerbol it seems likely that it disappeared from Switzerland after EP1, and then appeared only sporadically during subsequent interglacials, with the last of these being MIS 7 (Nuolen and Ried), although it may also have been present during the early Middle Pleistocene, MIS 11 and/or MIS 9.

5.5.2 Species that reappeared in Switzerland during later interglacials

Aegopinella ressmanni: found in Switzerland at IH, IS, Wil, Ams, Hoc, A-B 2, A-B 1, Hungerbol 2, Nuolen, Niederweningen and other Eemian sites, but is missing from Sous-Terre and Montfleury (Appendix 2). This is an East-Central European species, whose modern geographical distribution includes most of Austria, the far SE corner of Germany, the NE corner of Italy, Slovenia, Croatia and western Hungary. In Austria it has been found in deposits dating from EP3 at Deutsch-Altenburg (4A), the early Middle Pleistocene at Krems (levels 4/2, 4/1), MIS 11 or MIS 9 at Stratzing, MIS 5e at Aigen/Hohlweg and Furth/Hohlweg, plus several Holocene sites. In the Czech Republic it is known from early Middle Pleistocene sites at Zlatý Kůň-Höhle and Zlatý Kůň-C718, a Middle Pleistocene site at Pažica, and a MIS 5e site at Letky. In Slovakia it has been found at an early Middle Pleistocene site at Hradište and a MIS 5e site at Bojnice-Kirkhof. In Poland it has been documented from EP2 sediments at Kielniki. In Hungary it is known from EP2/3, MIS 5e and Holocene deposits. In southern Germany it may be present in EP1 strata at Uhlenberg, but is certainly known from deposits dating from EP3 at Osterbuch, MIS 13 at Bietigheim-Bissingen and Schmiechen-Blaubeuren, MIS 11 at Hundersingen, and MIS 5e at Bötzingen. In The Netherlands it may be present in EP1 deposits at Maalbeek Pit and Russel-Tiglia-Egypte Pit, Tegelen. It has never been recorded in France.

The regular presence of *Aegopinella ressmanni* in Swiss interglacial faunas shows that for much of the Pleistocene up until the Eemian, Switzerland lay within the geographical range of this species, while during parts of the Pleistocene its range also extended further north into southern Germany, eastwards into the Czech Republic and Slovakia, and occasionally further westwards. Since the Eemian it appears that its geographical range may have shifted significantly towards the east.

Cepaea nemoralis: found in Switzerland only at Wil, Hoc(upper) and in late Holocene deposits. This is a Western, Southern and Central European species that lives today in Spain, Portugal, much of Britain and Ireland, all of France, Holland, Belgium, Germany, Denmark, locally introduced in south-western Scandinavia, scattered localities in Poland, much of Italy, Switzerland, parts of Austria and the Czech Republic, Hungary and the Balkans. The distribution of this highly adaptable taxon is still expanding due to local introductions. In Austria it has been found in strata dating from EP3 at Krems (7/1, 5) and the late Holocene. In the Czech Republic it is known from EP2/EP3 strata at Chlum, late Middle Pleistocene contexts at Sedlec-Prague, Turold and Židenice-Růženin Dvůr, plus a few MIS 5e sites. In southern and central Germany it is known from deposits dating from EP3 at Untermassfeld, MIS 17 at Kärlich, MIS 15 at Miesenheim, MIS 15-13 in the 'Mosbach Sands' at Wiesbaden and their equivalent at Herxheim, MIS 13 at Bietigheim-Bissingen and Breitenberghöhle-Göβweinstein, MIS 11 at Bilzingsleben II, Kärlich and Seebach, MIS 9 at Lengefeld-Bad Kösen, Neumark-Sud and Schöningen 12, MIS 7 at Weimar-Ehringsdorf, redeposited in MIS 6 strata at Rain and Zeuchfeld, and MIS 5e at Bötzingen, Burgtonna, Neumark-Nord, Niederhummel, Tönchesberg and Weimar-Ehringsdorf. In The Netherlands it has been found in MIS 9 sediments at Bélvèdere Pit. In France, it is known from deposits dating from MIS 17 at Hanhoffen, MIS 15-13 at Mothern, probable MIS 15-13 strata in deep cores in the Upper Rhine Graben at l'Hôpital Civil and Polygone, Strasbourg, Dingheim and Marckolsheim, MIS 13 at Hangenbieten and Hanhoffen, MIS 11 at La Celle, Hanhoffen and St Pierre les Elbeuf, MIS 9 at Piégu, MIS 7 at Abîmes de la Fage and Menchecourt-Abbeville, and MIS 5e at Caours and Resson. In southern England it has been found in contexts dating from MIS 15 at West Runton, MIS 11 at Barnfield Pit, Dierden's Pit and Southfleet Road/Swanscombe, Beeches Pit, West Stow (Icklingham), Hitchin and Woodston, MIS 9 at Purfleet, MIS 7 at Ilford, and MIS 5e at Bobbitshole/Ipswhich, Tattershall Castle, Tattershall Thorpe and Trafalgar Square/London. In Italy it is known from deposits dating from EP3 in the Crostolo River Valley, Emilia-Romagna, MIS 15 and 13 at Campani Quarry, Toscana, and MIS 5e at Livorno town, Toscana.

Cepaea nemoralis seems to have originated in south-western Europe during the Late Pliocene or the start of EP1, before expanding northwards and north-eastwards during EP1, then regularly extending its distribution towards the north and east during interglacial periods. During the later Holocene it has extended its distribution further northwards and eastwards than ever before due to human activities. It may well have been present in Switzerland during some interglacial periods of the later Early Pleistocene, the Middle Pleistocene and the Late Pleistocene, but until now there is no evidence for this. It seems to have only reappeared in Switzerland during Roman times.

Clausilia bidentata: found at IH, IS, Wil, Ams, Hoc, A-B 2, Hungerbol, Sous-Terre, Niederweningen, Zell, Giez and Spiezberg. This is a Western European species, whose modern geographical distribution includes Britain and Ireland, France, NE Spain, the Low Countries, western, central and northern Germany, southern and western Fennoscandia, NW Poland and the Baltic States, plus NW Italy. In south-western and western Switzerland (Cantons GE, VD, NE, JU) it is known today and from Holocene contexts. Subfossil, it has never been found in Austria or the Czech Republic. In southern and central Germany it has been recorded from deep cores in the Upper Rhine Graben in strata dating from MIS 11 at Ludwigshafen, and probable MIS 5e at Groβ-Rohrheim and Wolfskehlen. It is also known from deposits dating from MIS 13 at Bietigheim-Bissingen, MIS 11 at Bilzingsleben II and Steinheim an der Murr, MIS 9 at Bad-Cannstatt/Stuttgart, Lengefeld-Bad Kösen, and Neumark-Sud, MIS 7 at Rain and Weimar-Ehringsdorf, and MIS 5e at Burgtonna, Heilbronn-Böckingen, Tönchesberg, Parkhöhle-Weimar and Weimar-Ehringsdorf. In The Netherlands it has only been recorded from MIS 9 sediments at the Bélvèdere Pit. In France it has been found in deposits dating from the Late Pliocene (MN16b) at Sessenheim, MIS 17 and MIS 13 at Hanhoffen, MIS 11 at Arrest, Hanhoffen, La Celle, St Acheul, St Pierre les Elbeuf and Vernon, MIS 9 at Soucy, MIS 6 at Piégu, and MIS 5e at Caours, Chambolle and Mens. In southern England it has been found at sites dating from MIS 15 (West Runton), MIS 11, MIS 9, MIS 7 and MIS 5e.
Clausilia bidentata thus regularly extended its geographical range eastwards during past interglacials, although unlike many interglacial species it also persisted into the early, more mild phases of some glacial periods (such as Hungerbol 1). It seems that it was a regular element in Swiss Interglacial molluscan faunas, although it appears to have been more widespread during a majority of previous interglacials.

Discus perspectivus: found in Switzerland at Ams, Wil, Hoc, Sous-Terre, Ried, Niederweningen and other Eemian sites (Appendix 2). This is an East-Central and Eastern European species whose modern geographical distribution includes much of Austria, the SE corner plus scattered localities in southern Germany, the NE corner of Italy, the Czech Republic, Slovakia, Slovenia, southernmost Poland, Hungary and then continues to the east and south-east. In Austria this species has been found at Stranzendorf in EP1 sediments (level Kov8), at Deutsch-Altenburg in EP2 (2C1, 37) and late EP2 (4B) deposits, at Krems in strata dating from EP2 (Kov-4, 8/2), EP3 (7/1) and the early Middle Pleistocene (4/2, 4/1), in MIS 11 and MIS 9 levels from the Vienna Basin, in MIS 11 or MIS 9 silts at Stratzing, and in MIS 5e contexts at Aigen/Hohlweg, Krems/Hundssteig and Wetzleinsdorf, plus a number of Holocene sites. In the Czech Republic it is known from EP3 sites at Stránská skála I and Únětice-Holý vrch, early Middle Pleistocene sites at Mladeč-Höhle and Zlatý Kůň-Höhle, plus several Middle Pleistocene and MIS 5e sites. In Slovakia it has been recorded from EP3 sites at Bojnice-Úboče and Ostrá hora, plus several Middle Pleistocene and MIS 5e sites. In Hungary it has been found in deposits dating from the early Middle Pleistocene and MIS 5e. In southern and central Germany it has been found in deposits dating from the Late Pliocene at Bären- und Karlshöhle, Erpfingen, EP1 at Hörlis, Rottenburg and Uhlenberg, EP3 at Osterbuch, Zeuchfeld and a deep core in the Upper Rhine Graben near Viernheim, MIS 15-13 in the ‘Mosbach Sands’ at Wiesbaden, MIS 13 at Bietigheim-Bissingen, Bilzingsleben I, Breitenberghöhle-Göβweinstein, Schmiechen-Blaubeuren and Weiβenburg 7, MIS 11 at Bilzingsleben II, Hundersingen and Leilenkopf, MIS 9 at Bad-Cannstatt/Stuttgart, Bilzingsleben III, Lengefeld-Bad Kösen, Neumark-Sud and Schöningen 12, MIS 7 at Höchstadt, and MIS

5e at Bötzingen, Burgtonna, Dieβen, Eichenreid, Hausen, Neumark-Nord, Thonstetten and Weimar-Ehringsdorf. In The Netherlands it has only been found in EP1 deposits at Maalbeek Pit and Russel-Tiglia-Egypte Pit, Tegelen. In France it is only known from Alsace, in a probable MIS 15-13 level in a core in the Upper Rhine Graben at Polygone, Strasbourg, and MIS 13 sediments at Hangenbieten.
Discus perspectivus seems to have first appeared towards the end of the Late Pliocene somewhere to the east of Switzerland and then increased its range during EP1, EP2 and EP3. It was a regular element in Swiss molluscan faunas during past interglacials, and may well have also been present during both the early Middle Pleistocene and MIS 9.

Euomphalia strigella: found in Switzerland at Hoc(upper), Ecoteaux, Sous-Terre and Montfleury, Grandson, plus several Eemian sites. This is a Central and Eastern European species, whose modern geographical distribution includes eastern France, Switzerland, southern, central and eastern Germany, southernmost Fennoscandia, Austria, the Czech Republic, Slovakia, northern Italy, Slovenia, and continues to the east and south-east. In Austria it has been found at Stranzendorf in deposits dating from the Late Pliocene (levels Kov4, C) and EP1 (most levels), in EP1 sediments at Unterparschenbrunn, at Deutsch-Altenburg in contexts dating from EP2 (30A, 2C1, 17, 22A, 33, 37, 38, 45), late EP2 (4B) and EP3 (4A), at Krems in strata dating from EP2 (10), EP3 (7) and the early Middle Pleistocene (4/2), early Middle Pleistocene sediments at Hundsheim, MIS 11, MIS 9 and MIS 5e levels in the Vienna Basin, MIS 11 or MIS 9 silts at Stratzing, MIS 5e sediments at Aigen/Hohlweg, Krems/Hundssteig, Paudorf and Willendorf, and a number of later sites. In the Czech Republic it is known from EP3 sites at Hlubná, Stránská skála I, Suchdol-Kozi hřbety, Únětice-Holý vrch, early Middle Pleistocene sites at Přezletice and Zlatý Kůň-Höhle, several Middle Pleistocene and a number of MIS 5e sites. In Slovakia it has been found at sites dating from EP2/EP3 at Gombasek-Steinbasek, EP3 at Ivanovce-Skala, Nové Mesto-Skalka, Ostrá hora and Slovenská skala, the early Middle Pleistocene at Pažica and Vyšny Ružbachy-Modzele, plus several Middle Pleistocene and a number of MIS 5e sites. In Hungary it has been found in EP1, EP2, EP3, Middle and Late Pleistocene deposits, and in Ukraine in MIS 5e strata at Kolodiiv. In southern and central Germany it has possibly been found in deposits dating from EP1 at Frechen, and with certainty from EP3 at Kalbsrieth and Zeuchfeld, MIS 11 at Bilzingsleben II, Leilenkopf, Lengefeld-Bad Kösen and Seebach, MIS 9 at Lengefeld-Bad Kösen and Neumark-Sud, MIS 8 at Lengefeld-Bad Kösen, MIS 7 at Weimar-Ehringsdorf, early MIS 6 at Mainz-Weisenau and MIS 5e at Burgtonna, Bonau, Neumark-Nord, Rottenburg, Tönchesberg, Wallertheim, Parkhöhle-Weimar and Weimar-Ehringsdorf. In France it is only known from the east, in sediments dating from MIS 11 at Coupy and Hanhoffen, MIS 9, MIS 8 and MIS 7 at Achenheim, and MIS 5e at Chaignay, Chambolle, Dijon, Mens and Vanvey.
Euomphalia strigella seems to have first appeared during the Late Pliocene to the east of Switzerland in an area that included eastern Austria, before expanding its range during EP1 to EP3. It seems to have first arrived in Switzerland during the final part of EP1, then reappeared during the early Middle Pleistocene (MIS 15) and subsequently became a regular element in Swiss interglacial molluscan faunas.

Orcula dolium: present at A-B 2, A-B 1, WHO, Bürgerspital and Riehen. This is a Central European species, whose modern geographical distribution includes the SW corner of Germany, parts of eastern France, Switzerland, northern Italy, Slovenia, Austria, the east of the Czech Republic, Slovakia, Hungary, Croatia and western Serbia. In Austria it has been found in MIS 11, MIS 9, MIS 5e and MIS 5d-5a levels in the Vienna Basin, in MIS 11 or MIS 9 silts at Stratzing, and MIS 5e deposits at Krems/Hundssteig, Paudorf and Willendorf, as well as in Würm and Holocene sediments, but nothing older. It is rare in deposits from the Czech Republic, but in Slovakia has been found at an EP3 site at Slovanská Skala, a few from the Middle Pleistocene and MIS 5e, plus a number from the Würm and the Holocene. In Poland it is known from EP2 sediments at Kielniki. In Hungary it has been found in EP2/EP3, early Middle and Late Pleistocene deposits. In southern Germany it has rarely been recorded, including probable finds in EP1 deposits at Hörlis and Uhlenberg, and more securely in EP3 sediments at Osterbuch, and MIS 3 strata at Rheinfelden. In The Netherlands it is only known from MIS 5e deposits at Opgespoten-Oostenpolder. It has only been found in eastern France, in deposits dating from MIS 9 and MIS 7 at Chaignay and from MIS 5e at Dijon. In Italy it is known from deposits dating from the Late Pliocene at Fossano, Cuneo and the Cerbaie Hills, Toscana, EP3 in the Stirone River Valley, Emilia-Romagna, Middle Pleistocene from the Aurelian Formation in Rome (MIS 9) and the Liri Basin, Lazio, and MIS 5e at Livorno town, Toscana. *Orcula dolium* seems to have first appeared during the Late Pliocene in central and northern Italy, before spreading to Switzerland and southern Germany during EP1. It may have been present in Switzerland during the early Middle Pleistocene, MIS 11, MIS 9 and MIS 7, but as it tends to have a rather localised presence it is difficult to be certain. *O. dolium* has also been recorded from interstadial deposits. In Switzerland, for example, it has been found in contexts dating from early MIS 6 at WHO and early to mid-MIS 3 during the mid-Würm in the Ajoie region of Canton Jura (Thew unpublished).

Ruthenica filograna: found at IH, Hoc, Sous-Terre, Niederweningen and Zell. This East-Central and Eastern European species has a modern distribution that includes much of Austria, east-central and southern Germany, the Czech Republic, Slovakia, Poland, Ukraine, NE Italy and then continues towards the east and south-east. It also reaches the far NE corner of Switzerland bordering the Bodensee. In Austria it has been found in strata dating from the end of the Late Pliocene (MN16b) at Neudegg, EP1 at Stranzendorf (level F), EP2 at Krems (9), early Middle Pleistocene at Hundsheim, MIS 11 in the Vienna Basin, MIS 11 or MIS 9 at Stratzing and MIS 5e at Aigen/Hohlweg, Furth/Hohlweg, Krems/Hundssteig, Paudorf, Wetzleinsdorf and Willendorf, plus a number of Holocene sites. In the Czech Republic it is known from EP3 sites at Stránská skála I and Únětice-Holý vrch, early Middle Pleistocene sites at Dolni Věstonice, Mladeč-Höhle and Zlatý Kůň-Höhle, plus several Middle Pleistocene and MIS 5e sites. In Slovakia it has been recorded at an EP2/EP3 site at Gombasek-Steinbasek, EP3 sites at Bojnice-Úboče and Slovenská skala, an early Middle Pleistocene site at Vyšny Ružbachy-Modzele, plus several Middle Pleistocene and MIS 5e sites. In Poland it has been documented from EP2 sediments at Kielniki, MIS 19/17 strata at Kozi Grzbiet and at MIS 5e sites. In Hungary it has been found in EP1, EP2/EP3, early Middle Pleistocene and MIS 5e deposits, being in the Bükk Mountains from EP2. In southern and central Germany it has been recorded in deposits dating from EP3 at Kalbsrieth, Wendelstein and Zeuchfeld, MIS 17 at Kärlich, MIS 15-13 in the 'Mosbach Sands' at Wiesbaden, MIS 13 at Bilzingsleben I, Breitenberghöhle-Göβweinstein, Brüheim-Gotha and Schmiechen-Blaubeuren, MIS 11 at Bilzingsleben II, Heilbronn, Leilenkopf and Seebach, MIS 9 at Bad-Cannstatt/Stuttgart, Lengefeld-Bad Kösen and Neumark-Sud, MIS 5e at Bötzingen, Burgtonna, Heilbronn-Böckingen, Hurlach, Neumark-Nord, Sesselfelsgrotte, Tönchesberg, Wallertheim, Parkhöhle-Weimar and Weimar-Ehringsdorf and MIS 5c at Bad-Cannstatt/Stuttgart.

There are no records from The Netherlands. In France it is known from sediments dating from MIS 17 at Eschau, MIS 13 at Hangenbieten, MIS 11 at La Celle, St Acheul and Vernon, and MIS 5e at Caours, Chambolle, Dijon, St-Pierre-de-Cherennes/St-Marcellin and in SE France at the Grand Abri aux Puces/Vaison-la-Romaine, Vaucluse. It has also been found in southern England in MIS 11 sediments at Hitchin and Beeches Pit/West Stow. In Italy it is known from MIS 13 strata at Valle Giumentina in Abruzzo.
It thus appears that *Ruthenica filograna* had a geographical range that regularly extended significantly to the west during previous interglacials, and must have contributed to Swiss molluscan faunas during most interglacial periods (possibly absent from MIS 7), although unlike the Holocene it would probably have been present across much of lowland Switzerland.

5.5.3 Marker species for Tiefere Deckenschotter deposits

There are biostratigraphic marker species that first appeared at Hungerbol 2.

Aegopis klemmi: found in Switzerland only at Hungerbol 2 and Sous-Terre (Appendix 2). This extinct Central European species seems to have had a geographical distribution that mostly lay to the north, north-east and east of Switzerland. In Austria it has been found at Krems in sediments dating from EP2 (9, 8/2), EP3 (7) and the early Middle Pleistocene (4/2) and in early Middle Pleistocene deposits at Hundsheim (Schlickum and Ložek 1965). In the Czech Republic it is known from early Middle Pleistocene sites at Mladeč-Höhle and Zlatý Kůň-Höhle and a Middle Pleistocene site at Karlštejn-Altán. In Slovakia it has been found at an EP3 site at Nové Mesto-Skalka. In Hungary it has been found in EP2/EP3 and early Middle Pleistocene deposits. In southern Germany it has only been found in MIS 13 sediments at Bietigheim-Bissingen and Weiβenburg 7. In France it is known from MIS 11 sediments at Coupy and MIS 9 strata at Soucy. *Aegopis klemmi* seems to have arrived in Switzerland through Austria or southern Germany during EP3, and then been sporadically present in Switzerland during interglacials of the Middle Pleistocene, including MIS 11. It appears to have become extinct after MIS 9.

Theodoxus danubialis (=*serratiliniformis*)[17]: found in Switzerland only at Hungerbol 2. This is an East-Central and Eastern European species, whose modern geographical distribution includes most of Austria, the SE corner of Germany, NE Italy, Slovenia and then continues towards the east, reflecting the drainage systems of the River Danube and neighbouring rivers. In Austria it has been found in a number of Late Pleistocene and Holocene deposits, but the only earlier example is a possible shell from late EP 1 sediments at Deutsch-Altenburg (D-A 3). It has never been found in the Czech Republic and is only known from a few Holocene deposits in Slovakia. In Hungary it has been found in Early, Middle and Late Pleistocene deposits. In southern and central Germany it is present in deposits dating from the Late Pliocene (MN16a) at Hambach, MIS 13 at Bietigheim-Bissingen and Bilzingsleben I, MIS 11 at Bilzingsleben II and Steinheim an der Murr, plus Berlin in northern Germany, and MIS 7 redeposited in MIS 6 strata at Zeuchfeld. It is known from the MIS 11 Herzeele Formation at one site in NW France and five sites in SW Belgium. In The Netherlands it is known from the EP1 at Dordrecht, MIS 9 at Wageningen and MIS 5e at Bakkersdam, and in Belgium from MIS 5e at

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[17] This study follows the position taken by Meijer (1988b), who considers *Theodoxus serratiliniformis* to be a synonym of *Theodoxus danubialis*.

Zelzate. In southern England it has been found in deposits dating from MIS 11 at Barnfield Pit and Dierden's Pit/Swanscombe plus Bradwell Hall and East Hyde/Tillingham, and MIS 7 at Whittlesey. In Italy it has been found in EP2 and EP3 deposits from the Stirone River in Emilia-Romagna. It thus appears that this species had several episodes of significant westwards expansion during EP2, EP3, MIS 13, MIS 11 and MIS 5e (cf. Meijer 1988b, Meijer and Preece 1995, p.103), and not all of the river systems with this species were directly connected. Thus Hungerbol 2 need not have been directly connected to the Danube system when dispersal took place. *Theodoxus danubialis* may have been living in parts of Switzerland during EP2, EP3 and the early Middle Pleistocene, but as it seems to have disappeared from south-western and central Germany after MIS 11, it seems unlikely that it was present in Switzerland after this time.

5.5.4 Marker species for Middle Late Pleistocene deposits

Aegopis verticillus (=*acieformis*)[18]: found in Switzerland only at Sous-Terre (MIS 11) and Niederweningen (MIS 5e). This is an East-Central and South-Eastern European species, whose modern geographical distribution includes east/central Austria, parts of the Czech Republic, isolated populations in SE Germany, the NE corner of Italy, Slovenia and then continues south-eastwards into the Balkans. In Austria it has been found in deposits dating from the early Middle Pleistocene at Krems (4/2, 4/1)[19] and Hundsheim, MIS 11 and MIS 9 levels within the Vienna Basin, MIS 11 or MIS 9 at Stratzing, MIS 5e at Aigen/Hohlweg, Furth/Hohlweg, Krems/Hundssteig, Paudorf, Wetzleinsdorf and Willendorf, and a number of Holocene sites. In the Czech Republic it is known from an EP3 site at Stránská skála II, early Middle Pleistocenes sites at Zlatý Kůň-Höhle and Zlatý Kůň-C718, plus several Middle Pleistocene and MIS 5e sites. In Slovakia it has been recorded from EP3 sites at Bojnice-Úboče, Nové Mesto-Skalka, Ostrá hora, Plešivec and Slovenská skala, plus several Middle Pleistocene and MIS 5e sites. In Poland it has been found at MIS 5e sites. In Hungary it has been recorded in EP2/EP3, early Middle Pleistocene and MIS 5e deposits. In southern and central Germany it is known from deposits dating from MIS 13 at Bietigheim-Bissingen and Bilzingsleben I, Breitenberghöhle-Göβweinstein, Brüheim-Gotha, Schmiechen-Blaubeuren and Weiβenburg 7, MIS 11 at Bilzingsleben II, MIS 9 at Bad-Cannstatt/Stuttgart, Lengefeld-Bad Kösen, Neumark-Sud and Schöningen 12, MIS 7 redeposited in MIS 6 strata at Rain and Zeuchfeld, and MIS 5e at Bötzingen, Burgtonna, Dieβen, Hurlach, Neumark-Nord, Tönchesberg and Parkhöhle-Weimar. It has never been found in The Netherlands, but in France is known from MIS 11 deposits at Achenheim, Coupy, La Celle, St. Pierre les Elbeuf and Vernon, and an MIS 9 level at Achenheim.

Aegopis verticillus is a reliable indicator species for interglacial periods, which greatly expanded its geographical range westwards during past interglacials. Although it has only been found in MIS 11 and MIS 5e deposits in Switzerland, it may also have been present during the early Middle Pleistocene, especially MIS 13, and possibly during MIS 9.

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[18] The evidence for the separation of *Aegopis acieformis* from *Aegopis vorticillus* is unconvincing (cf. Wernert 1955), while there are strong biogeographical indications that *A. verticillus* spread westwards during past interglacials. *A. acieformis* is thus considered to be a synonym of *A. verticillus* in this study.

[19] Early Pleistocene records from Stranzendorf and Krems are incorrect and correspond to one or more different species of *Aegopis*, possibly including *A. klemmi*; cf. Appendix 5.

Zonitoides sepultus: found in Switzerland only at Sous-Terre (MIS 11; Appendix 2). This extinct species had a Central European geographical distribution (Preece and Meijer 2002). In Austria it has only been found in early Middle Pleistocene strata at Krems (4/2). In the Czech Republic it is known from EP3 sites at Červený kopec, Stránská skála I and Stránská skála II, and early Middle Pleistocene sites at Mladeč-Höhle, Zlatý Kůň-Höhle and Zlatý Kůň-C718. In Slovakia it has been found at an EP3 site at Bojnice-Úboče and an early Middle Pleistocene site at Hradište. In Poland it is known from EP2 strata at Kielniki. In Hungary it has been found in EP2/EP3 and early Middle Pleistocene levels. In southern Germany it is known from deposits dating from the Late Pliocene (MN16b) at Bären- und Karlshöhle, Erpfingen, MIS 13 at Adlerberg-Nördlingen, Bietigheim-Bissingen, Schmiechen-Blaubeuren, Dyckerhof Pit/Wiesbaden-Biebrich and Elisabethen Höhe/Wiesbaden and MIS 9 at Bad-Cannstatt/Stuttgart. In The Netherlands it has been found in EP1 sediments at Russel-Tiglia-Egypte Pit and MIS 9 sediments at Bélvèdere Pit. In France it is known from MIS 11 deposits at Saint Pierre les Elbeuf and Vernon, while in southern England it has been found in MIS 11 strata at Clacton-on-Sea, Barnfield Pit/Swanscombe and Beeches Pit/West Stow, and MIS 9 deposits at Barling. *Zonitoides sepultus* thus appears to have had several episodes of westwards expansion, during EP1, MIS 13, MIS 11 and MIS 9, but to then have become extinct during the later Middle Pleistocene after MIS 9. The site at Sous-Terre appears to be the furthest to the south-west that this species has ever been found, so it seems likely that it was only sporadically present in Switzerland during the Middle Pleistocene.

5.5.5 Marker species for Eemian (Late Pleistocene) deposits

There are a number of typical interglacial marker species, like *Aegopis verticillus*, *Discus perspectivus* and *Ruthenica filograna* (see above), which were present in Early and/or Middle Pleistocene interglacials in Switzerland, and then reappeared during the Eemian. These were joined by new interglacial taxa that can be considered to be typical markers for the Eemian in Switzerland, such as *Daudebardia brevipes* and *Daudebardia rufa*, as well as *Acicula lineata* and *Pagodulina pagodula,* that otherwise have only been found at Ecoteaux (MIS 15).

Pagodulina pagodula: found in Switzerland only at Ecoteaux, Niederweningen, Thalgut and Zell. This is a Southern and Central European species, whose modern geographical distribution includes southern, central and eastern France, northern Italy and most of Austria, with further outliers towards the east and south-east. Strangely, although its modern distribution approaches the western, north-western and southern frontiers of Switzerland, it appears never to have spread into Swiss territory during the Holocene. In Austria it is known from an early Middle Pleistocene level at Krems (4/1), and MIS 5e sediments at Aigen/Hohlweg, Furth/Hohlweg and Paudorf. In the Czech Republic it has been found in early Middle Pleistocene strata at Mladeč-Höhle, late Middle Pleistocene levels at Želátovice and Tučin, and a few MIS 5e sites. In Slovakia it has been recorded from early Middle Pleistocene sediments at Hradište, from Middle Pleistocene strata at Pažica and at several MIS 5e sites. It first appeared in Hungary during the Middle Pleistocene. In southern and central Germany it is known from deposits dating from MIS 13 at Breitenberghöhle-Gößweinstein and probably Weißenburg 7, MIS 11 at Bilzingsleben II, MIS 9 at Bilzingsleben III, Lengefeld-Bad Kösen, Neumark-Sud and Schöningen 12 and MIS 5e at Bötzingen, Burgtonna, Dießen, Eichenreid, Hurlach,

Neumark-Nord, Tönchesberg, Parkhöhle-Weimar and Weimar-Ehringsdorf. It has never been found in The Netherlands. In France it is known from strata dating from MIS 11 at La Celle, MIS 9 at Soucy and MIS 5e at Caours. In Italy is known from MIS 13 deposits at Valle Giumentina in Abruzzo.
Pagodulina pagodula is only ever found in true interglacial contexts. Although it has so far only been recorded from MIS 15 and Eemian deposits in Switzerland, it may also have been present during MIS 11 and MIS 9. As this species seems to have first appeared in Central and Eastern Europe during the early Middle Pleistocene **it has great potential as a biostratigraphical marker**, and may be an **Eemian marker species for Switzerland**.

Daudebardia brevipes: found in pre-Holocene deposits in Switzerland only at Flurlingen and Niederweningen. This Central and South-Eastern European species has a modern geographical distribution that includes south-western Germany, parts of Austria, the Czech Republic, Slovakia, southern Poland, and NW Hungary, then continues south into Italy and south-east into the Balkans as far as Turkey. It is also present in northernmost Switzerland. This species has only ever been found in true interglacial contexts, including a late Middle Pleistocene site at Želátovice and some MIS 5e sites in the Czech Republic, a few MIS 5e sites in Slovakia. It first appeared in Hungary during MIS 5e. It is also known from MIS 5e deposits at Eichenreid in SE Germany and Burgtonna in central Germany. It seems likely that *Daudebardia brevipes* was more widespread in lowland Switzerland during the Eemian, although there is no evidence that it was present during earlier interglacials. **It has great potential as a biostratigraphical marker** and seems to be an **Eemian marker species for Switzerland**.

Daudebardia rufa: found in pre-Holocene deposits in Switzerland only at Niederweningen. This Central and South-Eastern European species has a modern geographical distribution that includes south-western and central Germany, parts of Austria, the Czech Republic, Slovakia, southern Poland, and NW Hungary, then continues south into Italy and south-east into the Balkans as far as Turkey. It is also present in the far north-west of Switzerland. Like *D. brevipes*, this species has only ever been found in true interglacial contexts. These include an MIS 5e site at Paudorf in north-eastern Austria, in late Middle Pleistocene sites at Želátovice and Turold, plus several MIS 5e sites in the Czech Republic, and a few MIS 5e sites in Slovakia. It first appeared in Hungary during MIS 5e. It is known from MIS 13 deposits at Breitenberghöhle-Göβweinstein in SE Germany, MIS 5e levels at Burgtonna and Parkhöhle-Weimar in central Germany and Hurlach in south-central Germany. It has also been recorded in France from MIS 5e sediments at Caours and Chambolle, and in Italy in MIS 7 deposits at Poggetti Vecchi, Toscana and MIS 5e sediments at Salviano-Livorno, Toscana. Given this evidence, it seems likely that *Daudebardia rufa* was more widespread in lowland Switzerland during the Eemian, although there is no evidence that it was present during earlier interglacials. **It has great potential as a biostratigraphical marker** and seems to be an **Eemian marker species for Switzerland**.

In addition, there are several other species whose geographical distributions during the Eemian (MIS 5e) extended significantly further than their Holocene limits. These include:

Aegopinella nitidula: found in pre-Holocene deposits in Switzerland only at Zell, LU. This is a Western European species whose modern geographical distribution includes the

UK, most of France, central and northern Germany and the north of the Czech Republic. It seems to have disappeared from Switzerland after the Eemian.

Platyla dupuyi: found in pre-Holocene deposits in Switzerland only at Les Tuileries, VD. This is a South-Western European species whose modern geographical distribution includes south-western and east-central France. It has been found in a few Holocene contexts in the Geneva Basin but seems to have since become extinct in Switzerland. It appears to have never extended its distribution as far north as the Yverdon region since the Eemian. In north-western France it has been found in MIS 11 contexts at St Pierre les Elbeuf and Vernon, while in eastern France it has been found in deposits dating from MIS 9 and MIS 7 at Chaignay, and MIS 5e at Chambolle and Vanvey.

Trochulus caelatus: found in pre-Holocene deposits in Switzerland only at Flurlingen, ZH. This species is today confined to a small area of the Birs Valley (JU, SO, BL) in western Switzerland, but it appears that during the Eemian its distribution spread further to the north-east within the area of the Jura Mountains.

5.6 Molluscan biostratigraphical marker species that are still widely present among Holocene faunas in Switzerland

Apart from taxa that have subsequently disappeared from molluscan faunas in Switzerland, or became restricted to small areas, it is equally important to record the first appearance of certain key forest species that subsequently became a regular component of Swiss interglacial faunas.

5.6.1 Species that first appeared during the Early Pleistocene

Marker species that first appeared at Albishorn-Bürglen 1 and/or Hungerbol 2

There are several species that are absent from the Irchel sites and from Albishorn-Bürglen 2, which first appeared at Albishorn-Bürglen 1 and/or at Hungerbol 2.

Clausilia cruciata: present at Hungerbol 2, Sous-Terre and Montfleury (MIS 11), Nuolen, Grandson and Ried (MIS 7) and several Eemian sites (MIS 5e; Appendix 2). This is a Central and North-Central European species, whose modern geographical distribution includes southern Germany, eastern France, Switzerland, Austria, northern Italy and the Apennines of central Italy, western Slovenia, the Czech Republic and Slovakia, southern Poland, NE Ukraine and Romania, as well as central Sweden, SE Finland, the Baltic States and western Russia. In Austria it has only been found at Deutsch-Altenburg in EP2 (30A, 2C1, 22A) and late EP2 (4B[20]) contexts, and in EP3 strata at Krems (7/2). In the Czech Republic it is known from EP3 sites at Červený kopec, Hlubná, Stránská skála I and Stránská skála II, early Middle Pleistocene strata at Mladeč-Höhle and Zlatý Kůň-Höhle, and some MIS 5e sites. In Slovakia it has only been found in a few MIS 5e contexts. In Poland it has been recorded from MIS 19/17 sediments at Kozi Grzbiet. In Hungary it has been found in EP2/EP3, Middle Pleistocene and MIS 5e deposits, being present in the Bükk Mountains from EP3. In southern and central Germany it is known

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[20] Also listed for D-A 37 in Frank and Rabeder 1997d, but not in Nordsieck 2007 (p.140). Records for D-A 30A and 4B have been verified by Nordsieck (2021), for 30A, 2C1 and 22A by NT (Appendix 5). Records for Krems levels Kov-5 to Kov-1 in Kovanda et al. 1995 are doubted by Nordsieck (2007, 2021).

from deep cores in the Upper Rhine Graben in strata dating from EP3 near Viernheim, and MIS 11 at Mannheim/Lindenhof. Also in deposits dating from EP3 at Fuchsberg (but nothing earlier), MIS 15-13 in the 'Mosbach Sands' at Wiesbaden and their equivalent at Herxheim, MIS 13 at Bietigheim-Bissingen, Breitenberghöhle-Göβweinstein, Schmiechen-Blaubeuren and Weiβenburg 7, MIS 7 at Weimar-Ehringsdorf, and MIS 5e at Hurlach and Parkhöhle-Weimar. In France it has only been found in eastern Alsace in deposits dating from MIS 17 at Hanhoffen, MIS 13 at Hangenbieten and Hanhoffen, MIS 11, MIS 9 and MIS 7 at Achenheim. It has not been found in The Netherlands[21]. In Italy it is known from MIS 13 sediments at Campani Quarry, Toscana and a MIS 5e context at Livorno town, Toscana, but nothing earlier.
This evidence suggests that *Clausilia cruciata* is a relatively recent species that first appeared in central Europe early in EP2 and reached Switzerland during EP2 or EP3 and subsequently became a regular component of Swiss interglacial molluscan faunas.

Cochlodina fimbriata: present at A-B 1, Hungerbol 2, Nuolen (MIS 7) and several Eemian sites (MIS 5e). This is a South-Central European species, whose modern geographical distribution includes the SW corner of Germany, parts of eastern France, Switzerland, northern Italy, western Slovenia, parts of eastern Austria and an isolated population in Slovakia. It seems never to have been found as a Quaternary fossil in Austria, the Czech Republic or Slovakia, and there also appear to be no finds from interglacial deposits in southern Germany, eastern France or northern Italy, meaning that the records from Albishorn-Bürglen 1 and Hungerbol 2 could be among the earliest known.

Macrogastra attenuata: present at A-B 1, Hungerbol 2, Sous-Terre and Montfleury (MIS 11), Grandson and Ried (MIS 7), and several Eemian (MIS 5e) sites. This is a Central and South-Central European species, whose modern geographical distribution includes SW and west-central Germany, eastern Belgium, eastern France, Switzerland, western Austria, western Slovenia, northern and central Italy, as well as outliers in northern Germany, Denmark and the eastern Pyrenees. In Austria is only known from a possible EP3 context at Deutsch-Altenburg (4A) and a few Holocene sites. It has never been found in the Czech Republic or Slovakia. In southern Germany it is only known from deposits dating from MIS 13 at Bietigheim-Bissingen, Breitenberghöhle-Göβweinstein and Schmiechen-Blaubeuren, and MIS 11 at Bilzingsleben II and in a deep core in the Upper Rhine Graben near Ludwighafen, but nothing earlier. In France it has only been found in the east in MIS 11 strata at Coupy and the SE in MIS 5e levels at the Grand Abri aux Puces/Vaison-la-Romaine, Vaucluse, while in Italy it is known from MIS 13 deposits at Campani Quarry, Toscana, but nothing earlier. This evidence suggests that *Macrogastra attenuata* may have first appeared during early EP2 in Central Europe, including Switzerland, then subsequently became a regular component of Swiss interglacial molluscan faunas. It seems to have greatly expanded its range during the Holocene.

Macrogastra plicatula: present at A-B 1, Hungerbol 2, Sous-Terre and Montfleury (MIS 11), Ried (MIS 7) and several Eemian sites (MIS 5e). This is a widespread Central and Eastern European species, whose modern geographical distribution includes most of Germany, eastern France, Switzerland, Austria, southern Fennoscandia, the Czech Republic, Slovakia, Poland, northern and central Italy, Slovenia, and then continues

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[21] A tentative record from mid EP2 (Waalian) sediments in Core Hendrik Ido Ambacht is probably *C. pumila*.

towards the east and south-east. In Austria it has been found in EP1 deposits at Stranzendorf (levels F, K, K/L, L)[22], at Deutsch-Altenburg in contexts dating from EP2 (30A, 2C1, 31) late EP2 (4B), and the early Middle Pleistocene (28), at Krems in strata dating from EP2 (11, 9, 8/2), EP3 (7) and the early Middle Pleistocene (4/2, 4/1), early Middle Pleistocene deposits at Hundsheim, MIS 11 levels within the Vienna Basin, and MIS 5e and Holocene contexts at a number of sites. In the Czech Republic it is known from early Middle Pleistocene sites at Mladeč-Höhle, Zlatý Kůň-Höhle and Zlatý Kůň-C718, as well as several Middle Pleistocene and MIS 5e sites. In Slovakia it has been recorded from an EP3 site at Plešivec and a few MIS 5e contexts. In Poland it has been documented from EP2 sediments at Kielniki and MIS 19/17 at Kozi Grzbiet. In Hungary it has been found in EP2/EP3, Middle Pleistocene and MIS 5e deposits. In southern and central Germany it has been found in deep cores in the Upper Rhine Graben in strata dating from MIS 15-13 near Mannheim-Ladenburg, MIS 11 at Mannheim/Lindenhof, and in deposits dating from EP1 at Rottenburg, EP3 at Osterbuch, MIS 15-13 in the 'Mosbach Sands' at Wiesbaden, MIS 13 at Bietigheim-Bissingen, Breitenberghöhle-Gößweinstein, Schmiechen-Blaubeuren and Weißenburg 7, MIS 11 at Bilzingsleben II and Steinheim an der Murr, MIS 9 at Bad-Cannstatt/Stuttgart, Lengefeld-Bad Kösen, Neumark-Sud, MIS 7 at Weimar-Ehringsdorf and MIS 5e at Bötzingen, Burgtonna, Dießen, Bonau, Hausen, Heilbronn-Böckingen, Hurlach, Neumark-Nord, Rottenburg, Thonstetten, Parkhöhle-Weimar and Weimar-Ehringsdorf. In France it has been found in sediments dating from MIS 17 at Hanhoffen, in probable MIS 15-13 strata in a core in the Upper Rhine Graben at Marckolsheim, MIS 11 at St Pierre les Elbeuf, and MIS 9/7 at Lampertheim. In Italy it is known from MIS 5e deposits at Villa San Giorgio-Livorno, Toscana and Rocca del Campione, Cherasco, Cuneo and Early Würm strata at Moncucco Torinese, Asti.
It thus appears that *Macrogastra plicatula* first appeared during early EP1 somewhere to the east of Switzerland, and then extended its geographical range during EP1 to EP3. It first reached Switzerland during EP2 and subsequently became a regular element in Swiss interglacial molluscan faunas.

Monachoides incarnatus: present at A-B 1, Sous-Terre and Montfleury (MIS 11), Nuolen, Grandson and Ried (MIS 7) and several Eemian sites (MIS 5e), but seems to be absent from Hungerbol 2 (Appendix 2). This is a Central-East European species, whose modern geographical distribution includes most of Germany, eastern Holland, eastern Belgium and eastern France, Switzerland, northernmost Italy, Austria, the Czech Republic, Slovakia, Poland, Hungary and then continues towards the south-east. In Austria it is known from Late Pliocene (MN16b) strata at Neudegg, at Stranzendorf in deposits dating from the Late Pliocene (level C) and EP1 (levels D, K, K/L, L, L/M), at Deutsch-Altenburg in contexts dating from EP2 (38, 45) and late EP2 (4B), at Krems in levels dating from EP2 (8/2), EP3 (7, 7/1) and the early Middle Pleistocene (4/2, 4/1), in MIS 11, MIS 9 and MIS 5e levels in the Vienna Basin, MIS 11 or 9 silts at Stratzing, in later Middle Pleistocene deposits at Wien-Favoritenstraße and in MIS 5e sediments at Aigen/Hohlweg, Furth/Hohlweg, Krems/Hundssteig, Paudorf and Willendorf. In the Czech Republic it is known from an EP2/EP3 site at Chlum, EP3 sites at Červený kopec, Stránská skála I and Únětice-Holý vrch, early Middle Pleistocene contexts at Dolni Věstonice, Mladeč-Höhle, Zlatý Kůň-Höhle and Zlatý Kůň-C718, plus several Middle

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[22] Specimens noted in level Kov1 at Stranzendorf by Kovanda et al. 1995 are almost certainly a misidentification, as this level dates from the Late Pliocene and there are no other records from this period.

Pleistocene and MIS 5e sites. In Slovakia it has been recorded from EP3 sites at Nové Mesto-Skalka, Ostrá hora and Slovenská skala, an early Middle Pleistocene tufa at Malé Bielice, plus at several Middle Pleistocene and MIS 5e sites. In Poland it has been found at MIS 5e sites. In Hungary it is known from EP1, EP2/EP3, Middle Pleistocene and MIS 5e strata. In southern and central Germany it has been found in deep cores in the Upper Rhine Graben in strata dating from EP1 near Viernheim/Weinheim, EP1-EP3 and MIS 11 near Viernheim, EP3 at Biebesheim, and MIS 11 at Mannheim/Lindenhof and Ludwigshafen. Also in deposits dating from the Late Pliocene (MN 16b) at Bären- und Karlshöhle, Erpfingen, EP1 at Frechen and Hörlis, EP3 at Kalbsrieth, MIS 13 in the 'Mosbach Sands' at Wiesbaden, and at Bietigheim-Bissingen, Breitenberghöhle-Göβweinstein and Weiβenburg 7, early MIS 12 at Uichteritz, MIS 11 at Bilzingsleben II, Heilbronn and Seebach, MIS 9 at Lengefeld-Bad Kösen, Neumark-Sud and Schöningen 12, MIS 7 at Höchstadt, Rain and Weimar-Ehringsdorf, and MIS 5e at Bötzingen, Burgtonna, Dieβen, Bonau, Hurlach, Neumark-Nord, Niederhummel, Oberheisesheim, Tönchesberg, Parkhöhle-Weimar and Weimar-Ehringsdorf. In the Netherlands it has been found in EP3 strata in Core 38H/148, Leerdam. In France it is known from a probable MIS 15-13 level in a core in the Upper Rhine Graben at Dingsheim, and in deposits dating from MIS 13 at Hanhoffen, MIS 11 at Coupy, St Acheul, St Pierre les Elbeuf and Vernon, MIS 9 at Achenheim, and MIS 5e at Chambolle. In southern England it has been found in MIS 15/13 strata at Sun Hole/Cheddar.

Monachoides incarnatus appears to have first appeared during the Late Pliocene somewhere to the east of Switzerland, before expanding its range during EP1 to EP3. It seems to have first arrived in Switzerland during EP2 and subsequently became a regular element in Swiss interglacial molluscan faunas from the Middle Pleistocene onwards.

Platyla polita: present at Hungerbol 2, Sous-Terre (MIS 11), Nuolen (MIS 7) and several Eemian sites (MIS 5e). This is a Central and Eastern European species, whose modern geographical distribution includes most of Germany, parts of central-eastern France, scattered localities in northern and central Italy, Switzerland, Austria, the Czech Republic, Slovakia, Poland, and then further to the east and south-east, and is also in north-eastern Spain. In Austria this species has only been found in Holocene contexts, but nothing earlier. In the Czech Republic it is known from an EP3 site at Stránská skála I, plus a few Middle Pleistocene and MIS 5e sites. In Slovakia it has been found in EP3 sites at Bojnice-Úboče and Slovenská Skala, early Middle Pleistocene sites at Malé Bielice and Vyšny Ružbachy-Modzele, plus a few Middle Pleistocene and MIS 5e sites. In Poland it has been documented from EP2 sediments at Kielniki, MIS 19/17 at Kozi Grzbiet and at MIS 5e sites. In Hungary it has been found in EP3, Middle Pleistocene and MIS 5e deposits, being in the Bükk Mountains from EP3. In southern and central Germany it is known from deposits dating from EP3 at Untermassfeld and Zeuchfeld, MIS 15-13 in the 'Mosbach Sands' at Wiesbaden, MIS 13 at Bietigheim-Bissingen and Schmiechen-Blaubeuren, MIS 11 at Bilzingsleben II, Hundersingen, Seebach and Steinheim an der Murr, MIS 9 at Bad-Cannstatt/Stuttgart, Lengefeld-Bad Kösen and Neumark-Sud, MIS 7 at Weimar-Ehringsdorf, and MIS 5e at Bötzingen, Burgtonna, Dieβen, Bonau, Hurlach, Moosham, Neumark-Nord, Niederhummel, Parkhöhle-Weimar and Weimar-Ehringsdorf. In France it has been found in sediments dating from the Late Pliocene (MN16b) at Sessenheim, MIS 13 at Hangenbieten, MIS 11 at La Celle, St Acheul and St Pierre les Elbeuf, and MIS 5e at Caours and Mens. In southern England it is known from sites dating from MIS 11 at Hitchin, Barfield and Dierden's

Pit/Swanscombe and Beeches Pit/West Stow. In Italy it has been recorded in deposits dating from the Late Pliocene at Ceresole d'Alba, Cuneo, and the Cerbaie Hills, Toscana and EP3 in the Stirone River Valley, Emilia-Romagna, although some of these may be problematic as there are closely similar endemic Italian species (cf. Boeters et al. 1989). *Platyla polita* seems have first appeared during the Late Pliocene in France and north-central Italy, but may have become confined to Italy during EP1 before expanding its range towards the north and north-east during EP 2 to EP3. It seems to have first appeared in Switzerland during late EP2 or EP3 and subsequently became a regular element in Swiss interglacial molluscan faunas.

5.6.2 Species that first appeared during the Middle to Late Pleistocene

There are several species that first appeared during the Middle Pleistocene and then became a regular component of Swiss molluscan faunas or important local species.

Acicula lineata: first seen at Ecoteaux (MIS 15), then at Niederweningen, Bürgerspital and Port Valais (MIS 5e; Appendix 2). This is a Central European species, whose modern geographical distribution includes southernmost Germany, Switzerland, eastern and southern France, parts of northern Italy and most of Austria. In Austria it is only known from Holocene contexts, and has never been found in the Czech Republic or Slovakia. It is little known from pre-Holocene interglacial deposits in southern Germany and southern and eastern France, with the exception of shells from Late Pliocene (MN16b) levels at Sessenheim, Alsace. In Northern Italy, by contrast, it is known from Late Pliocene contexts at Tassarolo, Alessandria, Ceresole d'Alba, Cuneo, Molinetta, Asti and the Cerbaie Hills, Toscana and Early Würm deposits at Moncucco Torinese, Asti. It seems that *Acicula lineata* first appeared during the Late Pliocene in France and northern Italy, before disappearing from Central Europe at the start of EP1, and only expanding northwards again from northern Italy into Central Europe during the early Middle Pleistocene and again during the Late Pleistocene, and then Western and Eastern Europe during the Late Pleistocene or the Holocene. Thus, the records from the Swiss Plateau are among the earliest known from the Pleistocene of Central Europe. ***Acicula lineata* seems to be a useful biostratigraphical marker for the Eemian in Switzerland**.

Acicula lineolata: in Switzerland found in pre-Holocene deposits only at Ecoteaux (MIS 15) and Zell (MIS 5e; Appendix 2). This is a South-Eastern European species whose modern geographical distribution includes the south-eastern extremity of Switzerland, eastern Austria, south-eastern Germany, northern Italy and Slovenia. It has rarely if ever been recorded from Pleistocene sediments. It seems to have disappeared from most of southern, eastern and central Switzerland after the Eemian.

Cepaea sylvatica: first seen in Switzerland at Sous-Terre (MIS 11), then at Les Tuileries and 'Giez' (MIS 5e). This is a Central European species with a fairly restricted geographical distribution that includes the Jura Mountains, the Alpine areas of west-central Switzerland, eastern France and NW Italy, as well as the Rhine Valley of SW Germany. Until now it has mainly been found sub-fossil in the Rhine Valley, in sands dating from MIS 13 at Herxheim in SW Germany, and from MIS 13 at Hangenbieten, MIS 11 at Hanhoffen and MIS 7 at Achenheim in Alsace, as well as MIS 11 at Coupy in France. It is not known from elsewhere in France, Germany or Italy. The new records from western Switzerland and Coupy are among the earliest known for this species.

Cochlostoma septemspirale: first seen in Switzerland at Sous-Terre (MIS 11), then the late Eemian site at Port Valais. This is a South-Central and South-Eastern European species, whose modern geographical distribution includes eastern France, Switzerland, northern Italy, parts of central and eastern Austria, Slovenia and then continues towards the south-east. In Austria it has only been found at a few sites, including in MIS 11 and possibly MIS 9 levels in the Vienna Basin, and MIS 5e deposits at Furth/Hohlweg and Krems/Hundssteig. It is absent from the Czech Republic and Slovakia. In southern Germany it is only known from strata dating from MIS 15-13 in a deep core at Groβ-Rohrheim and MIS 9 at Bad-Cannstatt/Stuttgart. In France it has been found in deposits dating from MIS 11 at La Celle in the north-east, in the eastern part from MIS 9 and MIS 7 at Chaignay, MIS 7 at Abîmes de la Fage and MIS 5e at Mens and Vanvey, and in the south-east from MIS 5e at the Grand Abri aux Puces/Vaison-la-Romaine, Vaucluse.
It would appear from this evidence that *Cochlostoma septemspirale* may be a fairly recent species that first appeared during EP2 or EP3 somewhere to the south-west of Switzerland and then spread north-eastwards into Switzerland, possibly during the early Middle Pleistocene. It subsequently became an important, if rather localised element of Swiss interglacial molluscan faunas in areas where there is a calcareous substrate like the Jura.

Helicodonta obvoluta: first seen in Switzerland at Sous-Terre (MIS 11), then at several Eemian sites (MIS 5e). This a widespread Central European species, whose modern geographical distribution includes most of France, southern and central Germany, Switzerland, northern and central Italy, Slovenia, Austria, the Czech Republic, western Slovakia, western Hungary and then continues towards the south-east. In Austria it has been found at Krems in strata dating from the early Middle Pleistocene (4/2, 4/1)[23], MIS 11, MIS 9 and MIS 5e levels in the Vienna Basin, MIS 11 or MIS 9 silts at Stratzing, and in MIS 5e sediments at Aigen/Hohlweg, Furth/Hohlweg, Paudorf, Wetzleindorf and Willendorf. In the Czech Republic it is known from an EP3 site at Stránská skála II, from early Middle Pleistocene strata at Mladeč-Höhle, several Middle Pleistocene contexts and a number of MIS 5e sites. In Slovakia it has been recorded from EP3 strata at Bojnice-Úboče, Ostrá hora and Slovenská skala, from several Middle Pleistocene contexts and several MIS 5e sites. In Poland it has been found at MIS 5e sites. In Hungary it is known from early Middle and later Pleistocene and MIS 5e deposits. In southern and central Germany it has been found in deep cores in the Upper Rhine Graben in strata dating from EP3 near Viernheim and MIS 11 at Mannheim/Lindenhof and Ludwigshafen. Also in deposits dating from EP3 at Kalbsrieth, MIS 17 at Diersheim, MIS 15-13 in the 'Mosbach Sands' at Wiesbaden and their equivalent at Herxheim, MIS 13 at Bietigheim-Bissingen, Breitenberghöhle-Göβweinstein, Schmiechen-Blaubeuren and Weiβenburg 7, MIS 11 at Bilzingsleben II, Hundersingen and Leilenkopf, MIS 9 at Bad-Cannstatt/Stuttgart, Lengefeld-Bad Kösen, Neumark-Sud and Schöningen 12, MIS 7 at Höchstadt, Rain and Weimar-Ehringsdorf, and MIS 5e at Bötzingen, Burgtonna, Dieβen, Eichenreid, Bonau, Hurlach, Neumark-Nord, Niederhummel, Rottenburg, Thonstetten, Tönchesberg, Parkhöhle-Weimar and Weimar-Ehringsdorf. In France it is known from deposits dating from the Late Pliocene (MN16b) at Sessenheim, MIS 17 at Eschau and Hanhoffen, in a probable MIS 15-13 level in a core in the Upper Rhine Graben at Dingsheim, MIS 13 at Hangenbieten and Hanhoffen, MIS 11 at Achenheim, Arrest, Coupy, Hanhoffen, La Celle, St Acheul, St Pierre les Elbeuf and Vernon, MIS 9 at Achenheim and Chaignay,

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[23] Early Pleistocene records from Stranzendorf and the lower levels at Krems are incorrect; cf. Appendix 5.

MIS 7 at Achenheim and Chaignay, and MIS 5e at Caours, Chaignay, Chambolle, Dijon, Mens, Resson, Schiltigheim and Vanvey, and in the south-east at the Grand Abri aux Puces/Vaison-la-Romaine, Vaucluse. In southern England it has been found in strata dating from MIS 11 at Hitchin, Barnfield and Dierden's Pit/Swanscombe and Beeches Pit/West Stow, MIS 9 at Purfleet and MIS 5e at Bobbitshole/Ipswhich and Trafalgar Square/London. In Italy it is known from sediments dating from the Late Pliocene at Dusino, Asti[24] and possibly the Cerbaie Hills, Toscana, EP2 in the Mugello Basin, Toscana, the Steggio Basin, Veneto, EP3 in the Crostolo River Valley, Emilia-Romagna, MIS 13 at Campani Quarry, Toscana and Valle Giumentina, Abruzzo, later Middle Pleistocene in the Liri Basin, Lazio, MIS 5e at Boccabianca, Ascoli Piceno and Salviano-Livorno, Toscana and the Early Würm at Moncucco Torinese, Asti.

Helicodonta obvoluta seems to have first appeared during the Late Pliocene in West-Central and Southern Europe between France and north-central Italy, before disappearing from north of the Alps to become a Southern European species during EP1-EP2. During EP3 it seems to have expanded its range northwards into southern and central Germany, the Czech Republic and Slovakia, before reappearing more widely in Central Europe during the early Middle Pleistocene. It may have arrived in Switzerland during the early Middle Pleistocene, then subsequently became a fairly regular element in Swiss interglacial molluscan faunas, including MIS 11, although it might have been absent during MIS 7. This species seems to **represent a biostratigraphical marker species for Swiss molluscan faunas from the Middle Pleistocene onwards.**

Sphyradium doliolum: first seen in Switzerland at Sous-Terre (MIS 11), then at Niederweningen (MIS 5e). This is a Central and South-Eastern European and Western Asian species, whose modern geographical distribution includes all of Germany except the north, SE Belgium, most of France except the north-west, south-western and southernmost Switzerland, north-central Italy, Austria, the Czech Republic, Slovakia, southernmost Poland, Hungary, and then continues towards the east and the south-east, but avoids the north. In Austria it has been found in deposits dating from EP2 at Krems (level 9), later Middle Pleistocene at Wien/Favoritenstraβe, MIS 11 or MIS 9 silts at Stratzing, and MIS 5e at Aigen/Hohlweg, Furth/Hohlweg, Paudorf, Wetzleinsdorf and Willendorf, but nothing earlier. In the Czech Republic it is known from EP3 sites at Stránská skála I, Stránská skála II, Suchdol-Kozi hřbety and Únětice-Holý vrch, an early Middle Pleistocene site at Zlatý Kůň-Höhle, plus several Middle Pleistocene and MIS 5e sites. In Slovakia it has been recorded at a EP2/EP3 site at Gombasek-Steinbasek, EP3 sites at Plešivec and Slovenská skala, plus several Middle Pleistocene and MIS 5e sites. In Poland it has been documented from EP2 sediments at Kielniki. In Hungary it is known from EP1, EP2/EP3, Middle Pleistocene and MIS 5e strata. In southern and central Germany it has been found in deposits dating from MIS 13 at Breitenberghöhle-Göβweinstein, MIS 11 at Bilzingsleben II and Seebach, MIS 9 at Lengefeld-Bad Kösen and Neumark-Sud and Schöningen 12, MIS 7 at Weimar-Ehringsdorf and MIS 5e at Burgtonna, Neumark-Nord, Rottenburg, Schöningen, Tönchesberg, Parkhöhle-Weimar and Weimar-Ehringsdorf. In The Netherlands it has only been recorded from EP2 (Waalian) levels in Core Zuurland-2, Brielle. In France it has been found in deposits dating from MIS 11 at Hanhoffen, La Celle and Vernon, MIS 9 at Chaignay, MIS 7 at Achenheim and Chaignay and MIS 5e at Caours and Mens. In Italy it has been recorded

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[24] The record from Ceresole d'Alba, Cuneo is incorrect (Nordsieck 2013b, p.177).

from MIS 13 strata at Campani Quarry, Toscana and Valle Giumentina, Abruzzo and MIS 5e contexts at Boccabianca, Ascoli Piceno and Salviano-Livorno, Toscana.
Sphyradium doliolum appears to have originated in Eastern and South-Eastern Europe, before expanding its range into Central and Western Europe during EP2 to EP3. It might have first arrived in Switzerland during the early Middle Pleistocene, then subsequently became a regular element in Swiss interglacial molluscan faunas, although it may have been absent during MIS 7. This species seems to **represent a biostratigraphical marker species for Swiss molluscan faunas from the Middle Pleistocene onwards.**

Pomatias elegans: first seen in Switzerland at Grandson (MIS 7). This Western and Southern European species, has a modern geographical distribution that includes western Germany, France, England and Wales, NE Spain, west, north-west and southernmost Switzerland, all of Italy, eastern Austria, western Hungary, Slovenia, and then continues towards the south-east into the Balkans and Greece. It is unknown as a Quaternary fossil in Austria. It is absent from the Czech Republic apart from two Holocene sites and from Slovakia except for an early Middle Pleistocene tufa at Malé Bielice. In Hungary it is known from a few early Middle Pleistocene and MIS 5e sites. In southern Germany it has only been found in deep cores in the Upper Rhine Graben in strata dating from EP3 and MIS 11 near Viernheim and MIS 11 at Groβ-Rohrheim, and in the MIS 15-13 'Mosbach Sands' at Wiesbaden. In France it is known from deposits dating from final EP3 at Grâce-Autoroute/Somme, MIS 11 at La Celle and Vernon, MIS 9 and MIS 7 at Dijon, MIS 7 at Abîmes de la Fage and Menchecourt-Abbeville, and MIS 5e at Chambolle, Erquinghem, Schiltigheim and in the SE at the Grand Abri aux Puces/Vaison-la-Romaine, Vaucluse and Baume Moula-Guercy, Ardèche. In southern England it has been found in MIS 11 levels at Barnfield Pit/Swanscombe, Barnham and Beeches Pit/West Stow, and MIS 10 or 8 at Red Barns-Portchester. In Italy it is known from deposits dating from the Late Pliocene at Madonna di Casale, Asti, RDB Quarry/Villafranca d'Asti, Asti, and the Cerbaie Hills, Toscana, EP1 at Castelnuovo Berardenga, Toscana, EP2 in the Steggio Basin, Veneto, the Mugello Basin, Toscana and the Leffe Basin, Bergamo, EP3 from the Crostolo River Valley and the Stirone River Valley, Emilia-Romagna, in MIS 15 and MIS 13 at Campani Quarry, Toscana, MIS 14 in the Sulmona Basin, Aquila, MIS 13 at Valle Giumentina, Abruzzo, MIS 11 at Monrupino near Trieste, MIS 5e at Boccabianca, Ascoli Piceno, Salviano-Livorno and Villa San Giorgio-Livorno, Toscana and the Early Würm at Moncucco Torinese, Asti.
It seems that *Pomatias elegans* first appeared during the Late Pliocene in northern-central Italy, before expanding into southern, central and northern France and south-western Germany during EP3 and possibly EP2. It seems to have only reached Switzerland during the Middle Pleistocene. As it tends to have a rather localised distribution, restricted to areas with a calcareous substrate, it may also have been a localised element of Swiss interglacial molluscan faunas during EP3, MIS 15/13, MIS 11 and MIS 9.

Semilimax semilimax: first seen in Switzerland at Nuolen and Ried (MIS 7), then at Niederweningen, Wolfbach and Zell (MIS 5e). This a Central European species, whose modern geographical distribution includes much of Germany except for the north and the Rhine Valley, the NE corner of Switzerland, the NE corner of Italy, Austria, the Czech Republic, Slovakia, eastern Hungary and then continues towards the south-east. The fragility of its shell means that reliable records from older Quaternary deposits are fairly rare. In Austria it has been found in deposits dating from late EP2 (4B) and EP3 (4A) at

Deutsch-Altenburg, MIS 11 and possibly MIS 5e in the Vienna Basin, MIS 5e at Willendorf, and in Holocene deposits. In the Czech Republic it is known from EP3 sites at Suchdol-Kozi hřbety and Únětice-Holý vrch, an early Middle Pleistocene strata at Zlatý Kůň-Höhle, and a few Middle Pleistocene and MIS 5e sites. In Slovakia it has been recorded from an EP3 site at Ostrá hora, and a few Middle Pleistocene and MIS 5e sites. In Hungary it has been found in EP2/EP3, Middle Pleistocene and MIS 5e deposits, being present in the Bükk Mountains from EP3. In southern and central Germany it is known from deposits dating from EP3 at Osterbuch, MIS 13 at Bietigheim-Bissingen, Breitenberghöhle-Göβweinstein and Schmiechen-Blaubeuren, MIS 11 at Bilzingsleben II, MIS 9 at Neumark-Sud, and MIS 5e at Eicherloh, Bonau, Hurlach, Neumark-Nord, Niederhummel, Parkhöhle-Weimar and Weimar-Ehringsdorf. In southern England it has been found in MIS 15 sediments at West Runton and MIS 11 deposits at Beeches Pit, West Stow (Icklingham) and Hitchin. The available evidence suggests that *Semilimax semilimax* might be a fairly recent species that first appeared during EP1 or EP2 to the east of Switzerland, before extending its range during EP2 to EP3, and then expanded its range westwards during subsequent interglacial periods. It may have first appeared in Switzerland during the early Middle Pleistocene, and have already been present during MIS 11 and MIS 9. This species seems to **represent a biostratigraphical marker species for Swiss molluscan faunas, from the Middle Pleistocene onwards.**

5.7 Results of the AAR Dating of shell material

The results from the four series of AAR Dating measurements undertaken between 2018 and 2021 have been extremely valuable for dating the various sites (Penkman et al. 2024). They have also established that shell fragments from the large terrestrial gastropod species *Arianta arbustorum* (AA), *Fruticola fruticum* (FF) and *Cepaea hortensis* (CH) can all generate valuable data, providing that they are fairly fresh and have not been too affected by post-burial leaching, and have not been subject to post-depositional heating due to human activities or heating during laboratory processing. Worm granules (WG) can also produce useful results, although these have to be treated with caution due to the danger of them being intrusive so require that during field excavation and sampling all superficial material that may have been affected by soil processes is removed. The most reliable results seem to be produced by the opercula from the freshwater gastropod *Bithynia tentaculata* (BT) and by slug plates (SP), because these are formed of compact calcite while shells are formed of more porous aragonite.

Unfortunately, it is rare for sites to have all of these types of material (cf. Figure 9). BT, for example, are virtually absent from the Irchel sites, probably due to the fact that the Hasli Formation largely consists of silts and fine sands brought in by flooding, although small fragments of BT opercula could be recovered from the sands at the base of the HF at Hochwacht and Amselboden. SP are abundant at Hasli and Steig, but are rare at Hochwacht. BT are common in the lowest levels at Hungerbol, but SP are rare throughout the sequence. Frequencies of AA, FF and CH are equally variable, thus requiring that the results from several different materials are compared for each site.

The results have been invaluable in establishing a first Aminostratigraphy for Switzerland that can be compared with those from other European countries such as the UK, The Netherlands, France and Germany (Meijer and Cleveringa 2009, Penkman et al. 2007,

Figure 9: Molluscan material used for the AAR Dating programme

Figure 9: Molluscan material used and that could be used for the AAR Dating programme

Stages	Period	Swiss coordinates		Site name in the AAR report	Sites	Site code for AAR Dates	Aquatic	Terrestrial			Slug plates (calcite)	Worm granules (calcite)	Outcrop / Drilling, Accessible / Not Accessible	Reliability of sample (stratigraphy, sampling, storage, processing etc.)	Comments
							Bithynia tentaculata operculae (calcite)	*Arianta arbustorum* shells (aragonite)	*Fruticola fruticum* shells (aragonite)	*Cepaea hortensis* shells *(aragonite)*					
Holocene	Holocene	2564 480	1206 390	**Lake Neuchâtel**	Hauterive-Champréveyres, NE 19th/20th century beach	LN	BT						O, Nacc	sampling and sample processing by NT	a beach deposit so some mixing
		2616 765	1234 395	**Oberbipp**	Oberbipp, BE early to mid-Boreal, beneath a Late Neolithic dolmen + from inside the dolmen	Obe		AA abundant	some	some	some	abundant	O, Nacc	samples taken 2011/2012 beneath + at base of a Neolithic dolmen. Age = Boreal + Subboreal. Stratigraphy, plus sample treatment in Basel ok	AA, FF and CH are early Subboreal, SP and WG are early-mid Boreal; unfortunately it was not possible to get all material from the same layer
		2673 800	1258 850		Boppelsen-Cholholz, ZH early Boreal	BoCh		AA some		rare	rare	rare	O, Nacc	old sample (Jayet 1948); but stratigraphy good and and sample treatment probably ok? No sieve residue available	
		2759 659	2242 699	**Abri Unterkobel**	Abri Unterkobel, SG Boreal/Mesolithic layers in a rockshelter	AU		AA	FF	na	na	na	O, Nacc	stratigraphy, sampling and sample treatment good; processed in Saint Gallen and Basel	shells heated within layers by hearth activity and the burning of dung layers
		2499 175	1117 750	**Sous-Terre upper**	Sous-Terre, GE - upper layer 8m terrace; earlier Preboreal	Ge	BT			rare	rare	few	O, Nacc	old sample (Jayet early 60's), but stratigraphy good and sample treatment ok (processed by NT)	the sampled sediment represents an Early Holocene 8 m terrace
Late Pleistocene	Würm (MIS 3)	2670 825	1262 095		Niederweningen, ZH - 1990 (early-mid MIS 3) construction pit		BT rare + possible new material?	AA few			rare	moderate	O, Nacc + D, Acc	Thomas Bolliger samples (1990); stratigraphy and sample treatment ok (uses same processing methods as DK)	there are new samples available from the 2018 cores, plant no plans to analyse them
		2686 160	1229 990		Sihlbrugg, ZH (early-mid MIS 3?) gravel quarry			AA few			rare	rare	O, Nacc	Thomas Bolliger sample (1989/1990); sample treatment ok (uses same processing methods as DK). No sieve residue available	
		2574 660	1173 120		Bertigny, Pont-la-Ville, FR (early-mid MIS 3?)			AA few			rare	rare	O, Nacc	old sample (Favre early 1940's); but stratigraphy good and and sample treatment probably ok? Sieve residue available	
	Early Würm	2665 550	1259 270		Baden, Niederterrasse, AG (MIS 5c or 5a) base of doline infill			AA			some	abundant	O, Nacc	old sample (Albert Heim 1919); taphonomy and stratigraphy unsure but probably ok, sample treatment good (processed by NT)	
		2555 630	1200 650		Boudry/Champ-le-Sage West, NE (MIS 5a?) motorway trench		BT						O, Nacc	sample taken in 1998 in the construction trench for the A5 motorway; stratigraphy, sampling and sample treatment all good.	The material is held in the Latenium (archaeological museum), NE
		2576 340	1205 310		Muntschemier-Gugglerацher, BE (MIS 5c?) gravel quarry		BT	AA few		rare			O, Nacc	sample taken by NT in 1996 in the gravel quarry; stratigraphy, sampling and sample treatment all good (done by NT)	
	Eemian	2670 409	1262 380	**Niederweningen 2015** (AA, FF)	Niederweningen, ZH - 2015 (MIS 5e) Column B	Nie	BT few	AA	FF	moderate	some	moderate	O, Nacc and D, Acc	stratigraphy, sampling and sample treatment all good (done by NT)	there are samples from 2015 still to sieve
		(2) 2670 514 (3) 2670 428	1262 322 1262 363	**Niederweningen 2018** Core 2 (BT, SP) Core 3 (AA, FF, CH, WG)	Niederweningen, ZH - 2018 (MIS 5e) Cores NW18/2 and NW18/3	Nie	BT some	AA	FF	moderate	some	moderate	O, Nacc and D, Acc	stratigraphy, sampling and sample treatment all good (done by NT)	there are a few samples from 2018 still to sieve
		2610 810	1268 145		Bürgerspital, BL (MIS 5e) base of Niederterrasse		BT few but no operculae	AA some	FF few	some	rare	rare	O, Nacc	old sample (Woltersdorf 1954), but stratigraphy good and sample treatment probably ok?	
		2685 250	1247 810		Wolfbach, Zürich, ZH (MIS 5e)			AA some	FF few	few		moderate	O, Acc	sampled D. Kälin 2021, stratigraphy, sampling and sample treatment all good	
		2689 910	1282 080		Flurlingen, ZH (MIS 5e) tufa, Hochterrasse			AA few	FF few	rare		rare	O, Nacc?	old sample (Wehrli 1890's), but stratigraphy and sample treatment probably ok? No sieveing residue available	the sampled deposit is a cimented tufa, so shells needed to be extracted individually, hence the absence of smaller species
		2664 350	1270 960		Bad Zurzach, AG (MIS 5e) base of Niederterrasse			AA few	FF few	rare			D, Nacc	sample from 1994; stratigraphy, sampling and sample treatment all probably good. No sieve residue available	
		2637 190	1220 460		Zell, LU - Kiesgrube Meier (MIS 5e) mid-1940's			AA		some	few	rare	O, Nacc	old samples (Forcart 1940, Jayet mid-1940's), but stratigraphy is good (Forcart) and sample treatment probably ok? No sieve residues available	the shells from the Forcart samples seem to have been mostly lost since they were lodged in the Basel Natural History Muesum
		2636 552	1220 110-112	**Zell 2019**	Zell, LU (MIS 5e) Kiesgrube 2019	Zell19		AA	FF few	some	moderate	moderate	O, Acc new outcrop	new samples taken by DK in 2019; stratigraphy, sampling, sample treatment all good	DK took new samples in flood silts, different to the silts/sands sampled by Forcart + Jayet; the gravel quarry is now several hundred metres across so the deposits can be somewhat different
		2538 525	1184 440		"Giez"/Grandson, VD (MIS 5e)		BT few	AA few	FF	abundant	moderate	fairly abundant	O, Nacc? may still be visible	old samples (Jayet early 1960's), but sample treatment probably ok (Jayet used standard processing methods)	
		2537 430-490	1183 200-230		Les Tuileries, VD (MIS 5e) gravel quarry		BT few	AA some	FF	moderate	some	abundant	O, Nacc	old samples (Jayet early 1960's), but stratigraphy good and and sample treatment probably ok? two samples processed by NT; no sieve residues available for Jayet samples, but are available for two newly processed samples	
		2608 990	1186 615	**Thalgut**	Thalgut, BE (MIS 5e) gravel quarry	Th	BT some			rare			O, probably Nacc? need to check	there are variations in stratigraphy due to the sampling of different profiles: Schlüchter bulk samples were taken in 1971/72 (+ some pollen, Welten 1982); Welten's new quarry samples + core from base of quarry were taken in 1983; Preusser's samples were taken ca.2000. Sample treatment probably ok? No sieve residues available	the site could be resampled, but this would require a major effort. As earlier lake deposits were not exposed in the quarry when Schluchter sampled, problems with AAR results probably come from the material being heated during laboratory processing
						Th2	BT some							newly sieved by N. Thew using material sampled by Schlüchter in 1971/72	
		2610 890	1183 750		Thungschneit, BE (MIS 5e? or earlier) gravel quarry		BT few						O, probably Nacc? need to check	Schlüchter samples (1971/72), this is equivalenet to the Jaberg Seetone; stratigraphy and sample treatment probably ok? No sieve residues available	only 5 BT operculae remain from this site, as the rest of the material seems to have been lost.
Middle Pleistocene	later Middle Pleistocene	2672 670	1269 080		Fisibach, AG (MIS 6?)							rare	O, Acc	one test sample; stratigraphy good and and sample treatment ok	this site requires new excavation and sampling; the test sample has a poor assemblage, but more shells have been observed lower in the sequence
		2499 230	1120 850		World Health Organisation, GE (MIS 6)	WHO		AA moderate		rare	moderate	NA	D, Nacc	old samples (Chaix early 1980's), but sample treatment probably ok.? No sieve residues are available	
		2499 250	1120 050		Petit Saconnex, GE 1961 (MIS 6)			AA some			rare	moderate	O, Nacc	old samples (Jayet early 1960's), but stratigraphy good and and sample treatment probably ok? No sieve residues are available	this material has not been reanalysed, so identification errors remain
		2498 930	1119 760		Petit Saconnex, GE 1994 (MIS 6)	PS94		AA some			rare	moderate	O, Nacc	new samples processed by NT; stratigraphy and sample treatment ok; sieve residues are available	
		2502 180	1117 960		Parc La Grange, GE (MIS 6) Borehole							rare	D, Nacc	old sample (Favre 1939), but stratigraphy good and and sample treatment probably ok. Small sieve residue is available	
		2502 020	1117 220		La Petite Boissière, GE (MIS 6) Borehole			AA few			some	some	D, Nacc	old sample (Favre 1940), but stratigraphy good and and sample treatment probably ok. Small sieve residue is available	
		2609 680	1184 400		Ried, BE (MIS 6) gravel quarry			AA few	FF few	few	rare	moderate	O, Nacc	Schlüchter samples (1971/72); stratigraphy and sample treatment possibly ok?	
		2609 680	1184 400		Ried, BE (MIS 7) gravel quarry			AA few	FF abundant	few	some	moderate	O, Nacc	Schlüchter samples (1971/72), proceessed 2021 by DK; stratigraphy and sample treatment ok	
		2539 300	1184 700	**Grandson**	Grandson, VD (MIS 7) lignite mine	Gr	BT	AA		some		rare	O, Nacc	old samples (1942-44), but stratigraphy and sample treatment ok? (samples washed by Favre in 40's and by M. Weidmann in 1970); sieve residue available for one of the two samples	additional unprocessed samples from the 1942-44 are still available
		2710 370	1228 440	**Nuolen 1**	Nuolen 1, SZ - middle level (MIS 7) eastern gravel quarry	Nuo1	BT				rare	rare	O, Acc? need to check	Thomas Bolliger samples (1989); stratigraphy and sample treatment ok (uses same processing methods as DK); no sieve residue available	
		2710 160	1228 620	**Nuolen 2**	Nuolen 2, SZ - middle level (MIS 7) western gravel quarry			AA	FF few	some (large shells)	rare	some	O, Acc? need to check	Thomas Bolliger samples (1989); stratigraphy and sample treatment ok (uses same processing methods as DK); no sieve residue available	
				Nuolen 3	Nuolen 3, SZ - middle level (MIS 7) western gravel quarry	Nuo3	BT rare	AA	FF few	fairly abundant	some	moderate	O, Acc? need to check	Thomas Bolliger samples (1989); stratigraphy and sample treatment ok (uses same processing methods as DK); and some remaining sample material processed by NT; sieve residue is available	
		2494 400	1119 265	**Montfleury**	Montfleury 1, GE - upper (MIS 10) Core			AA few			fairly abundant	fairly abundant		old samples (1946), but stratigraphy and sample treatment probably ok? (Favre used standard processing methods)	cold period glacial/interstadial
					Montfleury 2 - middle (MIS 11) Core			AA few		few	some	fairly abundant but very small		old samples (1946), but stratigraphy and sample treatment probably ok? (Favre used standard processing methods)	end of the same warm period
					Montfleury 3, GE - lower (MIS 11) Core	Mtf			FF		rare	some	D, Nacc	old samples (1946), but stratigraphy and sample treatment probably ok? (Favre used standard processing methods)	warm period interglacial
		2499 175	1117 750	**Sous-Terre lower**	Sous-Terre, GE - middle (MIS 10) construction trench			AA rare				rare	O, Nacc	Above the 'interglacial' layer were compact silts; 1.15 kg was processed by NT but yielded very few shells	
					Sous-Terre, GE - lower (MIS 11) construction trench	SoT	BT rare	AA moderate	FF	fairly abundant	some	moderate	O, Nacc	old samples (Jayet early 1960's), but stratigraphy and sample treatment probably ok? 4.7 kg (dry weight) of remaining 'interglacial' sample sediment was processed by NT	
	earlier Middle	2555 370	1154 680	**Ecoteaux B**	Ecoteaux, VD, Site B (MIS 15) samples correlated with core sequence	Eco	BT					rare	O, probably Acc + D, Acc	older samples (M. Weidmann 1990), but stratigraphy and sample treatment ok (described in publication); sieve residues available for 3 out of 4 samples	sediments from the core are still available
Early Pleistocene	Tiefere DS EP3	2708 130	1282 510	**Hungerbol 1**	Hungerbol 1, D - 2017 interstadial in succeeding cold period	Hun1	BT rare	AAa bit weathered			rare	fairly abundant	O, Acc	stratigraphy, sampling, sample treatment all good	Hungerbol 2 is a warm period interglacial deposit separated from the interstadial silts of Hungerbol 1 by cold period gravels
		2708 100	1282 500	**Hungerbol 2**	Hungerbol 2, D - 2017 Interglacial	Hun2	BT	AA fairly weathered	FF	some fairly weathered	rare	moderate	O, Acc	stratigraphy, sampling, sample treatment all good	
		2708 100	1282 500		Hungerbol 2, D - 2019 Interglacial		BT	AA moderate	FF some but fairly weathered	some fairly weathered	rare	moderate	O, Acc	stratigraphy, sampling, sample treatment all good	
	upper part HDS EP2?	2683 442	1234 425	**Albishorn Bürglen 1**	Albishorn-Bürglen 1, ZH - 2016 overbank deposits / 872 m asl	Alb1	BT small operculum frags present	AA few	FF few	few	rare	rare	O, Acc	NAGRA 2017 samples taken by DK; stratigraphy, sampling, + processing all good	
	Höhere DS EP1	2666 020	1261 460		Freienwil, AG - Frei c.1910 silty-sand between 2 gravel units								O, Acc	sampled by R. Frei between 1908 and 1910; stratigraphy good	the wherabouts of the shells is unknown; part of the Frei collection is in ETH Zürich, but these shells could not be found
		2683 380	1234 525	**Albishorn Bürglen 2**	Albishorn-Bürglen 2, ZH - 2017 silt layer within lower gravels		BT few - shells but no operculae	AA few	FF few	few	rare	rare	O, Acc	MB 2017 sample; stratigraphy, sampling, sample treatment all good	
		2683 377-326	1234 526-573	**Albishorn Bürglen 2**	Albishorn-Bürglen 2, ZH - 2019 silts/sands within lower gravels 848-864 m asl	Alb2	BT small operculum frags present	AA some but too weathered	FF some but too weathered	some but too weathered	some	moderate	O, Acc	stratigraphy, sampling, sample treatment all good	
		2686 050	1268 300	**Irchel Hochwacht Graf**	Irchel Hochwacht, ZH - Graf 1993	HOC93		AA few	FF some rather weathered		some	very few sorted from sediment by Graf	O, Acc	stratigraphy, sampling, sample treatment all probably ok? No sieve residue available	the fauna resembles those from the upper part of the sequences in 2019 Columns 1 and 2
		2686 080	1268 280	**Irchel Hochwacht 2019**	Irchel Hochwacht, ZH - 2019 Column 1	HOC19	BT rare	AA some a bit weathered	FF few	moderate	AA some (3 levels, 2 profiles)	moderate	O, Acc	stratigraphy, sampling, sample treatment all good	most samples have been analysed; only two samples remain unprocessed
		2686 052	1268 252	**Irchel Hochwacht 2019**	Irchel Hochwacht, ZH - 2019 Column 2 / 654 m asl	IHoc		AA moderate	FF few	some		moderate	O, Acc	stratigraphy, sampling, sample treatment all good	DK took new large samples from Column 2 in 2020
		2686 052	1268 252	**Irchel Hochwacht 2019**	Irchel Hochwacht, ZH - 2019 Column 2 / **upper channel**	HOC19upper		AA some	FF some	moderate	few	moderate	O, Acc	stratigraphy, sampling, sample treatment all good	
		2687 150	1266 125		Forenirchel, ZH - Graf 1993						some	fairly abundant	O, probably Acc	stratigraphy, sampling, sample treatment all probably ok? No sieve residue available	
		2687 252	1266 114	**Irchel Amselboden 2021**	Irchel Amselboden, ZH - 2021	IAms21	BT rare	AA few	FF some	moderate	some/moderate	moderate	O, Acc	stratigraphy, sampling, sample treatment all good	
		2688 505	1265 635	**Irchel Steig 2018/2019**	Irchel Steig, ZH - 2018/19	ISt		AA few small frags	FF few small frags	some small frags	some/moderate	moderate /abundant	O, Acc	stratigraphy, sampling, sample treatment all good	analysed samples come from Column 1
		2688 542	1265 628	**Irchel Steig 2020**	Irchel Steig, ZH - 2020	Steig20	BT very rare	AA some a bit weathered	FF few	some a bit weathered	some/moderate	moderate /abundant	O, Acc	stratigraphy, sampling, sample treatment all good	
		2688 950	1265 550	**Irchel Hasli Bräm**	Irchel Hasli, ZH - Bräm 1955	IHB		AA few	FF some	moderate	some/moderate	abundant	O, in principal Acc	old samples (Bräm early 50's), but stratigraphy and sample treatment probably ok; sieving residues were available	
		2688 950	1265 550	**Irchel Hasli 1994/95**	Irchel Hasli, ZH - 1994/95	IHK		AA rare	FF rare	some well preserved	some/moderate	moderate /abundant	O, Acc	stratigraphy, sampling, sample treatment all good; two out of three sieve residues were available	this material represents the upper faunal level of IH 2018 Layer 13
		2688 950	1265 550		Irchel Hasli, ZH - 2017			AA rare	FF rare	few	rare	some	O, Acc	stratigraphy, sampling, sample treatment all good	this material comes mostly from IH 2018 Layer 12
		2688 950	1265 550	**Irchel Hasli 2018/2019**	Irchel Hasli, ZH - 2018/19	IHN		AA few	FF some but a bit weathered	moderate but weathered	some/moderate rather weathered	moderate /abundant	O, Acc	stratigraphy, sampling, sample treatment all good. Graules are ra enad rather small in the upper levels, but large and abundant in the lower layers	all samples come from the upper faunal level, Layer 13
	beneath HDS EP1	2687 005	1267 578	**Irchel Ebni**	Irchel Ebni, ZH - 2017	IEb					moderate but poss. weathered	moderate /abundant	O, Acc	stratigraphy, sampling, sample treatment all good	

🟩	samples selected for the first series of AAR Dating
🟩	samples selected for the second series of AAR Dating
🟦	samples selected for the third series of AAR Dating
🟨	samples that could sill be chosen for AAR Dating
🟨	samples from 2019/2021 that are being processed / yet to be processed
🟦	samples selected for a fourth series of AAR Dating
🟧	samples selected for a possible small fifth series for AAR Dating

Note: we need 3 mollusc samples for every sediment sample

2008, 2011, 2013). They have confirmed stratigraphical and pollen data that place Niederweningen and Zell within the Eemian (cf. Sections 6.2.1, 6.2.3), and attribute Nuolen and Grandson to MIS 7 (cf. Sections 6.1.7, 6.1.8) while Petit Saconnex and WHO probably date from early MIS 6 (cf. Sections 6.1.5, 6.1.6). The material from Montfleury and Sous-Terre is older than first thought, and may date from MIS 11 (cf. Sections 6.1.2 6.1.3), while Ecoteaux is even earlier and might possibly correspond to MIS 15 (cf. Section 6.1.1). Although the analysis of interglacial molluscan material from around Switzerland has been undertaken to help provide ages for the Irchel sites, Albishorn-Bürglen and Hungerbol, the new dates for Ecoteaux, Montfleury, Sous-Terre, Grandson, Nuolen, Petit Saconnex and WHO are of considerable importance for the study of the Quaternary in Switzerland.

The results from the Irchel sites, Albishorn-Bürglen 2 and Hungerbol 1 and 2 have so far proved somewhat difficult to interpret due to the effects of post-depositional weathering on some shell fragments from AA, FF and CH, and problems with post-depositional intrusion for the worm granules (WG). Nevertheless, the data suggests that:

1. The Irchel sites, including the Bräm material, seem to have more or less the same age, supporting the stratigraphic model published by Graf (1993), that Hasli, Steig, Hochwacht and Amselboden all belong to the same unit, the Hasli Formation.
2. For some shell materials it seems that a poor separation between sites (for SP between Irchel Ebni and the Hasli Formation sites, or for BT between Irchel Hochwacht and Hungerbol) might suggest that the AAR Dating method is reaching a limit where it no longer produces significantly greater values with age.
3. Despite problems separating Irchel Ebni from the oldest Hasli Formation samples, the values for SP in some cases respect the stratigraphic order within the HF deposits, with Hoch 13 and 16B (Parts 1c + 2b) being older than Hoch 7 (Part 3) and Hoch 20 (upper channel). Moreover, in spite of the problems with WG due to intrusive elements, it appears that those from the base of Albishorn-Bürglen 2 are somewhat older than most of the granules from the Irchel sites. This is in keeping with their stratigraphic position, as the WG from A-B 2 come from near the base of the sequence while most of those analysed from the HF come from the upper levels of this unit (Part 3), with the exception of those from Hochwacht (Part 2b).
4. Due to problems with the differential availability of shell material (no CH and few SP at Hungerbol) and shell weathering (FF), it has proved difficult to get reliable data to assess the age differences between Hungerbol and the Irchel sites, the exception being the values for AA, where Hungerbol is clearly younger.
5. There are no discernible differences between the values for Hungerbol 2 and Hungerbol 1, which agrees with field observations that there is little stratigraphical separation between the two units (cf. Section 5.8.3).
6. The likely date of MIS 7 for Grandson is notable as this site has a curve with up to 2% of *Pterocarya* pollen, and it has been suggested that this tree species disappeared from Europe after MIS 9, when it was still well represented in travertine deposits at Stuttgart (Ufrecht 2022, p.284-285).

5.8 Conclusions for the dating of the sites from Irchel, Albishorn-Bürglen and Hungerbol

Figure 10 presents both the best estimates for the dating of the various study sites and the representation of the various molluscan biostratigraphical marker species through time.

5.8.1 Dating of the HDS Irchel sites and Albishorn-Bürglen 2

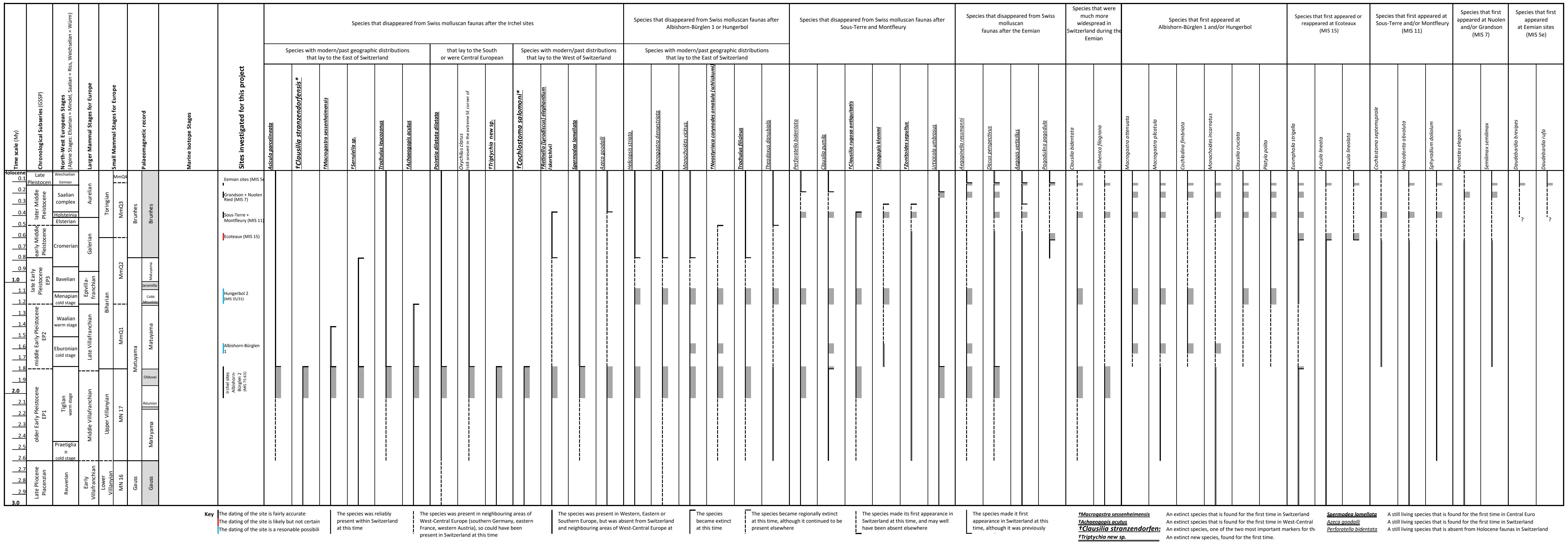
The sequence through the Irchel Plateau begins with the cold climate fluvioglacial Langacher-Schotter, while the finely bedded gravels, sands and silts with calcareous nodules and biological remains that follow at Ebni represent an interglacial (cf. Section 3.1.1). The fluvioglacial gravels of the Irchel-Schotter and succeeding Steig-Schotter indicate even colder conditions, as the thickness and coarseness of these deposits (boulders up to 1.5 m) may suggest that a glacier front was not far away. These two gravel units seem to be separated by a modest palaeosol (Graf 1993, p.39) that may represent an interstadial. The thick flood silts and fine sands rich in biological material of the Hasli Formation, together with the fine sediments of the 'upper channel' at Hochwacht seem to represent a single period of more or less warm interglacial conditions. These are succeeded by the fluvioglacial gravels of the Forenirchel-Schotter, indicating a return to much colder conditions (Graf 1993, p.101-104). Graf (2019, fig.16, p.21-23) has shown that the Höhere Deckenschotter (HDS) in northern Switzerland can be roughly divided into **three sub-units** that reflect the nature and petrographic composition of the deposits (cf. Section 5.1). It seems possible from their stratigraphic position within the Irchel sequence and their petrographic composition, that the Langacher-Schotter and the warm period silts at Irchel Ebni correspond to the first sub-unit, while the Irchel-Schotter, Steig-Schotter and Hasli Formation represent the second sub-unit, and the Forenirchel-Schotter may belong to the third (cf. Section 3.1.1).

Dating evidence for the HDS in northern Switzerland is scarce. The silts at Irchel Ebni, which seem to belong to **the first sub-unit of the HDS**, have a palaeomagnetic signal with normal polarity (Scheidt et al. 2023), which might possibly correspond to the Réunion (Feni) Subchron due to their stratigraphic position below the Hasli Formation.

The flood silts and fine sands of the Hasli Formation (HF) seems to belong to the **second sub-unit of the HDS**. In the profiles studied at Hasli, Steig, Amselboden and Hochwacht, the sediments, molluscan faunas and AAR Dating values are consistently similar, and thus appear to represent a single stratigraphic unit (Tables 5, 6a, 6b). The sites share the same important molluscan biostratigraphic marker species (Figure 3; cf. Section 5.5.1). These include several that have long been extinct, such as *Clausilia stranzendorfensis*, *Cochlostoma salomoni*, *Neostyriaca dehmi* and *Triptychia* sp., which disappeared at the end of the Tiglian c.1.8 My, *Macrogastra sessenheimensis*, which died out between c.1.5 and 1.3 My and *Archaegopis acutus*, which became extinct c.1.2 My (Figures 7, 8 and 10; cf. Section 5.5.1). The East-Central European species *C. stranzendorfensis* and the Western European taxon *C. salomoni* represent two of the most important molluscan biostratigraphical markers for the older Early Pleistocene in Central Europe. Hasli, Amselboden and Hochwacht also share the species association *Cochlostoma salomoni* - *Spermodea lamellata*, which before this study seems only to have been found at three other sites in Central Europe, all dating from EP1. Furthermore, the Irchel faunas include many species with modern or palaeodistributions that lie far from the Swiss Plateau that

Figure 10: Molluscan species representation through time at the various analysed sites

Figure 10: Representation through time of the principal molluscan species at the various analysed sites



have never previously been found in Swiss Quaternary deposits. These include 6 that lived much further to the west and/or south-west, 4 that lived further to the south, 14 that lived far to the east and 3 more that lived to the south-east of Switzerland. These provide a further indication for the notable age of the HF, while showing that the climate is likely to have been considerably warmer than today, with higher summer temperatures and significantly milder winters (cf. Section 3.1.5). The presence of such species throughout the HF, as well as in the fine sediments of the ‘upper channel’ at Hochwacht, indicates that these deposits probably accumulated before c.1.8 My. This is in good agreement with global surface palaeotemperature reconstructions that indicate a significantly warmer climate during the older Early Pleistocene before c.1.8 Ma (Snyder 2016, Fig.1).

The small mammal remains recovered from the upper part of the HF at Hasli (Layers 13 + 12, Table 1; Bolliger et al. 1996, Cuenca-Bescós 2015, Cuenca-Bescós and Urresti pers. comm., Fejfar pers. comm.) include the key biostratigraphic markers *Mimomys reidi/tigliensis, M. pliocaenicus, Clethrionomys kretzoii* and cf. *Villanyia* sp. that all became extinct in Western-Central Europe around 1.8 My, placing this fauna firmly within biozone MN17 of the European small mammal chronology. Furthermore, the presence of *Pliomys episcopalis/simplicior* implies that this assemblage dates from the upper part of MN17, as it first appeared in Central Europe during the Olduvai Subchron after 1.934 My, being also found at Uhlenberg (Maul and Markova 2007). The small mammals thus suggest a date between c.1.93 and 1.78 My for the upper part of the Hasli Formation.

The presence of *Fagus* (beech) pollen at Hochwacht and Hasli is also important (K. Bieri in Graf 1993, p.46; Thew et al. 2024), although the grains at the former site may largely derive from contamination during sampling. Pollen from this tree was relatively well represented during the Tiglian, but became rare during the remainder of the Early Pleistocene (Bludau 1995, Hahne et al. 2008), again suggesting that the HF probably dates from before c.1.8 My. Pollen from a layer of flood silts and fine sands at Tromsberg, AG, Dürn-Gländ, around 2 km to the west of the silts from a similar stratigraphic position with oldest Early Pleistocene molluscs at Freienwil, AG (cf. Section 3.5), includes *Carpinus*, ***Fagus*** and *Pinus*, with lesser frequencies of *Alnus*, *Betula* and *Corylus* (Knipping pers. comm.), similar to the pollen from the middle part of the HF at Hasli (Thew et al. 2024).

Finally, the palaeomagnetic data from the HF gives a distinct signal for reversed polarity in the lower part of this unit at Hochwacht and possibly Hasli and a clear signal for normal polarity in its upper levels at both sites (Graf 1993, p.44-45, Scheidt et al. 2023). This change appears to occur during Part 3 of the HF at Hasli, below the level with the small mammal remains. Given the evidence for the antiquity of the biological data, this switch in polarity should correspond to the start of the Olduvai Subchron that is dated to 1.934 My, while the end of the Olduvai is at 1.775 My (Raffi et al. 2020, Cohen and Gibbard 2022). Similarly, the up to 1.2 m of silty-sands and silts with calcareous nodules in the lower part of the Egg Plateau sequence at Egghalden, ZH, which seem to be in a similar stratigraphic position to the silts of the HF (Graf 2019, fig.16), also have a palaeomagnetic signal with reversed polarity (Graf 1993, p.50-66, Scheidt et al. 2023). By contrast, the up to 1.3 m of silts and sands with calcareous nodules at Roggenfeld, from the Mandach Plateau, AG, which might possibly correlate with the HF, produced a signal with normal polarity (Graf 1993, p.94-97; Scheidt et al. 2023).

The deposits of the 'upper channel' that succeed the HF at Hochwacht have very similar molluscan faunas and appear to belong to the same biostratigraphic and chrono-stratigraphic period as the HF, although slightly younger (Figure 3; cf. Section 3.1.7). The HF together with the deposits of the upper channel, seem therefore to date from between c.2.1/2.0 and c.1.8 My. In the MIS curve this period represents MIS 75 to 63, from 2.04 to 1.76 My, as before MIS 75 the climate was notably cooler and after MIS 63 the climate again became much colder. The upper levels at Hasli with the small mammal remains might therefore date between 1.934/925 and some time before 1.76 My.

It seems likely that the fluvial gravels associated with warm interglacial molluscs at Albishorn-Bürglen 2 (the Albisboden-Schotter) are of similar age to the HF, as their molluscan faunas include the same marker species (*Acicula parcelineata*, *Archaegopis acutus*, *Clausilia stranzendorfensis*, *Cochlostoma salomoni*, *Macrogastra sessenheimensis*, *Poiretia dilatata dilatata*, *Retinella* (*Lyrodiscus*) *elephantium*, *Trochulus filicinus* and *Trochulus leucozonus*; Figures 3, 7, 8, 10) and they have a comparable stratigraphic position within the HDS complex (cf. Section 3.3.1). The lower part of these gravels also has reversed palaeomagnetic polarity like the lower half of the HF (Graf 2019, p.9-10). Up to 1.4 m of flood silts with calcareous nodules in the upper part of the sequence at Roggenfeld, Mandach Plateau, AG, in a comparable stratigraphic position to the HF, have a palaeomagnetic signal with normal polarity (Graf 1993, p.88-98) like the upper levels of the HF, while pollen from the silts at Roggenfeld include *Abies*, *Picea* and *Pinus*, similar to Part 3 of the HF at Hasli (cf. Section 3.1.3).

As the Hasli Formation and the deposits of the 'upper channel' appear to have accumulated during an interval of mainly warm interglacial conditions between 2.04 and 1.76 My, while the thick fluvioglacial gravels that preceded the HF represent truly cold conditions, it seems plausible to correlate the accumulation of the Irchel-Schotter and the Steig-Schotter with MIS 78-76 in the MIS curve, which dates from 2.09 to 2.04 My. This cold interval had significantly higher $\delta^{18}O$ values and lasted for longer than any other such period during the second half of EP1, while there is strong evidence across Europe for glacial activity at this time (cf. Section 5.3). If true, then the modest palaeosol between these two gravels noted by Graf may correspond to the interstadial episode MIS 77.

Before the cold period represented by the Irchel and Steig gravels, there was an interval of warm interglacial conditions during MIS 81-79, from c.2.145 to 2.09 My, that includes the Feni (Réunion) Subchron of normal polarity from 2.155 to 2.120 (Raffi et al. 2020), in accord with the palaeomagnetic normal polarity of the Ebni silts.

Preceding this warm interval, there was an earlier cold period with notably higher $\delta^{18}O$ values during MIS 82, which although somewhat shorter, from 2.17 to 2.145 My, was nevertheless associated with significant evidence for glacial activity across Europe (cf. Section 5.3). It is this interval that may correspond to the Langacher-Schotter.

This approach of comparing sequences with cold and warm climate deposits with cycles in the MIS curve has already been attempted for northern Switzerland by Kuhlemann and Rahn (2013), who correlated the first phases of HDS deposition in northern Switzerland with MIS 100, 96 and 82 rather than MIS 82 and 78-76, and attributed the Hasli Formation to MIS 81-79, rather than to MIS 75-63, as concluded here. They lacked the biostratigraphical dating evidence for the Irchel deposits that is presented here, however, so despite the differences in the final conclusions, the MIS curve is of obvious importance for an understanding of Pleistocene terrestrial deposits in Western-Central Europe.

5.8.2 Dating of the HDS site of Albishorn-Bürglen 1

The interglacial floodplain silts that constitute Albishorn-Bürglen 1 lie within the upper part of a HDS terrace, separated from the underlying fluvial gravels of Albishorn-Bürglen 2 by 2-6 m of fluvioglacial gravels with large boulders, followed by 9-12 m of compact basal moraine (Bürglen Till). The silts are in turn overlain by 24-30 m of largely cemented fluvioglacial gravels with intercalated layers of glacial till (Albiswald Schotter-Till; cf. Section 3.3.2; Graf 2019, p.8-11). This sequence implies an important stratigraphic break, after the warm period represented by the thick gravels of Albishorn-Bürglen 2, when a major advance by the Linth-Rhine Glacier led to the formation of the fluvioglacial gravels and Bürglen Till. Then, after an interglacial period represented by the silts of Albishorn-Bürglen 1, a second glacial advance led to the deposition of the Albiswald Schotter-Till. The Albishorn-Bürglen 2 gravels seem to represent the **first** and **second sub-units of the HDS in northern Switzerland**, as outlined in Graf 2019 (fig.16, p.21-23; cf. Section 5.1), which date from EP1 (Section 5.8.1), while Graf has attributed all of the succeeding deposits, including the Albishorn-Bürglen 1 silts, to the **third sub-unit of the HDS**. As there appears to be no evidence in any of the HDS sequences across northern Switzerland for a prolonged gap between the second and third sub-units of the HDS, it seems possible that the two glacial periods and the intervening Albishorn-Bürglen 1 interglacial may correspond to EP2, between 1.8 and 1.2 My.

The molluscan assemblages within the Albishorn-Bürglen 1 silts include a number of warm stenotherm species, showing that these silts represent a second interglacial period within the HDS sequence at this site. Even so, they are significantly different from the faunas of Albishorn-Bürglen 2 and the Irchel sites, as all of the most important biostratigraphical marker species for EP1 have disappeared and only a few Early Pleistocene marker taxa continue to be present, while there are four new marker species that were commonly present among Swiss interglacial molluscan faunas from then onwards (Figures 3, 8, 10; cf. Section 3.3.2). Furthermore, all of the species with modern or palaeo-distributions that lay far to the west or to the south have also disappeared, as well as most of those with distributions that lay far to the east, probably due to a period of much colder conditions after the period represented by Albishorn-Bürglen 2 and the Irchel sites. This evidence suggests that the molluscan faunas of Albishorn-Bürglen 1 are probably post-Tiglian, and may correspond to EP2 or EP3. As the faunas are nevertheless younger than those from Hungerbol 2 that seem to belong to EP3 (cf. Section 5.8.3), this rather suggests that A-B 1 may well date from EP2.

A pollen sequence through the Albishorn-Bürglen 1 silts at the same location seems to represent a single warm interglacial period. Importantly, there is no sign of *Fagus* among the suite of thermophile tree species despite thousands of pollen grains being counted (Knipping pers. comm.). *Fagus* pollen is rather common in EP1 contexts, but is rare in deposits dating from EP2 and EP3 (Bludau 1995, Hahne et al. 2008). As *Fagus* seems to have been found in the Hasli Formation at Hasli and possibly Hochwacht, this provides another strong indication that the Albishorn-Bürglen 1 silts are significantly younger than the deposits at Irchel and Albishorn-Bürglen 2 and come from a different biostratigraphic period, which may be EP2 or EP3.

The Albishorn-Bürglen 1 silts have a weak palaeomagnetic signal for normal polarity that seems to result from pedogenetically-induced chemical remnant magnetisation (cf. Graf 2019, p.10-11, Scheidt et al. 2023). At Boppelsen, the up to 2.6 m of bedded silts, sands and gravels with calcareous nodules at Cholholz produced a signal with normal polarity, as did 2.1 m of bedded silts and sands c.7 m lower in the sequence (Scheidt et al. 2023) that may correspond to the 1.1 m of bedded sands that Graf documented at Boppelsen and Riese (1993, p.66-71). By contrast, c.0.8 m of silts and fine sands with calcareous nodules at the Uetliberg, ZH, from a comparable stratigraphic position within the third sub-unit of the HDS, have a clear signal for reversed polarity that corresponds to the Matuyama Chron after 1.79/77 My (Graf 2019, p.11-16, Scheidt et al. 2023). As the five short intervals with normal polarity between 1.78 and 1.1 My all correspond to colder periods (MIS 54, 48, 38, 36 and 34; cf. Ogg 2020), a reversed signal may be more credible.

Around 1.76 My there was a notable cooling that marks the transition from the Tiglian warm stage to the Eburonian cold stage in the North-West European Chronology. This major change took place just after the end of the Olduvai Subchron (at 1.78 My) and denotes the transition from the older Early Pleistocene (EP1) to the middle Early Pleistocene (EP2). The cooling is marked by a significant increase in mean δ^{18}O values in the MIS curve (at the start of MIS 62) and coincides with important faunal changes in both terrestrial and oceanic sequences across the Northern Hemisphere (Cohen and Gibbard 2022) that mark the transition from the Gelasian to the Calabrian Stage. These include the extinction of several key marker species at the Villanyian/Biharian transition (zones MN17/MmQ1) in the European small mammal chronology, as well as the loss of a number of molluscan biostratigraphic markers.

The middle Early Pleistocene (EP2) incorporates two stages in the North-West European Chronology: the Eburonian cold stage, from 1.76-1.49 My, and the Waalian warm stage from 1.49-1.22 My (Westerhoff et al. 2020, fig.1). The periods during EP2 with the clearest evidence for significant glacial activity in lowland Europe seem to have been MIS 58 (1.67-1.64 My), MIS 52 (1.545-1.525 My) and MIS 50 (1.51-1.49 My; cf. Section 5.3), all of which lie within the Eburonian, while the Waalian has only modest signs of glacial activity during MIS 46. This suggests that the glaciogenic deposits that envelope the silts of Albishorn-Bürglen 1 may date from the Eburonian. Of the Eburonian cold periods, the MIS curve suggests that MIS 58 lasted for somewhat longer, MIS 52 was slightly colder, while MIS 50 had a similar climate to MIS 58 but came after a warmer interval (MIS 51) that was both the briefest and least temperate of EP2. If the first glacial advance that deposited the fluvioglacial boulder layer and the Bürglen Till may possibly correspond to MIS 58, then the later advance that led to the Albiswald Schotter-Till complex might perhaps represent MIS 52-50. Such correlations are plausible as both glacial advances imply considerably colder conditions, and these were the two coldest periods during EP2. If these suggested correlations for the glacial deposits are valid, then the interglacial silts of Albishorn-Bürglen 1 might perhaps represent MIS 57-55, or possibly MIS 57-53 between 1.64 and 1.545 My. The MIS curve suggests that MIS 57-55 was the longest and warmest interglacial period during EP2, making it a credible candidate for the interglacial silts, while MIS 53 was one of the shortest. If the silts at Albishorn-Bürglen 1 do indeed date from EP2, this would make them the first deposit with biological material from this period known in Switzerland.

An age between 1.67 and 1.49 My for the third sub-unit of the HDS in northern Switzerland would be in line with a proposed Eburonian age for the Ältere Deckenschotter in Baden-Württemberg (cf. Doppler et al. 2011, Tab. 3). The age correlations suggested above would also be in accord with the climato-stratigraphic sequence constructed for The Netherlands, which shows two notable cold periods separated by an interglacial during the later part of the Eburonian, followed by significantly warmer conditions during the Waalian (Westerhoff et al. 2020, fig.1).

5.8.3 Dating of the TDS sites of Hungerbol 2 and Hungerbol 1

The silts of Hungerbol 2 lie near the base of a TDS terrace, and both these flood silts and the underlying finely bedded sandy gravels seem to have been deposited by a fairly large lowland meandering river with a sand and gravel bed, bordered by a forested floodplain, during an interglacial period with similar temperatures to today (cf. Sections 4.1.2, 4.1.3). After a hiatus that coincides with a gravel layer, the flood silts of Hungerbol 1 appear to have accumulated during an interstadial early on in the succeeding cold period. There followed up to 3 m of slope deposits linked with a colder climate, succeeded by up to 5.5 m of fluvioglacial *Bannholz-Schotter* capped by a thin layer of glacial diamict, suggesting full glacial conditions.

The molluscan faunas from Hungerbol 2 still appear to belong within the Early Pleistocene, due to the continued presence of eastern species like *Macrogastra densestriata*, *Monachoides vicinus* and *Trochulus filicinus* and an absence of Middle Pleistocene marker taxa like *Helicodonta obvoluta*. The faunas are similar to those of Albishorn-Bürglen 1, but include two new biostratigraphic markers that subsequently became regular elements in Swiss interglacial molluscan faunas (Figures 8, 10, cf. Section 4.1.4). The evidence suggests that Hungerbol 2 probably dates from EP2 or EP3. AAR Dating shows that *Bithynia* opercula from Hungerbol 2 are much older than those from Ecoteaux that seem to date from the early Middle Pleistocene, while shells from *Arianta arbustorum* are clearly younger than those from the Irchel sites (cf. Section 5.7). The small mammal remains recovered from the silts of Hungerbol 2 are restricted to two unidentified species of rootless Lagurid (Fejfar pers. comm.), which are fairly likely to have been *Lagurus arankae* and *Prolagurus pannonicus* (cf. Section 4.1.4). If correct, this would suggest a date between 1.8/1.7 and 1.1/1.0 My, spanning EP2 and the first part of EP3.

The reference site for the TDS in northern Switzerland is Iberig, AG (Preusser et al. 2011, p.286-287). After an episode of deep incision caused by glacial scouring, the *Wolfacher-Till* was succeeded by the fluvioglacial *Wolfacher-Schotter*, although a similar clast petrography shows that they represent a single glacial period (Graf 2009b). A well-developed palaeosol at the surface of the gravels then formed during a warm interglacial. After moderate incision came the fluvioglacial *Iberig-Schotter* (that was analysed for this study; cf. Section 4.2), which has a different clast petrography. These gravels were succeeded by c.8 m of alluvial silts and fine sands with molluscs and plant remains typical of a warm period, which were capped by a well-developed palaeosol. Further moderate glacial incision was followed by the *Bärensgraben-Till* and the fluvioglacial *Bärensgraben-Schotter*, which represent a single glaciation due to a similar clast petrography (Graf 2009b). The sequence thus shows evidence of a significant glacier advance linked with deep incision during a much colder period, then a warm interglacial (the palaeosol), then another glacial period with a less advanced ice front, then a second possibly more prolonged interval of warm climate (the silts plus palaeosol), and finally a third very cold glacial period accompanied by another notable glacier advance.

In addition to Hungerbol, Graf (2009a, p.19-25, 34-37) has documented several other TDS profiles at the Schiener Berg (D), which lies c.50 km ENE of Iberig. At the base of the sequence, are several channels eroded into the Molasse with remains of probable glaciogenic deposits in places. At Hungerbol the base of one such channel has interglacial fluvial gravels, sands and silts, which are covered by the fluvioglacial *Bannholz-Schotter*. Nearby, the Bannholz-Schotter reaches up to 15 m thick and includes bands of glacial diamict, striated clasts and large boulders, indicating that a glacier front lay close by. At the Schrotzburg, c.2.5 km NE of Hungerbol, up to 30 m of coarse fluvioglacial *Bohlingen-Schotter*, which seems to be contemporary with the Bannholz-Schotter, is succeeded in the Bohlinger Gorge by 0.7 m of bedded fluvial gravels, then 0.8 m of silts/sands with calcareous nodules capped by a well-developed palaeosol. These are followed by up to 50 m of *Schrotzburg-Till*, then c.15 m of fluvioglacial *Schrotzburg-Schotter*, which represent a single glacial period. The Schiener Berg sequence thus includes erosional channels with probable glaciogenic sediments, then interglacial fluvial sediments at Hungerbol, then glaciogenic deposits linked with a nearby ice front, then probable warm period alluvial sediments capped by a palaeosol, and finally by thick glacial deposits formed by a major glacier advance. Around 3 km W of Hungerbol the fluvioglacial *Wolkensteinerberg-Schotter* (p.39-40), formed at a somewhat lower level after moderate incision, represents the *TDS unteres Niveau*, the final phase of the TDS complex.

Unfortunately, there is little dating evidence available for the TDS complexes of northern Switzerland and southern Germany. A sand lens near the summit of TDS gravels at Allschwil, BL, has reversed palaeomagnetic polarity (Zollinger 1991), so may date from EP2 or EP3. At Lichtenegg/Höchsten, north of the Bodensee, glaciogenic sediments with reversed polarity are succeeded by sands capped by a thick interglacial palaeosol, then by basal till and gravels deposited by the Rhine Glacier, and finally by thick *Jüngere Deckenschotter* gravels, all of which seem to date from EP3 (cf. Section 5.1). At Unterpfauzenwald near Steinental, *Tiefere-Ältere Deckenschotter* gravels that appear to date from the first part of EP3 are capped by a well-developed interglacial palaeosol, and then by two units of glacial till from the Rhine Glacier that are separated by interglacial peaty deposits pollen-dated to EP3 (the Bavelian; cf. Section 5.1). There is thus evidence from several locations in this area for significant glacial activity during EP3.

The available evidence suggests that both the episodes of incision at the start of the TDS at sites like Iberig and the Schiener Berg and the deposits that make up much of the TDS complex may well have been formed by glacial activity (cf. Section 5.2). This is unlikely to have occurred during the relative stability of the Waalian warm stage, the second part of EP2, as there is little evidence for glacial activity during this period across lowland Europe (cf. Section 5.3). By contrast, the start of EP3 marks the beginning of the Menapian cold stage in the North-Western European Chronology. It also coincided with the start of the longer more intense 100k climate cycles that characterise the Middle to Late Pleistocene, which led to much more significant glacial activity across the Northern Hemisphere. Indeed, during EP3 there seem to have been up to four periods with notable glacial activity in North-Western, Northern and Central Europe (cf. Section 5.3). The available biostratigraphic and stratigraphic evidence thus suggests that it is likely that the

TDS deposits in northern Switzerland and southern Germany date from EP3, the final phase of the Early Pleistocene.

In the MIS curve the start of EP3 coincides with MIS 36, which had the highest $\delta^{18}O$ values since the start of the Pleistocene but only lasted for 25k years (1.22-1.195 My), so may only have seen fairly localised glacial activity. By contrast MIS 34-32 had even higher $\delta^{18}O$ values and lasted for 55k years (1.145-1.09 My), which explains why it seems to have been the period with the most intense glacial activity since the start of the Pleistocene (cf. Section 5.3; Head and Gibbard 2015). MIS 30, saw a further increase in $\delta^{18}O$ values and lasted for 30k years (1.065-1.035 My), so may also have had rather significant glacial activity. MIS 24-22 (0.935-0.865 My) has been called the '*0.9 My super-cooling event*' (Head and Gibbard 2015, p.31-32), because high $\delta^{18}O$ values over a 70k period coincided with glacial advances across much of Europe (cf. Section 5.3). MIS 20 had even higher $\delta^{18}O$ values than previously but lasted for just 25k years (0.815-0.79 My), so seems only to have had significant glacial activity near mountainous areas (cf. Section 5.3). For the warm periods, MIS 35 seems to have been only moderately warm, but by contrast MIS 31 has been called a 'super-interglacial' and may have been much warmer (1.09-1.065 My). MIS 29-25 (1.035-0.935 My) was an interval of mostly warm climate that lasted for 100k years, although there were three brief episodes with cooler conditions (MIS 28b, 28a and MIS 26). MIS 21 was a warm interglacial period lasting 50k years (0.865-0.815 My) that marks the start of the Cromerian Complex in the North-West European Chronology. In the climato-stratigraphic sequence constructed for The Netherlands there is evidence for four periods of glacial activity during EP3, which have been correlated with MIS 34-32, MIS 30, MIS 24-22 and MIS 20. These are interrupted by the Bavel Interglacial (MIS 31), the Leerdam Interglacial (MIS 29-25) and Cromerian Interglacial I (MIS 21; cf. Section 5.3; Westerhoff et al. 2020, fig.1).

The three glacial units in the TDS sequence at Iberig, the Wolfacher-Till/Wolfacher-Schotter, Iberig-Schotter and Bärensgraben-Till/Bärensgraben-Schotter, may plausibly represent the three cold periods associated with the most significant glacial activity in Central Europe during EP3: MIS 34-32, MIS 30 and MIS 24-22 (Head and Gibbard 2015). This would give a total time window for the TDS till and fluvioglacial gravel units between 1.145 and 0.865 My, extended to 0.79 My if the TDS unteres Niveau is included that may correspond to MIS 20. If correct, this would also imply that the well-developed warm period palaeosol at Iberig correlates with MIS 31, while the 8 m of interglacial alluvial silts capped by a palaeosol would represent MIS 29-25. Palaeomagnetic data from sterile silty-sands within the *Iberig-Schotter* (also sampled for molluscs; cf. Section 4.2) shows normal polarity (Scheidt et al. 2023), suggesting that these fluvioglacial gravels may correspond to MIS 30 during the early part of the Jaramillo Subchron (1.076-1.008 Ma; Raffi et al. 2020, Cohen and Gibbard 2022), while supporting the correlations for the TDS proposed above. Normal polarities for sandy levels within the lowest TDS gravel units at Ängi, Mandach (AG), at Bruggerberg (AG) and at Cholfirst (ZH; Scheidt et al. 2023), may indicate that these gravels also correspond to MIS 30.

At the Schiener Berg, the glacial deposits of the Schrotzburg-Till/Schrotzburg-Schotter may well correlate with MIS 24-22, the '0.9 My super-cooling event,' due to their impressive thickness, while the fluvioglacial Wolkensteinerberg-Schotter of the TDS unteres Niveau might correspond to MIS 20. This would imply that the Bannholz-Schotter/Bohlingen-Schotter may represent MIS 34-32 or MIS 30. The warm period gravels, sands, silts and palaeosol of the Bohlinger Gorge may therefore represent either MIS 31 or MIS 29-25, the interglacial silts of Hungerbol 2 might correspond to MIS 35 (1.195-1.145 My) or MIS 31 (1.09-1.065 My), and the interstadial silts of Hungerbol 1 may correlate with early MIS 34 or early MIS 30. This would give a total time window for Hungerbol 2 between 1.195 and 1.065 My. The small mammal remains from Hungerbol 2 argue for an age before 1.1/1.0 My (see above), meaning that both MIS 35 and MIS 31 are plausible. Palaeomagnetic data from the silty-sands of Hungerbol 2 and Hungerbol 1 shows normal polarity for both levels, although the signal is patchy (Scheidt et al. 2023). The only example from the later Early Pleistocene for a warm period with normal polarity being succeeded by a cold period with normal polarity is the second part of MIS 31 followed by MIS 30 (cf. Cohen and Gibbard 2022), meaning that the interglacial deposits of Hungerbol 2 might represent MIS 31, while the interstadial sandy-silts of Hungerbol 1 may correspond to early MIS 30. The fluvioglacial gravels of the Bannholz-Schotter/Bohlingen-Schotter would then represent MIS 30, as this cold period correlates with the first part of the Jaramillo Subchron (1.076-1.008 Ma), while the warm period deposits and palaeosol of the Bohlinger Gorge might then correspond to MIS 29-25, and initial incision and the earliest glaciogenic deposits may equate to MIS 34-32, like at Iberig.

Additional evidence for more intense glacial activity in Switzerland during EP3 includes a sharp rise in the rate of glacial incision in the Rhône Valley between Visp and Martigny (VS) after c.1.0 My (Valla et al. 2011), and a ten-fold acceleration in the rate of glacial deepening in the Aare Valley near Interlaken (BE) after 1.0/0.8 My (Häuselmann et al. 2007b). A glacial advance seems to have reached Ecoteaux (VD) during EP3, forming glacial till and glaciolacustrine silts with reversed polarity (Pugin et al. 1993; cf. Section 6.1.1). In a review of Swiss Deckenschotter deposits that also used the MIS curve to estimate the ages of morphostratigraphic units, Kuhlemann and Rahn (2013), similarly concluded that the TDS probably dates from between MIS 36 and 24.

5.8.4 [redacted]

[redacted]

[redacted]

[redacted]

Figure 11: [redacted]

[redacted]

[redacted]

[redacted]

[redacted]

6 Molluscan faunas from Middle to Late Pleistocene and Holocene sites in the Swiss Plateau

The molluscan faunas from Middle to Late Pleistocene and Holocene sites presented below includes material loaned for this study, as well as from several other sites that have been previously studied by the author and new sites sampled by Daniel Kälin.

6.1 Middle Pleistocene sites

6.1.1 **Ecoteaux, VD** (Location A: 2556 360/1155 050; c.778 m asl; Location B: 2555 370/1154 680; 694 m asl)

The molluscs come from surface exposures within a fault-bounded palaeo-lake basin c.3.3 x 2.5 km that has been delineated by surface mapping and seismic profiling, while pollen, palaeomagnetic and calcimetric analyses were undertaken on a core extracted near the centre of the basin (2555 840/1154 130; 729 m asl; Pugin and Rossetti 1992, Pugin et al. 1993, Weidmann 1993, Wildi 2020). At the base of the core, overlying the glacially striated surface of the Lower Freshwater Molasse, is a *Lower Formation* of 2 m of basal till overlain by 14 m of glaciolacustrine varved clay-silts/fine sands with drop stones, then 12 m of late glacial laminated silts and fine sands, both of which have reversed palaeomagnetic polarity so date from the Early Pleistocene. These are followed by Middle Pleistocene sediments of the *Upper Formation*, which have normal polarity (Brunhes Chron). They begin with 1.5 m of glacial till, followed by 13.5 m of glaciolacustrine silty-sands with drop stones, then 1.0 m of late glacial silty-sands with some gravel. Above this are 11.5 m of dark grey/grey laminated sandy-silts with organic bands and wood pieces (Unit 7), followed by 5.5 m of grey silty-sands with organic bands and some wood pieces (Unit 8), with some gravel in the lower 1.3 m, followed after another unconformity by 10 m of LGM gravelly moraine, then basal till. The molluscs were sampled from near the base of the lacustrine sediments at two nearby surface exposures by M. Weidmann in 1990, with the silty and marly nature of the sediments confirming their correlation with the lower 4 m of Unit 7 in the core sequence. A new sample taken in silty-sandy sediments by G. Deplazes in 2019, came from a bit higher up in Unit 7.

Pollen shows that the lacustrine sediments of Units 7 and 8 correspond to two separate interglacials, as the upper 3 m of Unit 7 and the lower 1.3 m of Unit 8 (with gravel) show a notable increase in herbaceous plants, indicative of a colder interval between these two warm periods (Bezat, in Pugin et al. 1993). Nevertheless, the continuation of modest frequencies of *Abies, Alnus, Corylus*, *Quercus* and *Taxus* suggests that conditions were never truly cold. Importantly, the earlier interglacial has a curve with up to 2% of *Carya*, which became rare in most of Europe after the Early Pleistocene and disappeared from all but SE Europe after the Cromerian (Hahne et al. 2008, 2012, Orain et al. 2013, Combourieu-Nebout et al. 2015, Magri et al. 2017), indicating that both interglacials probably correspond to the early Middle Pleistocene, as postulated by Schlüchter et al. (2021). Both warm periods also have low frequencies of *Pterocarya*.

The molluscs come from the lower part of the earlier of the two interglacials. Three samples first scanned by F. Burri have now been completely analysed, together with four newly processed samples. The faunas include several terrestrial and aquatic species typical of interglacials (Table 11), in accord with the pollen. These include the bivalve *Pisidium clessini* (Appendix 2), which finally became extinct in Western Europe after MIS 7, but may have disappeared from Central Europe after MIS 15-13. *Pagodulina pagodula*, *Acicula lineata* and *Acicula lineolata* seem to have first appeared in Central Europe during the early Middle Pleistocene, but aside from Ecoteaux have only been found at Eemian sites in Switzerland, with *A. lineolata* being found just at Zell (cf. Section 6.2.3). *Euomphalia strigella* makes one of its earliest appearances in Switzerland (cf. Section 5.5.2). The absence of terrestrial Group 1 species may suggest that the molluscan faunas represent the earlier to middle part of a warm period. Also of note is the presence of the open ground snail *Vallonia declivis*, which has never previously been found in Quaternary sediments in Switzerland.

AAR dating on *Bithynia tentaculata* opercula (BT) shows that they are considerably older than those from Montfleury and Sous-Terre that may date from MIS 11, but significantly younger than those from Hungerbol, which seem to be late Early Pleistocene (cf. Section 5.7; Figure 9; Penkman et al. 2024). This suggests an age from the early Middle Pleistocene, in agreement with the pollen evidence. Moreover, in the MIS curve the most suitable match during the early Middle Pleistocene for two interglacials separated by a moderately cold period are MIS 15 to 13. As the molluscs come from the earlier of the two warm periods, this would imply that they may well correspond to MIS 15. If correct, this could suggest that the underlying glacial deposits with normal polarity might correspond to MIS 16, while the lowest glacial sediments with reversed polarity may represent a significant glaciation during EP3, of which the most likely is MIS 24-22.

The faunas from Unit 7 in Location A (Table 11) indicate that accumulation took place in shallow, rather calm water near the edge of a lake that was bordered by dense marsh vegetation. The presence of the moving water species *Pisidium subtruncatum* shows that a stream entered the lake nearby, as in smaller lakes it is normally only found near where water is inflowing. The lake became notably shallower between the two samples, while the aquatic vegetation and that of the marshy fringe became much richer. The molluscs from Location B are similar, but seem to have accumulated in somewhat deeper water. Of note is the additional presence in one sample of the moving water taxa, *Pisidium clessini*, *P. henslowanum* and *P. moitessierianum*, typical of large lowland rivers and larger lakes with wave action, as well as *P. lilljeborgii*, which in lowland situations in Central Europe today is confined to larger lakes. This suggests that the basin may have been somewhat larger than thought up until now, as in Switzerland the smallest lakes in which *P. moitessierianum* can be found today are the Greifensee (6.5 x 1.6 km; up to 32 m deep) and the Sarnersee (6 x 1.8 km; up to 52 m deep; Turner et al. 1998). The lake became notably shallower in Sample 6, as the aquatic flora and that of the marshy fringe became very rich. In Sample 7 very shallow, marshy conditions with seasonal drying out meant that no shells were preserved. At both locations, behind the marshy edge of the lake was an area of damp ground dominated by tall herbs, as well as patches of more open ground with low herbaceous vegetation, and beyond this was fairly open mixed woodland that seems to have become more diverse and deciduous in the upper samples.

6.1.2 **Sous-Terre, Geneva, GE** (2499 175/1117 750; c.378 m asl)

This site was sampled in 1967 by A. Jayet during work to reinforce the right bank of the Rhône (Jayet and Amberger 1969). The stratigraphy was compiled from field logs and boreholes. The base of the sequence consisted of up to 35 m of compact basal till with striated Alpine clasts, which lay directly on top of the Lower Freshwater Molasse. This was succeeded by 1 to 2 m of darkish grey diffusely laminated sandy-silts with organic material including wood, needles and seeds, frequent mollusc shells and some stones up to 5 cm, with a thin layer of laminated sandy lignite with shell fragments at its summit. Above this was 1.5 to 4 m of very compact laminated blue-grey silts oxidised to yellow-grey at their summit. These were covered by 4 to 4.5 m of compact and partially cemented fluvioglacial gravels, known as the '*Alluvion ancienne*', which nearby were up to 25 m thick (cf. Moscariello et al. 1998). After a hiatus came 0.5 to 1 m of compact LGM basal till with striated Alpine clasts, which nearby was up to 10 m thick. Above a clear unconformity was 0.7 m of grey marly silty-sands with stones and mollusc shells (the 'upper level' at this site; cf. Section 6.4.1), capped by 1 m of brown tufaceous sandy-silts with molluscs and small tile fragments (Roman?) and then a modern soil.

The molluscan assemblage comes from the grey sandy-silts with organic remains. Pollen data (A. Hofmann-Grobéty in Jayet and Amberger 1969; Girard 1970; Reynaud 1982, p.29-31) shows mixed coniferous-deciduous woodland, with thermophiles such as *Abies*, *Buxus*, *Carpinus*, *Corylus*, *Quercus*, *Taxus*, *Tilia* and *Ulmus*, but with no *Fagus* or *Pterocarya*, or from genera of trees and bushes that disappeared after the early Middle Pleistocene. The organic remains include needles and seeds from dominant *Picea*, together with some *Abies*, *Prunus*, *Quercus*, *Rubus*, *Sambucus*, *Taxus* and *Carex* (identified by NT), in good agreement with the pollen data.

A first analysis of the molluscs was undertaken by Jayet, but this exceptional material has been completely re-examined, including numerous unstudied shell fragments. Over 5 kg of sample sediment has also been newly processed in order to recover smaller species that may have been underrepresented in the existing material. The fauna (Table 12) includes a suite of interglacial species that are commonly present in Middle and Late Pleistocene and Holocene faunas. There are also several important biostratigraphical markers, including the extinct *Aegopis klemmi* (D: largest specimen 28 mm), *Clausilia rugosa antiquitatis* and *Zonitoides sepultus*, as well as *Clausilia pumila*, which subsequently vanished from Swiss faunas, plus *Aegopis vorticillus* and *Discus perspectivus* that have been absent from Swiss faunas since the Eemian, and *Ruthenica filograna* that disappeared from most of Switzerland after the Eemian (Figures 8 and 10; Appendix 2; cf. Section 5.5). The assemblage also has the earliest known shells of *Cochlostoma septemspirale* found in Switzerland.

Neither of the extinct species *Aegopis klemmi* and *Zonitoides sepultus* has ever previously been found in Switzerland, although the former has also been recorded from Hungerbol. Both seem to have disappeared from western and central European faunas after MIS 9 (cf. Section 5.5.3). *Clausilia rugosa antiquitatis* has also never previously been found in Switzerland, apart from its discovery at the Irchel sites, Albishorn-Bürglen 2, Hungerbol and Ecoteaux during this study. The latest records for this subspecies until now are from strata dating from MIS 11 in deep cores in the Upper Rhine Graben at Ludwigshafen and Mannheim/Lindenhof (cf. Section 5.5.1). This implies that the shells of *C. rugosa antiquitatis* from Sous-Terre are among the youngest known, and strengthening evidence for the antiquity of this site.

The rich assemblage is dominated by molluscs from terrestrial species (97.7%), which indicate fairly damp, dense largely deciduous woodland with many mature trees and a rich undergrowth of tall herbs and young trees (Table 12). The small component of aquatic molluscs (2.3%) includes a fairly high proportion of bivalves, suggesting that the shells were deposited by seasonal flow at the sheltered marshy margin of a large, slow-moving meandering river. The terrestrial molluscs would have been washed in by either surface run-off or retreating seasonal floodwaters.

Some 1.2 kg of the laminated blue-grey silts were also sieved. There are only rare shell fragments from just 4 species, together with wood pieces and needles from *Picea*. There seems to have been a significant change in the sedimentary context, with channel margin deposits being replaced by overbank flood silts, while the local environment saw the rather dense mixed deciduous-coniferous woodland be replaced by more open coniferous forest. A pollen sample from these silts had abundant *Picea* and *Pinus*, together with redeposited grains of *Corylus* and *Tilia* (Reynaud 1982, p.29). These changes suggest a significant climatic cooling, which seems to mark the start of a new cold period.

The interglacial level at Sous-Terre is one of the reference sites for AAR Dating during this study, with fragments of *Arianta arbustorum* (AA), *Fruticicola fruticum* (FF) and *Cepaea hortensis* (CH), slug plates (SP) and worm granules (WG) all being measured (cf. Section 5.7; Figure 9; Penkman et al. 2024). The values produced give consistently reliable results that are significantly older than those from Grandson and Nuolen, while the values for FF are almost identical to those from Montfleury. This evidence together with the molluscan biostratigraphic data indicates that Sous-Terre and Montfleury may correspond to MIS 11 from the later Middle Pleistocene, meaning that the overlying blue-grey laminated silts might represent MIS 10. Underlying both Sous-Terre and Montfleury are thick deposits of basal moraine that correspond to the '*Moraine basale inférieure*' and may well represent the 'Möhlin Glaciation,' as this seems to have been the most extensive in the Swiss Alpine foreland (Graf 2009b, p.164, Preusser et al. 2011). The glacial deposits (Bünten Till) at Möhlin seem likely to correspond to MIS 12 (Dieleman et al. 2022b), a period that also saw a major increase in the quantity and coarseness of debris supply into the Upper Rhine Graben north of Basel (Preusser et al. 2021).

6.1.3 **Montfleury, GE** (Montfleury 1: 2494 400/1119 265; 432.6 m asl)

The molluscan material comes from three levels, sampled from a core taken in 1946 ('Montfleury 1') that was first studied for pollen by Ludi (1953, p.21-25). A detailed description of this core was published in 1981, accompanied by new pollen data and a summary of the molluscan analysis undertaken by J. Favre in the late 1940's (Lanterno et al. 1981). A new core ('Montfleury 2') taken 115 m away in 1981/82 (2494 295/1119 310; 431.40 m asl), that is associated with an in-depth pollen study, can easily be correlated with Montfleury 1 (Wegmüller et al. 1995). Montfleury 1 and Montfleury 2 lie c.1.4 km and c.1.5 km to the NW of the modern Rhône.

In both cores the sequence began with c.30 m of glaciogenic deposits, including basal till, that in Montfleury 2 (MF2) overlay the Lower Freshwater Molasse. After up to 1.35 of sandy gravel, came a series of grey organic silts, sandy-silts and silty-sands, with organic material and mollusc shells in places (8 m thick in MF1 and 1.35 m in MF2), capped in MF1 by 0.5 m of compact laminated lignite. These silts, which Wegmüller et al. (1995) call the *Confignon Sequence*, have pollen spectra typical of an interglacial. Above a clear erosion surface, came a series of grey sandy-silts and grey-beige silty fine sands with some small stones and mollusc shells in places (6.3 m in MF1, 5 m in MF2), which

Wegmüller et al. call the *Vernier Sequence*. They are associated with pollen that has much higher proportions of herbaceous taxa, indicating significantly colder conditions. In MF1 these were succeeded by 6.1 m of grey clay-silts, silts, sandy-silts and silty-sands, and in MF2 by 15 m of grey organic silts, sandy-silts and silty-sands, with organic material and mollusc shells in places. These silts, which Wegmüller et al. call the *Montfleury Sequence*, are linked with pollen spectra typical of a second interglacial. Then, above an unconformity, came a thick sequence of partially cemented fluvioglacial gravels known as the '*Alluvion ancienne*' (36.3 m in MF 1, 32.6 m in MF2; cf. Moscariello et al. 1998), succeeded by LGM basal till and gravels (16.1 m in MF1, 19.3 m in MF2).

The pollen from both interglacials includes a fairly high proportion of conifers, along with thermophiles such as *Abies*, *Buxus*, *Carpinus*, *Corylus*, *Juglans*, *Quercus*, *Taxus*, *Tilia* and *Ulmus* but there is no *Pterocarya* or arboreal genera that disappeared after the early Middle Pleistocene. Grains of *Ostrya* pollen in the lower interglacial of MF 1 (Lüdi 1953) might possibly indicate an age of MIS 11, as this pollen has also been found in sediments from the 'Praclaux Interglacial' at Val-de-Lans, Isère (de Beaulieu et al. 1994). Unlike Sous-Terre, both warm periods have low frequencies of *Fagus* (up to 3% in the second), while the upper warm period also has *Fraxinus* and *Juglans*. The continuation of *Betula*, *Juniperus*, *Pinus* and *Picea*, during the colder interval indicates that conditions may not have corresponded to a full glacial. The sequence is similar to that from a core at Confignon, 4.2 km to the south, which also has two clearly defined interglacial periods linked with marly-silts that contain plant remains and molluscs, separated by a notable cold period (2495 420/1115 160; 431 m asl; Reynaud 1982, p.23-25, 32-36).

The two lower molluscan samples from MF 1 (Table 13) come from the earlier of the two interglacials, while the upper sample corresponds to the period of colder conditions that separate them. All of the material has been reanalysed, including numerous previously unidentified fragments. The molluscs from the lower interglacial include the biostratigraphical marker *Perforatella bidentata* that disappeared from Switzerland before the end of the Middle Pleistocene (Figures 8 and 10), as well as several taxa typical of interglacials (Table 13). The upper sample has no interglacial species or true forest molluscs, but shows a major rise in open ground taxa and includes the cold-tolerant pioneer *Columella columella* that is normally found in cold climate contexts, showing that this fauna represents an interval of much colder climate. Nevertheless, the abundance of the molluscs and the presence of *Lymnaea stagnalis*, which is intolerant of truly cold conditions, suggests that this level represents an interstadial within the colder period, in keeping with the pollen from MF 2, which found evidence for at least two interstadials.

The lowest sample, which included a *Quercus* acorn, indicates rather damp, fairly open, largely deciduous woodland with mature trees and a rich undergrowth of tall herbs and young trees. The aquatic molluscs show that the shells accumulated in fairly shallow but permanent water with some aquatic plants within a slow-flowing meandering river, probably the Rhône. The terrestrial shells would have been washed in by retreating seasonal floodwaters and surface run-off. By contrast, the shells from the second sample, which comes from near the summit of the sediments linked with the first interglacial, were deposited, along with abundant organic material, in calm, permanent but shallow water, choked with aquatic and marsh plants near the margin of the same river. The small number of non-marsh terrestrial shells suggests that by now this section of the river may have been largely cut-off from the active channel. Needles from *Picea* were also present.

A sharp decline in the proportion of forest species among non-marsh terrestrial molluscs and a rise in shells from open ground species (9% of non-marsh terrestrials, up from 0.4% in the lower sample) may suggest an opening out of the surrounding landscape, possibly due to a cooling climate near the end of this interglacial period. The third sample shows radically different conditions, with patches of bushes with abundant tall herbs and perhaps some scattered trees, open ground with low herbaceous vegetation and open marshy ground. The shells seem to have accumulated within flood silts deposited in a marshy area that was probably near to the same river.

AAR Dating on FF shells from the lowest sample gives values very similar to those from Sous-Terre, which lies 5 km to the ESE, so the two deposits are probably more or less contemporary. Nevertheless, the molluscan marker species present at Sous-Terre are absent from Montfleury, while *Perforatella bidentata* is missing from Sous-Terre, so the faunas may represent different phases of the same interglacial. As the lower Montfleury sample comes from the lower levels of the interglacial deposits, while the Sous-Terre shells seem to come mostly from the upper levels, the Montfleury fauna may be somewhat earlier. Montfleury and Sous-Terre have AAR values that make them significantly older than the sites at Nuolen and Grandson that seem to date from MIS 7 (cf. Section 5.7; Figure 9; Penkman et al. 2024), while biostratigraphic data from the molluscs at Sous-Terre suggest that both sites may correspond to MIS 11. If true, then the glaciogenic deposits beneath the interglacial sediments at Montfleury and Sous-Terre may represent MIS 12, while the succeeding cold-stage deposits could date from MIS 10, and the upper interglacial levels at Montfleury and Confignon might correspond to MIS 9. The glacial deposits underlying Sous-Terre and Montfleury correspond to the '*Sédiments glaciaires anciens*' and '*Moraine basale inférieure*' that seem to be fairly widely present south-west of Geneva. There seem to be no other glaciogenic deposits present until the thick gravels of the 'Alluvion ancienne' (Moscariello et al. 1998, fig.2).

6.1.4 Coupy, Bellegarde-sur-Valserine, Ain, France (c.390 m asl)

In summer 1936, improvement of the road from Bellegarde to Geneva to the east of Bellegarde and c.400 m to the SE of Coupy, revealed a sequence with 'Burdigalian' (Early Miocene) marine molasse, overlain by at least 2 m of basal moraine with a mix of subangular local limestone and molassic sandstones, and rather subrounded alpine clasts, then at least 3 m of partially cemented, bedded yellowish olive-grey fine to coarse sands with gravelly lenses, which A. Jayet (1938) interpreted as being "interglaciare". Above this were c.6 m of crudely bedded fluvioglacial gravels with blocks up to 0.4 m, which Jayet correlated with the 'Alluvion ancienne' of the Geneva area, overlain by c.1 m of LGM basal moraine, capped by gravelly moraine nearby. In February-March 1966 Jayet revisited the site after further road improvements, and was able to find and sample fragments of mollusc shells in the 'interglacial' sands (unpub. field notes).

All of the shell fragments from the interglacial sands show imprints from sand grains. Among the modest assemblage are fragments from several species typical of interglacial conditions. These include the extinct *Retinella elephantium*, which seems to have disappeared after MIS 11 (cf. Section 5.5.1; Appendix 2) and *Aegopis klemmi*, which became extinct after MIS 9 (cf. Section 5.5.3; Appendix 2). Also present are *Aegopis verticillus*, as well as *Macrogastra attenuata* and *Cepaea sylvatica*, which have both rarely been recorded sub-fossil in France (cf. Sections 5.6.1, 5.6.2).

Coupy lies around 25 km WSW of Sous-Terre, and 20 km SW of Montfleury, and like these two sites, it is overlain by the gravels of the 'Alluvion ancienne' and underlain by basal moraine. In the Geneva area the '*Alluvion ancienne*' is believed to date from MIS 6 (cf. Section 6.1.5), while the basal moraine at Sous-Terre and Montfleury is thought to correspond to MIS 12 (cf. Sections 6.1.2, 6.1.3). Given the stratigraphic and biostratigraphic data for Coupy, an age of MIS 11 seems plausible.

The assemblage indicates moderately open, largely deciduous woodland with mature trees and a rich understory of tall herbs. It is unclear how the bedded sands may have formed, but given their altitude 60-70 m above the present level of the Rhône and a total lack of aquatic molluscs, they are very unlikely to be alluvial sediments. Instead, they seem likely to have accumulated as a result of slope processes, notably slope wash, linked with the weathering of the Burdigalian marine molasse and morainic deposits that underlie the interglacial sands. Hence the presence among the sands of redeposited Tertiary marine bivalves (*Ostrea*), coral and ooids, plus frequent angular grains of Jura limestone, chert, and molassic sandstone and moderately frequent subrounded to rounded grains of quartzite, sandstone and alpine crystalline rocks, similar to the petrographic composition of the clasts within the underlying moraine.[25]

6.1.5 **Two boreholes, Geneva, GE** ('Puits du Parc de La Grange,' Service des Eaux 1939, est. 2502 180/1117 960; 404.26 m asl; 'Sondage de la Petite Boissière,' Service des Eaux 1940, est. 2502 020/1117 220; 411.30 m asl)

The molluscs come from two boreholes taken to the south-east of the Petit Lac of Lac Léman, in 1939 at Parc La Grange and in 1940 at Chemin de la Petite-Boissière, Geneva. They are of interest because in both cores ochre-coloured silts with shells were found beneath 25-30 m of partially cemented '*Alluvion ancienne*' gravels. While the 0.3 m thick silt layer from Parc de La Grange seems to lie unconformably above the '*Moraine basale inférieure*' that also underlies the interglacial silts at Sous-Terre and Montfleury, the 0.3 m of silts at la Petite Boissière appear to be younger as they overlie 20 m of 'Alluvion ancienne' gravels, a rare example of biological material being found within this unit (Reynaud 1982, p.44).

The faunas from the two cores are similar as both have low diversity and include the cold-tolerant pioneer *Columella columella*, typical of cold periods (Table 14), with Parc de La Grange also having *Pupilla alpicola* and *Vertigo genesii*, although good shell preservation suggests that both represent interstadials. In agreement with stratigraphic evidence suggesting that the two faunas are of somewhat different ages, the assemblage from Parc de La Grange has 11 terrestrial species in just 0.5 kg of sediment, including *Clausilia dubia*, *Abida secale* and *Vallonia costata* that are also known from intervals like the mid-Wurm interstadial (MIS 3; cf. Sections 6.3.3 to 6.3.6), while these are missing from the restricted fauna of just 7 species from 15 kg of sediment at la Petite Boissière.

The gravels of the 'Alluvion ancienne' that cover these silt layers, can reach up to 75 m thick in places, are reasonably well-sorted with sand lenses, and sometimes have large

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[25] In Jayet's field notebook (unpub.) he notes the petrography of 779 clasts from the underlying moraine: 234 light Jura limestone (30.0%), 214 dark Alpine limestone (27.5%), 236 'Burdigalian' marine molassic sandstone (30.3%), 31 Alpine sandstone (4.0%), 16 Alpine quartzite + 8 vein quartz (3.1%), 2 Alpine conglomerate (0.3%), 15 gneiss + 9 schist + 5 granite + 6 gabbro + 3 'roches vertes' all Alpine (4.9%).

erratic boulders and include thin layers of diamict with striated clasts, showing that they accumulated near an ice front during a full glacial (Joukowsky 1942, Reynaud 1982, Arn 1984, Maystre, and Vergain 1992). This may well have been MIS 6, as this was one of the most extensive Pleistocene glaciations in lowland Switzerland (Preusser et al. 2011) and there is ample evidence that the Rhône Glacier was present in the Geneva area during this period (cf. Guiter et al. 2005, Coutterand 2018). Moreover, these gravels were either partially or entirely removed by major erosion before the deposition of glaciogenic deposits up to 80 m thick in the Geneva area during the last glaciation (Moscariello et al. 1998 Wildi and Pugin 1998). Radiocarbon dates of >35 k BP and 25-30 k BP on secondary cement within the gravels (Maystre and Vergain 1992) are minimum ages.

The fauna from la Petite Boissière, in silts found within the 'Alluvion ancienne,' might therefore date from mid MIS 6, while the molluscs from Parc de La Grange are somewhat older and may be contemporary with those from Petit Saconnex and WHO.

The terrestrial molluscs from both sites accumulated in marshy ground. This was bordered at Parc de La Grange by an area with abundant tall herbs, bushes and some scattered trees, plus significant surfaces with low herbaceous vegetation, and at la Petite-Boissière by a more open landscape with abundant tall herbs plus some dwarf shrubs and bushes, plus surfaces with low herbaceous vegetation (Table 14). Although both assemblages are dominated by terrestrial species, they accumulated significantly below the present level of Lac Léman (c.372 m). While the assemblage from Parc La Grange at 358.16-46 m asl has a few small fragments from aquatic molluscs, the fauna from la Petite-Boissière at 363.20-50 m asl has none. As the two aquatic gastropod fragments at Parc La Grange were probably introduced by flooding from the lake, this might imply a mean lake-level of around 357.0-357.50 m, around 15 m below its present level, while the level for la Petite-Boissière would have been below 362.50 m asl.

6.1.6 **Petit Saconnex, Geneva, GE** (1961 site: 2499 250/1120 050; 433 m asl; 1994 site: 2498 930/1119 760; 433 m asl)

The site at Petit Saconnex was first sampled in 1961 in a construction trench for a new hotel, c.1.2 km from Lac Léman. Overlying the Lower Freshwater Molasse was up to 6 m of compact basal till with erosional pockets filled with gravel at the base, above which were up to 9 m of grey/blue-grey interstratified silts and sandy-silts, with lenses of lignite in places, molluscs and plant remains, covered by up to 1.5 m of fluvioglacial sandy gravels, then 0.5 up to 6.5 m of LGM basal till (Jayet et al. 1961). In 1994, a new construction trench around 0.4 km to the south-west and c.1.6 km from the lake, produced a similar sequence, although the mollusc-bearing silts were only up to 3.2 m thick and the plant remains were less well preserved, while the sandy gravels were up to 8 m thick and could be attributed to the 'Alluvion ancienne' by C. Ruchat (the cantonal geologist), who took three samples for molluscan analysis.

Pollen in the silts from two 1961 samples included a significant proportion of *Pinus*, together with low frequencies of *Alnus*, *Betula*, *Corylus*, *Juniperus*, *Picea* and *Salix*, abundant Gramineae and Cyperaceae, and low percentages of several other herbaceous plants (Jayet et al. 1961, p.71, Reynaud 1982, p.50). Jayet also identified needles from *Pinus*, *Picea* and *Juniperus*. The presence of *Alnus* and *Corylus* might either suggest a fairly mild interstadial early within a cold period, or be due to redeposited grains.

The molluscs studied by Jayet could not be found and may have been lost, so the discussion will largely focus on the 1994 samples. The faunas are of limited diversity and have no interglacial species, but they do include the cold-tolerant pioneer taxa *Columella columella* and *Vertigo genesii*, showing that they accumulated during a cold period (Table 15). Nevertheless, the relative abundance and rather good preservation of the shells suggest that they represent an interstadial. There is, however, a clear trend for a progressive loss of species during this short sequence, suggesting deteriorating conditions. The faunas from Petit Saconnex are similar to the fauna from the borehole at Parc La Grange discussed above (cf. Section 6.1.5), having a moderate diversity and the presence of forest species, including *Clausilia dubia*, *Trochulus montanus* and *Trochulus villosus*. The silts at the two sites also share a similar stratigraphic position, as they lie beneath the '*Alluvion ancienne*,' which may well date from MIS 6, but unconformably above the '*Moraine basale inférieure*' that might date from MIS 12 (cf. Sections 6.1.2, 6.1.3, 6.1.5). There appears to have been a major episode of erosion before the deposition of the silts at Parc La Grange and Petit Saconnex that removed the earlier sediments found at Sous-Terre, Montfleury and Confignon, which seem to date from MIS 11 to MIS 9. If this erosional event and the silts that followed, was the precursor to the deposition of the 'Alluvion ancienne,' this might suggest that the silts at Parc La Grange, Petit Saconnex and also WHO date from the early part of MIS 6. Alternatively, it is also possible that they may have accumulated during MIS 8. AAR Dating on fragments of AA together with WG, produced values that are fairly consistent with a proposed age for the Petit Saconnex silts of early MIS 6 or possibly MIS 8 (cf. Section 5.7).

Despite an absence of aquatic molluscs, a significant component of paludal snails suggests that the shells accumulated in a marshy area without permanent water. The non-marsh terrestrial fauna at the start of the sequence (Malacozone PS-1; Table 15) indicates a mix of rather damp, fairly open scrub-woodland, surfaces covered by abundant tall herbs and some patches of more open ground with low herbaceous vegetation. During Malacozone PS-2 the scrub-woodland became more open, areas of open ground increased and local conditions became damper.

6.1.7 World Health Organisation, Geneva, GE (2499 230/1120 850; 448 m asl)

The samples for this site come from a core taken in March 1979 in the Route des Morillons, just to the south-west of the WHO (OMS) headquarters, Geneva. The core material was passed to L. Chaix at the Musée d'Histoire Naturelle, Geneva, who processed the samples and undertook some preliminary analysis. Unfortunately, there were no sieve residues that could be resorted to extract fragments from smaller species, which are underrepresented. All the shell material has been reanalysed. This core lies 0.8 km to the north of the 1961 site at Petit Saconnex and 1.2 km from the 1994 site. The same core was also sampled for pollen by C. Reynaud. Overlying the Lower Freshwater Molasse was 3.2 m of gravelly moraine, then 2.3 m of compact weathered fluvioglacial gravel, above which were 3 m of grey sandy-silts with molluscs and wood fragments, then 4.7 m of LGM basal moraine with a large glacial erratic at its summit, followed by 1.3 m of silty colluvium with pebbles, capped by 0.3 m of reddish soil (Reynaud 1982).

The pollen in the lowest metre of the fossiliferous silts was badly corroded, but above this it had significant proportions of *Pinus* and *Picea*, together with low frequencies of *Alnus*, *Betula*, *Corylus*, *Juniperus*, *Quercus*, *Salix* and *Ulmus*, abundant Gramineae, Compositae and Cyperaceae, and low percentages of several other herbaceous plants (Reynaud 1982, fig.11). The presence of *Alnus*, *Corylus*, *Quercus* and *Ulmus* might suggest a rather mild interstadial early within a cold period, or be due to redeposited grains.

Compared with Petit Saconnex, the WHO profile lacks the '*Alluvion ancienne*,' but the overall sequence is rather similar and the underlying glaciogenic deposits seem likely to correspond to the '*Moraine basale inférieure*' that also underlies Petit Saconnex. Moreover, the molluscan faunas resemble each other so closely that they are very likely to be contemporary. Although the faunas from WHO lack the cold-tolerant pioneer taxa present at both Petit Saconnex and Parc La Grange discussed above (cf. Sections 6.1.4, 6.1.5), the fairly abundant and moderately well-preserved fauna, with rather limited species diversity and lack of interglacial taxa are typical of an interstadial during a cold period (Table 16). There are also forest species similar to those seen in the other two sequences, including *Clausilia dubia*, *Orcula dolium* and *Trochulus montanus*. This reinforces the impression that the WHO faunas may represent early MIS 6 or perhaps MIS 8. AAR Dating on fragments of AA together with SP produced values that are similar to those of Petit Saconnex and are fairly consistent with a proposed age for the WHO silts of early MIS 6 or possibly MIS 8 (cf. Section 5.7).

Marsh species are less well represented than at Petit Saconnex, in keeping with the slightly higher altitude of the deposit (by c.15 m), suggesting that the shells accumulated within a gently sloping marshy area. The non-marsh terrestrial molluscs indicate that at the start of the sequence (Malacozone WHO-1; Table 16) the local environment consisted of fairly damp, rather open scrub-woodland, plus surfaces covered by tall herbs and limited patches of more open ground with low herbaceous vegetation. This was succeeded by bushy scrub with some scattered trees, accompanied by larger surfaces with tall herbs and poorly vegetated open ground.

6.1.8 **Nuolen/Buechberg, SZ** (western gravel quarry: est. 2710 160/1228 620; c.488 m asl / eastern gravel quarry: est. 2710 370/1228 440; c.484 m asl)

Long known about due to the presence of lignite layers (Ludi 1953, p.86-88), samples were taken by T. Bolliger in 1989 in two separate gravel quarries located within a plateau that forms the southern flank of the molassic hill known as the Buechberg, and corresponds to the Hochterrasse. These and several other quarries were cut into a thick and extensive complex of gravels with bedding structures suggestive of fluvioglacial or deltaic deposits, while the lignites, bedded sands, silts and marly-silts between the gravel units appear to have accumulated in ponds or marshy areas within an alluvial floodplain during warmer periods. Although the two sampled gravel quarry profiles were c.300 m apart, a cumulative stratigraphy for the site could be constructed with the help of T. Bolliger (Appendix 4). In both profiles the samples were taken from the middle level of three distinct series of marly-silts with lignite layers that were separated by units of deltaic gravel. Sample 1 seems to have come from below the 'middle lignite', while Samples 2, 3 and 4 came from just above the 'middle lignite', although their relative order is not clear. The samples had been sieved and sorted, with no conserved residues, and only small quantities of unsieved sediment from Samples 2 (0.4 kg) and 3 (0.1 kg) were available for processing; this explains the notable discrepancy in shell frequencies between the samples (Table 17).

A lithostratigraphic study of the Buechberg Hochterrasse plateau by Schindler (2004, p.13-31; cf. Preusser et al. 2011, p.292-3) has shown that the major stratigraphic units can be traced across most of the area, meaning that correlations between the gravel pits are plausible. The base of the sequence consists of grey laminated lake silts and sands up to c.445 m asl (siltier and more organic above c.440 m asl), succeeded by deltaic sands with layers of silt and lignite up to 455/460 m asl ('**lower lignite**'), then deltaic sands and gravels up to c.470 m asl, then horizontally-bedded sands and silts with lignite bands up to 475/478 m asl ('**middle lignite**'), then bedded gravels up to c.483 m asl (*Bachtellen-Schotter*), followed in places by c.2 m of silts with lignite ('**upper lignite**'), then gravelly LGM moraine above an unconformity. Exposures in a gravel quarry near Lochgass (2710 690/1228 030), around 0.7 km to the SE of the eastern quarry, revealed at least 25 m of the basal lake sediments up to c.450/455 m asl, succeeded by up to 30 m of medium to coarse deltaic gravels, then a series of up to five levels with lignites and marly-silts interrupted by deltaic or fluvial sands and gravels, from c.455/460 up to c.470/475 m asl (estimated from photographic and map evidence; Schindler et al. 1985, p.189-190).

Pollen analysis by Welten (1988; diag. 12, plus diags. 8-11) has attributed the organic and silty deposits that correspond to the 'lower' and 'middle' lignite levels to 'Holstein 1' and the 'upper' lignite level to 'Holstein 2.' These can be correlated with the Meikirch Interglacials 1 and 2, which have been reliably dated by OSL to MIS 7e and 7c (Preusser et al. 2005, Railsback et al. 2015). The molluscan assemblages correspond to the lower of the two warm phases present at Nuolen, so date from MIS 7e.

The molluscan faunas have several species typical of warm interglacial conditions (Table 17). These include the biostratigraphical marker species *Urticicola umbrosus*, which in Switzerland has so far only been found in older Early Pleistocene deposits at the Irchel sites and Albishorn-Bürglen 2 (cf. Figures 8 and 10, Section 5.5.1), as well as the possible MIS 7 site at Ried (cf. Section 6.1.9). This reinforces the impression from the pollen data that the interglacial levels at Nuolen date from the Middle Pleistocene. The interglacial indicator species *Aegopinella ressmanni* is also present, which disappeared from Switzerland after the Eemian. AAR Dating of BT opercula from the eastern gravel quarry and AA, CH and WG from the western quarry, give values that are in accord with a date from MIS 7, as these are slightly older than those from Eemian levels at Niederweningen and are similar to those from Grandson, but are significantly younger than the values from Sous-Terre (cf. Section 5.7; Figure 9; Penkman et al. 2024).

The samples from the western gravel quarry have predominantly terrestrial faunas that indicate damp, fairly dense, mature, largely deciduous woodland with an undergrowth of tall herbs and bushes/young trees. The few aquatic shells together with the preserved plant material suggest accumulation in a shallow marshy area liable to regular flooding, within an alluvial floodplain near a river that was probably meandering. The virtual absence of open ground molluscs suggests that the alluvial forest encroached upon this marshy area.

The assemblage from the eastern quarry is rather different, as it consists largely of aquatic shells that seem to have accumulated in shallow water at the edge of a rather slow-flowing meandering river prone to notable water-level fluctuations, which explains the fairly low ratio of *Bithynia tentaculata* shells: opercula and the virtual absence of bivalves. The presence of numerous *Chara* oospores, together with ostracod valves, insect remains and abundant seeds confirm that there was only a gentle current and a fairly rich aquatic and marsh vegetation. The small terrestrial component is dominated by marsh snails.

6.1.9 **Grandson, VD** (2539 300/1184 700)

The molluscan material comes from two samples taken between 1942 and 1944 when there was a lignite mine at Grandson. The lower sample was taken by A. Jayet in grey-brown organic marly-silts just beneath the lowest of three lignite layers. This sample was partially analysed by J. Favre in the mid-1940's but never published; all of the material has been reanalysed including numerous previously unidentified fragments. The second sample was taken in 1944 by the mine's geologist H. Badoux in grey rather organic marly-silts that lie between the lower and the middle lignite layers; this sample was sieved by M. Weidmann in 1970, but never sorted. At the base of the sequence was a thick deposit of compact basal till of unknown age, widely present in this area, above which were up to c.1.4 m of marly-silts, followed by the lower lignite (up to 1.15 m), then up to 0.9 m of grey marly-silts, followed by the middle lignite (up to 1.55 m), then up to 0.7 m of grey marly-silts, before the upper lignite (up to 0.7 m thick). Above a clear erosion surface was up to 1.35 m of sandy gravels, followed by up to 0.7 m of silts that included a 0.2 m lignite layer. After another marked erosion surface were up to 12 m of sandy fluvioglacial gravels, then a clear hiatus followed by up to 6 m of compact LGM basal till. In nearby cores the lake deposits were present from 451 up to c.481 m asl (Jordi 1996, 2006).

The site was first sampled for pollen by Ludi in the 1940's (1953, p.30-35). Pollen analysis by Welten on a core taken 50-100 m to the north-west of the mined area in 1982 (1988, diag.13; Jordi, 1996, fig.7) shows that both sampled levels correspond to his 'Holstein 1,' due to close similarities with the Meikirch 1 interglacial, which has since been reliably dated by OSL to MIS 7e (Preusser et al. 2005, 2011, p.289). This might suggest that both levels with the molluscs correspond to MIS 7e. Abundant plant remains typical of an interglacial have also been found, as well as bones from red deer, elk, bison, horse, wild boar and beaver (Arn 1984, p.184-6).

The presence of *Pterocarya* (wingnut) at Grandson might possibly suggest an earlier date, however, as Schlüchter et al. (2021) claim that this pollen type indicates an interglacial that is MIS 9 or older, based on its absence from Meikirch. As this pollen type is rarely frequent (Magri et al., 2017; maximum 2% at Grandson, rare grains at Buechberg) and its presence at earlier sites is variable (present at Ecoteaux, absent from Montfleury and Sous-Terre), however, its presence or absence cannot be used as a reliable temporal marker until more research has been done for the Swiss Plateau and surrounding regions.

There are no biostratigraphical markers among the molluscan faunas from Grandson, but they include several species typical of interglacial periods (Table 18). The presence of *Pomatias elegans* is notable as this taxon has never previously been found in pre-Holocene deposits in Switzerland (cf. Section 5.6.2). AAR Dating of BT opercula and fragments of AA gave values that are similar to Nuolen, though clearly younger than Sous-Terre but older than the Eemian of Niederweningen, in agreement with pollen evidence suggesting an MIS 7 age for Grandson (cf. Section 5.7; Figure 9; Penkman et al. 2024). The Grandson sediments also lie beneath thick fluvioglacial gravels that seem to underlie the Eemian deposits at Les Tuileries (Jordi 1996, 2006; cf. Section 6.2.2).

The molluscs from both samples accumulated in shallow water at the margin of Lake Neuchâtel during a time when the level of the lake was c.50 m higher than it is today (429 m asl). The fauna from the lower sample points to rather shallow but permanent water with relatively little movement. The shells from the higher sample indicate significantly deeper water associated with greater wave action, as they include several taxa typical of moving water habitats (*Pisidium amnicum*, *Pisidium henslowanum*, *P. moitessierianum*, *P. nitidum* var. *arenicola*, *Unio* sp.) that are missing from the lower sample. There were abundant aquatic plants within the lake and a rich marsh flora at the lake margin. The mean lake-level seems to have risen from c.477 m during the lower sample, to c.479/480 m asl for the upper sample (cf. Thew 2016, p.2/19-24). There are also seeds from aquatic and marsh plants like *Chara* sp., *Potamogeton* sp., *Ranunculus* sect *Batrachium*, *Zannichellia palustris* and *Carex* sp. (identified by NT), together with ostracod valves.

The terrestrial molluscs show that behind the lake margin was damp, moderately dense, largely deciduous woodland with mature trees and a rich undergrowth dominated by tall herbs. Conditions may have been somewhat more open at the time of the lower sample. Macroremains from *Abies*, *Betula* and *Salix* (id. by NT) were also present in the samples.

6.1.10 Ried, BE (2609 680/1184 400; c.582 m asl)

The molluscs were sampled by C. Schlüchter in 1971/1972 in a gravel quarry at Ried in the Aare Valley (Schlüchter 1976, p.55-57). They come from a discontinuous layer of olive-grey silts with fine sand that overlay a thick deposit of horizontally bedded fluvioglacial gravels called the *Untere Münsingen-Schotter*, and were covered by a thin layer of sandy gravel that Schlüchter still included within the lower gravel unit. This sequence was succeeded by another thick body of fluvioglacial gravels, the *Obere Münsingen-Schotter*. While the base of the silty layer was largely undisturbed, the summit had been heavily eroded and in places the silty lenses were slightly displaced. The summital part of the Untere Münsingen-Schotter and the gravels that overlay the silty lenses showed signs of significant weathering, while the base of the overlying Obere Münsingen-Schotter did not.

The upper of two samples was first examined by M. Wüthrich during the early 1970's, while the other was processed by D. Kälin in 2021. The former sample has been re-examined for this study, while the second has been analysed for the first time. The molluscs from the lower sample are typical of an interglacial warm period. The shells (Table 24) from the upper sample seem to represent a mixed assemblage, because although the fauna is dominated by open ground molluscs that include the cold-tolerant pioneer *Columella columella*, around 8% of the fauna consists of forest and tolerant taxa normally typical of an interglacial period, including three that are warm stenotherms. All of the shells from both samples are well preserved, so as there was no obvious stratigraphic break within the silty lenses it seems likely that they included both the later part of a warm interglacial and the start of the succeeding cold period. Blocks of unsieved sample showed that the silts become notably sandier in the upper part of this layer, so it seems likely that this sedimentary change coincided with colder conditions. The lower sample includes the marker species *Aegopinella ressmanni* and *Discus perspectivus* that are characteristic of interglacials. More important is the presence of *Urticicola umbrosus*, which in Switzerland has only been found in older Early Pleistocene contexts at Irchel and Albishorn-Bürglen 2 and the probable MIS 7 site at Nuolen (cf. Section 6.1.7). Indeed, the molluscs from the lower sample at Ried are strikingly similar to the faunas from Nuolen, as both sites have only moderate diversity and are missing Eemian indicator species like *Pagodulina pagodula*, and the interglacial marker *Helicodonta obvoluta* that is present in most Eemian assemblages, although both are present in Eemian levels at nearby Thalgut (cf. Section 6.2.4).

The stratigraphy of the Aare Valley between Münsingen and the Thunersee is rather complex, but from the evidence given by Schlüchter (1976, p.55-57, fig.37) the silts at Ried are clearly older than the Eemian lake deposits at Thalgut but younger than the lake sediments at Jaberg, as they lie within the summital part of the Untere Münsingen-Schotter that underlies the former site but covers the latter. It is thus entirely plausible that the silty deposits at Ried represent MIS 7. If true, then the lower sample could date from MIS 7, while the upper sample could belong to the end of MIS 7 and the start of MIS 6. Interestingly, the Thalgut sequence includes a pedological horizon likely to have been caused by warm conditions (beneath the *Kirchdorf-Deltaschotter*) that lies between the two series of interglacial lake deposits, which might possibly correspond to the Reid silts (Preusser et al. 2011, p.288, Schlüchter et al. 2021, p.62-63; cf. Section 3.2.4).

The silts and shells of both samples (Table 24) seem to have accumulated in a shallow, stream-fed marshy pond, prone to seasonal drying out. During the lower level this was bordered by largely shaded marsh, as well as rather damp areas with tall herbs and open ground with low herbaceous vegetation. Behind this was fairly damp, moderately open, largely deciduous interglacial forest with a rich understory of tall herbs and bushes/young trees. During the upper level the ground was somewhat drier, so the marsh around the pond was less extensive and was dominated by low marsh plants, while behind this the landscape was largely open and consisted of fairly damp open ground with low herbaceous vegetation as well as patches with tall herbs, scattered trees and bushes.

6.1.11 **Fisibach, AG** (2672 614-670/1269 080-132; 388-390 m asl)

In 2016 a sample was taken 1.4 m below the summit of >2 m of horizontally-bedded grey-beige silty-sands, located in a small former sand pit north-west of Fisibach (AG). In 2022 a second sample was taken 75 m to the NW and 1.5-2 m lower down in the same deposit, which appears to be up to 4-5 m thick, while 3 more samples were taken nearby in 2023. These uncemented silty-sands, with rare scattered stones and a few thin gravel bands, are situated at an altitude significantly above the Niederterrasse of the Hochrhein.

The restricted diversity of the molluscan faunas is typical of a cold stage, although excellent shell preservation (Table 19), the Group 4 taxon *Trochulus villosus* and the presence of *B. tentaculata* rather suggest an interstadial. This seems to have occurred during the mid to later part of a glacial period, after an interval of truly cold conditions had caused the disappearance of most species. Despite rather low shell frequencies and a relative paucity of worm granules, the fine preservation of the shells, together with a sedimentological context that indicates moderate fluvial stability, rather points to a period of fairly mild interstadial climate. The decreasing number of molluscan species in the higher samples may suggest, however, that conditions were getting colder. The unbroken nature of many shells indicates that the assemblages have not been greatly affected by subsequent sedimentary compaction, and thus post-date the MIS 6 basal tills found at the summit of the Hochterrasse. Given the stratigraphic position of the silty-sands and the climatic indications from the molluscs, these faunas may date from late MIS 6.

Although most shells are terrestrial, fragments from the aquatic snail *Bithynia tentaculata* suggests that these bedded silty-sands probably represent flood deposits from the Rhine

(Table 19), while the well-preserved shells, low shell frequencies and relative paucity of worm granules point to rather rapid sedimentation. The terrestrial molluscs indicate accumulation in marshy ground bordered by surfaces covered by abundant tall herbs with bushes and possibly some scattered trees, as well as patches with low herbaceous vegetation. The worm granules (probably *Lumbricus* sp.) suggest soil development, as well as fairly moist conditions. Abraded fragments of redeposited shell, including from species typical of warm deciduous forests (such as *Isognomostoma isognomostomos*), show that upstream the river was eroding earlier interglacial deposits.

6.1.12 **Herteren, Sulperg, Wettingen, AG** (est. 2668 320/1257 290; 485 m asl)

In 1941 the mining geologist C. Friedlaender supervised a series of cores up to 20 m long being taken in a shallow valley between the Sulperg (Sulzberg) just east of Wettingen, and the hamlet of Herterenhof. These cores were intended to determine the extent of sandy sediments exploited at that time for use as foundry sand (Friedlaender 1942, Bitterli-Dreher et al. 2007, p.84-85). The cores revealed the existence of an elliptical basin c.0.6 km long NW-SE, by 0.1 km in width. Over molassic bedrock was up to 4-5 m of compact basal moraine truncated by a pronounced erosion surface, above which were 2-4 m of interbedded loessic silts, organic silts, silty-sands, and sands, all with rare pebbles, overlain by up to 1 m of bluish-grey sandy-silts and olive-grey silty-sands, then in places c.0.10 m of white powdery tufa with plants impressions, 0.2 m of bluish-grey sandy-silts and olive-grey silty-sands, up to 0.2 m of organic clay-silt, and then 2-4 m of peat, with wood pieces in the basal 0.6 m. These were covered by up to 12 m of loessic silts, sandy-silts and sands (Friedlaender 1942, Welten 1982, p.108-113). The layers below the peat seem to be slope deposits, composed of sand and pebbles weathered from the molasse and the moraine, mixed with loessic silt. Apart from the cores, the sequence was also visible in an open sand-pit, where two samples could be taken for molluscan analysis in the blue-grey sandy-silts and the white tufa. These were briefly examined by J. Favre, who extracted a few complete shells, but all of the shell material has now been reanalysed.

Pollen analysis on the cores was first undertaken by Lüdi (1953, p.116-120). A more recent study by Welten established that the peat spans from the Eemian until the Early Würm (MIS 5e-5a), while the loessic silts below the peat represent the end of MIS 6 and the basal moraine corresponds to MIS 6 (Welten 1982, diag.44).

The molluscan faunas in the two samples (Table 20) have fairly restricted diversities and include the cold-tolerant pioneer species *Columella columella* and *Vertigo genesii*, typical of a cold period, but increasing abundances and relatively good shell preservation rather suggest an interstadial. Indeed, the faunas are remarkably similar to those of the mid-Würm interstadial, MIS 3 (cf. Section 6.3.3 to 6.3.6). The species present are in accord with the pollen evidence that the faunas represent the late glacial of MIS 6. A radiocarbon date of 28,550-25,200 cal BP on a peat sample (Schindler 1977) is clearly too young.

The notable proportion of marsh molluscs in both samples shows that the shells accumulated in a marshy depression, with only low marsh plants in the lower sample (Group 12) but some taller marsh plants in the upper sample (Group 11; Table 20). The area around the depression was in the lower sample dominated by tall herbs with some shrubs and perhaps some scattered trees, as well as patches with low herbaceous vegetation. In the upper sample the arrival of the shade-loving taxa *Eucobresia diaphana* and *Trochulus villosus* indicate that there were increasing frequencies of bushes and trees.

6.2 Late Pleistocene sites dating from the Eemian

6.2.1 **Niederweningen, ZH** (NW15/Col A: 2670 369/1262 404; NW15/Col B: 2670 409/1262 380; Core NW18/2: 2670 514/1262 322, Core NW18/3: 2670 428/1262 363)

The material from this site comes from a construction trench for houses sampled by H. Furrer in 2015 and two cores taken in 2018. At the base of the sequence were sterile grey detritic sandy-silts, above which were grey detritic sandy-silts with plant debris and some shell fragments, then blue-grey marly-silts with plant debris and fairly abundant shells. Above came brownish-grey or grey tufaceous silts or creamy-grey silty tufa, all with abundant shell fragments, interrupted by thin layers of humified peat. Above this were a complex of peat layers, very organic silts and dark grey silts (equivalent to the so-called 'Lower Peat') with abundant wood from Alnus, Abies and Picea in its basal part but no preserved molluscs, then a series of grey silts or brownish-grey fairly organic silts interrupted by thin peaty bands. Around 250 m to the south-east of Core NW18/2 these are succeeded by the so-called 'Upper Peat,' which is associated with mammoth bones (Furrer et al. 2007; cf. Section 6.3.4). All these deposits seem to have accumulated at or near the margin of a lake that occupied much of the valley floor. A detailed analysis of the profiles from the construction trenches and the cores has revealed a fairly complex sequence that has been strongly influenced by fluctuations in the water-level that at times caused significant erosion, leading to hiatuses (Figure 12).

The exceptionally rich molluscan material has yielded a fauna with 71 terrestrial and 23 aquatic species from the blue-grey marly-silts and the tufaceous silts (Table 21). These include many species normally associated with warm interglacial conditions as well as an impressive series of biostratigraphical marker taxa that have only ever been found in contexts linked with full interglacial conditions in Western and Central Europe, including Aegopinella ressmanni, Aegopis vorticillus, Discus perspectivus and Ruthenica filograna, as well as Acicula lineata, Daudebardia brevipes, Daudebardia rufa and Pagodulina pagodula that seem to be indicators for the Eemian in Switzerland (Table 21, Figures 8 and 10; cf. Sections 5.5.3, 5.6.2). An Eemian (MIS 5e) date for this material seems fairly certain given its stratigraphic position above a unit of lacustrine silts dated by OSL to MIS 6, pollen characteristic of the Eemian within the mollusc-bearing layers (Wick pers. comm.) and pollen from the Lower Peat that covers the transition from the end of the Eemian to the beginning of the Early Würm (MIS 5d-5a; Welten 1988, Furrer et al. 2007, Anselmetti et al. 2010, Dehnert et al. 2012). AAR Dating of BT opercula, fragments of AA, FF and CH, as well as SP and WG (cf. Section 5.7; Figure 9; Penkman et al. 2024), make Niederweningen a key site in the new aminostratigraphy for Switzerland. They mostly give values that are fairly typical for the Eemian, and are younger than those from Grandson and Nuolen, although those for BT opercula are slightly older than expected.

The faunas show a clear progression from those typical for an earlier phase of the Eemian to those typical of the so-called 'climax phase,' as the local terrestrial environment saw damp, fairly open mixed coniferous-deciduous forest be gradually replaced by moderately dense, largely deciduous woodland with mature trees, then by even denser and more diverse forest, with a rich undergrowth of tall herbs and bushes/young trees.

The faunas within the blue laminated marly-silts accumulated within shallow but permanent water with a rich aquatic vegetation near the edge of a lake that seems to have

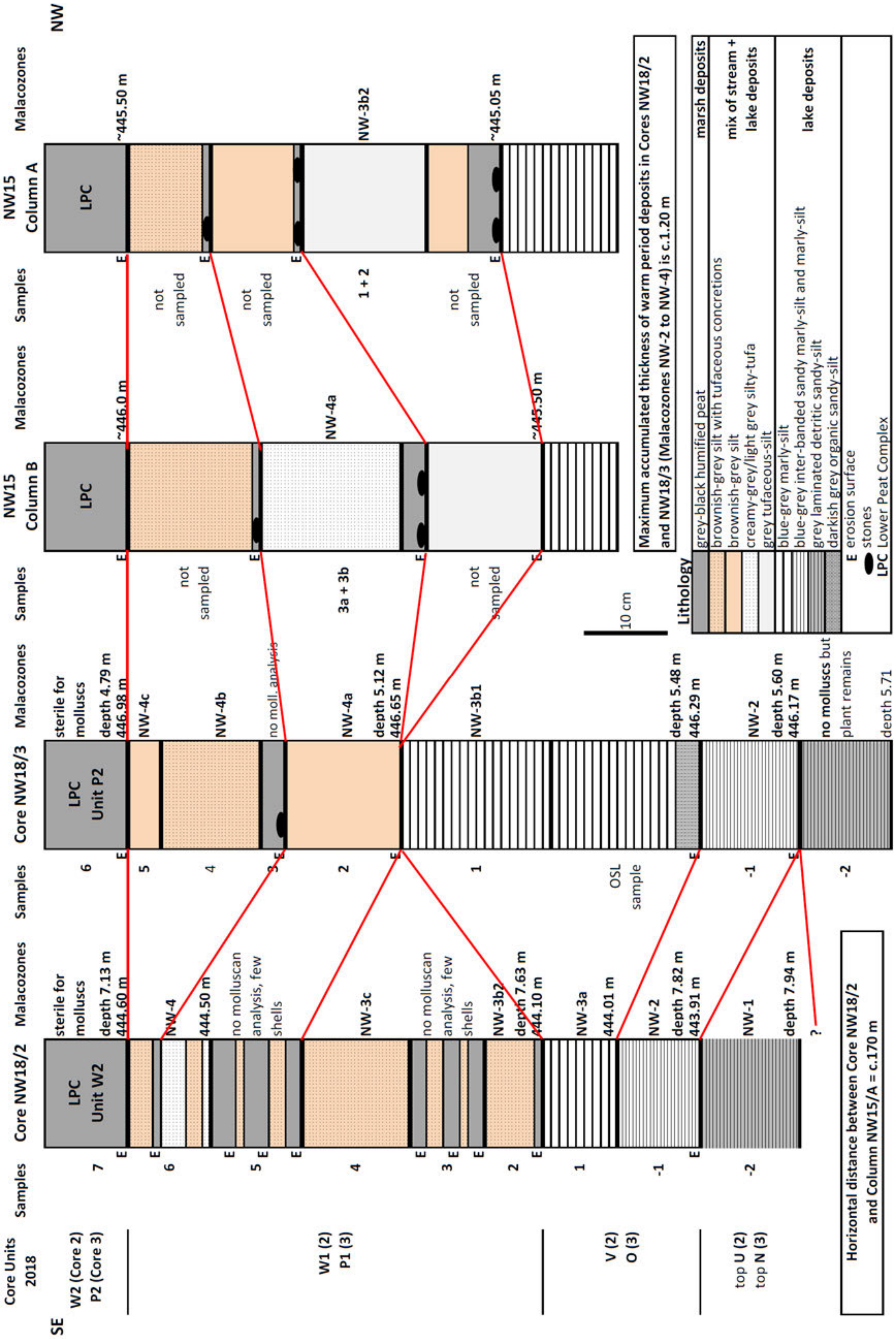

Figure 12: Correlations between Cores NW18/2 and NW18/3, plus Columns NW15/A and NW15/B at Niederweningen, based on lithology and malacozones

occupied much of the valley bottom during this period. After a significant fall in the level of the lake, the aquatic molluscs in the tufaceous silts reflect a shallow lake with abundant aquatic plants that was fringed by marshy vegetation, into which one or more small slow-flowing streams (presence of moving water taxa like *Pisidium tenuilineatum*) were flowing. Of interest is the presence of the pioneer marsh snail *Vertigo genesii*, suggesting that in places the marsh vegetation remained low.

The molluscs from the grey silts beneath the Eemian deposits seem to date from late MIS 6, as the faunas have limited diversity and there are no typical interglacial taxa. Moreover, the presence of *Pisidium lilljeborgii* is a reliable indicator of colder conditions, as this species requires well oxygenated water that it can only find in larger lakes with wave movement or small lakes in cooler locations. During late MIS 6, the aquatic molluscs indicate a shallow lake environment with a fairly rich aquatic flora similar to that seen during the Eemian, but surrounded by a more open terrestrial landscape.

6.2.2 **Les Tuileries, Yverdon, VD** (2537 430-480/1183 230; 479 m asl) **'Giez'/Grandson, VD** (est. 2538 525/1184 440; 479 m asl)

The shells from Les Tuileries were first studied by A. Jayet in the 1960's (Jayet and Portmann 1960, 1966) but have been completely reanalysed, while several small sediment samples were processed in order to obtain more shell material and look for smaller species that are underrepresented in the existing material. The shells from Giez/Grandson were also first looked at by A. Jayet but have been completely re-examined, while 1.5 kg of unwashed sediment was also processed to extract more shells. Jayet called this site 'Giez,' although it lies within the commune of Grandson.

Both sites come from a high lake terrace with lacustrine silts and marly-silts from c.469 up to c.476 m asl, known from several places around the south-western corner of Lake Neuchâtel (Arn 1984, p.187). These are covered unconformably by LGM moraine, while overlying up to 10-12 m of sandy fluvioglacial gravels, cemented in places, which seem to date from MIS 6, as they seem to cover the lacustrine deposits documented at Grandson that probably date from MIS 7 (cf. Section 6.1.8; Bertschy 1958, Jordi 1996, 2006).

Two biostratigraphical indicator species present at Les Tuileries (Table 22, Figures 8 and 10; cf. Section 5.5.3) are *Discus perspectivus* and *Platyla dupuyi*. The former was also found at Niederweningen, while the latter is a western species that was present in the Geneva basin earlier in the Holocene, but never got as far north as Lake Neuchâtel. Apart from the presence of these two marker taxa, Les Tuileries and Giez/Grandson can be fairly reliably attributed to the Eemian on stratigraphic grounds (Jordi 1996, 2006). Both sites have large fragments of FF, CH and WG that could perhaps be used for AAR Dating (Figure 9), while Giez/Grandson also has slug plates.

The faunas from Les Tuileries (Table 22) show a clear progression from a late glacial environment during Malacozone LT-1 (late MIS 6), through damp, very open, largely coniferous woodland in LT-2, to increasingly dense, somewhat drier and progressively more mature deciduous forest during LT-3 and LT-4. The fauna from Giez/Grandson is very similar to those from LT-3 at Les Tuileries.

The shells from Les Tuileries seem to have accumulated where a stream entered shallow, permanent, gently-moving water with a relatively abundant aquatic vegetation at the margin of a fairly large water body, which was probably Lake Neuchâtel. The absence of the typical moving water species that can be seen in the upper layer at Grandson suggests that the lake waters must have been rather sheltered in this location, similar to the fauna in the lower sample level at Grandson. The influence of the stream seems to have progressively increased during the sequence at Les Tuileries while that of the lake diminished. At Giez/Grandson the shells seem to have accumulated in a similar shallow water environment with aquatic plants and gentle water movement as Les Tuileries. The level of Lake Neuchâtel at that time seems to have been around 475 m asl, c.46 m above todays mean level (cf. Thew 2016, p.2/19-2/24).

6.2.3 **Zell, LU** (Forcart: 2637 210/1220 455; Jayet: est. 2637 190/1220 450; Kälin 2636 552/1220 110-112)

Molluscs from Kiesgrube Meier, south of Zell were first studied by L. Forcart in the early 1940's (Erni et al. 1943), but unfortunately most of the shells may have been lost. The same location was subsequently sampled by A. Jayet in 1948, and it is this material that has been re-examined here. Underlain by c.14 m of Hochterrasse fluvioglacial gravels (*Untere Zeller Schotter*), the Forcart and Jayet faunas were found at c.604-605 m asl in tufaceous silty-sands within a series of sands and sandy fine to medium gravels from 602 to 610 m asl, which seem to have been deposited by a river. Forcart only sampled the upper level of two horizons with shell material. The sequence was overlain by c.20 m of fluvioglacial gravels (*Obere Zeller Schotter*) that may date from MIS 4 (Preusser et al. 2001). Sparse pollen and plant remains in the mollusc-bearing sediments are typical of a warm interglacial (Härri in Erni et al. 1943). These fossiliferous deposits partially predate the organic silts, silty-sands and lignite layers at c.608-614 m asl studied by Wegmüller (1996) that largely correspond to the Eemian (MIS 5e), although the upper levels represent an Early Würm interstadial (Birrfeld Glaciation; MIS 5c) and the two periods were separated by 0.45 m of gravelly sand (MIS 5d). Beneath this were several metres of grey sands and silts that were not analysed (Wegmüller 1996, fig.3; 2001, fig.2). Küttel and Lotter (1987) studied several sequences with silts, tufaceous silts, gravelly sands, organic silts and lignite layers present between 598 and 620 m asl, and showed with both pollen and Ur-Th dates that these deposits span from the start of the Eemian until the Early Würm. Subsequent OSL dates from a sequence of silts, sands and thin peat layers likely to have been deposited by a meandering river, correspond to MIS 5e and MIS 5c (Preusser et al. 2001), while Uranium series dating of the upper peat layers confirms that they represent MIS 5c (Frechen et al. 2007). All of these studies looked at sequences from the same gravel quarry as Forcart and Jayet, but since 1980 this has greatly expanded in size, so the various profiles may be separated by several hundred metres. D. Kälin returned to the site in 2019 and took new bulk samples 740 m to the SW of the original profile, in c.7 m of silts, marly-silts and sandy-silts alternating with layers of fine to medium sandy gravel, which clearly represent meandering river deposits. The new samples are from near the top of these sediments, which are truncated by an erosion surface overlain by c.15 m of fluvioglacial gravels. The sequence at Zell lies less than 5 km from well-known lignite deposits at Gondiswil and Hüswil that also span from the Eemian to the Early Würm (Lüdi 1953, p.44-67, Wegmüller 1995, 1996, 2001, 2004).

The molluscs from this site (Table 23) include a number of typical interglacial species, among which are a range of biostratigraphical markers that firmly place the faunas within the Eemian. These include *Acicula lineolata*, *Aegopinella nitidula*, *Aegopinella* *ressmanni*, *Discus perspectivus*, *Pagodulina pagodula* and *Ruthenica filograna*. The first two taxa have only ever been found at Zell, while the other four have also been found at Niederweningen (Figures 8 and 10; Appendix 2; cf. Sections 5.5.3, 5.6.2, 6.2.1). When compared to the sequence from Niederweningen, the Zell faunas seems to correspond to a mid-phase of the Eemian, shortly before some of the late appearing marker species present at the former site could have arrived. The Kälin samples have faunas that are similar to those of Forcart and Jayet, but are missing the marker species *Acicula lineolata*, *Discus perspectivus*, *Pagodulina pagodula* and *Ruthenica filograna*, indicating that they represent an earlier phase of the Eemian. In the Jayet sample *Macrogastra plicatula* is represented by a form with unusually dense ribbing and no anterior lower palatal plica, similar to subspecies found today in northern Italy such as *M. plicatula amiatensis* (Nordsieck 2006, p.59, 61). The presence of this subspecies together with the southern taxon *Acicula lineolata*, might be an indication of a significantly warmer climate. AAR Dating of fragments of AA, as well as SP and WG from the Kälin samples has given values that for AA and WG may seem to be a bit too old. For SP they are clearly younger than the probable early MIS 6 site at WHO (cf. Section 6.1.6), but appear to be slightly older than the material from Niederweningen (cf. Section 5.7). This may be because the faunas from the new samples at Zell represent an earlier phase of the Eemian than the ‘climax phase’ shells analysed from Niederweningen.

The paludal snails and few aquatic molluscs from Zell seem to confirm stratigraphical observations that the shells accumulated in a large stream or small river, with reaches of both more active flow and quieter water with aquatic plants, which was fringed by marshy ground. The terrestrial faunas indicate damp, moderately dense largely deciduous woodland with large mature trees and a rich understory of tall herbs and bushes/young trees, which became somewhat denser and more diverse in the later part of the sequence.

6.2.4 **Thalgut, BE** (2608 990/1186 615; 610 m asl)

The gravel quarry at Thalgut, in the Aar Valley, was sampled by C. Schlüchter in 1971/72 and the molluscs were first studied by M. Wüthrich (Schlüchter 1976). The material has been completely reanalysed, adding numerous shells from 0.7 kg of previously unprocessed sediment. The samples were taken within a body of up to 5 m of laminated marly-silts, sandy-silts and silty-sands with bands of organic detritus, typical of warm period lake deposits, which were present between c.600 and 610 m asl. Welten analysed pollen from the 1971/72 samples (Welten 1982, diag. 14), but due to unsatisfactory results returned in 1983 to take new samples from the quarry face as well as from a core sunk beneath the quarry floor. He demonstrated that these lake sediments were of Eemian age (Welten 1988, p.25, diags. 15, 16), which has since been confirmed by OSL Dating (sampled in 2002; Preusser and Schlüchter 2004). Schlüchter found macroremains from *Abies*, *Betula*, *Corylus*, *Picea*, *Pinus*, *Quercus* and *Salix* in the lake silts.

In addition to several species normally associated with warm conditions, the molluscs at Thalgut include the classic interglacial markers *Aegopinella ressmanni* and *Discus perspectivus*, as well as *Pagodulina pagodula*, which may be an indicator for the Eemian in Switzerland, confirming that these deposits date from MIS 5e (Figures 8 and 10). Unfortunately, AAR Dating on BT opercula from Thalgut has given values that are more in keeping with a pre-Eemian date (cf. Section 5.7; Figure 9; Penkman et al. 2024). As the shells cannot possibly come from the earlier lake deposits, this suggests that the bulk sediment may have been heated during laboratory drying as this tends to 'age' AAR Dates, as shown by shells from Holocene levels at Abri Unterkobel (cf. Section 6.4.2).

The diverse aquatic fauna (Table 24) includes species typical of moving water, indicating that the shells accumulated in fairly shallow water not far from the margin of a moderately large lowland lake with some wave action and a fairly rich aquatic flora, while the paludal snails show that the lake was fringed by rather dense marsh vegetation. The molluscs were accompanied by ostracod valves from several species and *Chara* oospores. This lake may well have been a larger, early version of the lake known today as the Gerzensee, which lies just 400 m to the west and has a surface at 602 m asl. The terrestrial molluscs suggest that around the lake was damp, moderately open, largely deciduous woodland with mature trees and a rich understory of tall herbs and bushes/young trees.

In the quarry sequence and the 1983 core, the Eemian lake deposits are underlain by a series of deltaic gravels, then by layers of glaciolacustrine silt/water-lain till, and then a thick series of fluvioglacial deltaic gravels. Beneath these are the fore-sets of a prograding delta from c.530 up to c.565 m asl, and then lower lacustrine silts from <462 up to c.530 m asl. Welten (1988) assigned these lower silts to the Holstein 1 Interglacial due to the presence of *Pterocarya*, but the abundance of *Fagus* (up to 58% of total pollen) is totally unlike the spectra from Meikirch and Grandson, suggesting that this lower lacustrine unit may predate MIS 7 and be MIS 11 or older (Schlüchter 1989a, 1989b, Schlüchter et al. 2021). These silts are certainly Middle Pleistocene as the whole Thalgut sequence has normal palaeomagnetic polarity (Forster 1991). Despite sampling that took place up to 30 years apart, the sequences documented by Schlüchter in 1971/72, Welten in 1983 and Preusser in 2002 are rather similar, with the pre-Eemian lake deposits consistently lying c.40 m below the Eemian lake sediments and c.15-20 m below the quarry floor. Comparable lower lacustrine deposits were sampled by Schlüchter at Jaberg, BE (the *Jaberg-Seetone*), where pollen analysis shows that they have similar spectra with *Pterocarya* and rather frequent *Fagus* (Welten 1982, diag. 11, 1988, diag. 14), although the recovered shell material has unfortunately been lost. In cores taken at Jaberg the lower lacustrine silts are present from <522 up to 530 m asl, while deltaic silts and sands are present from 530 up to 560 m asl (1972 core) or 575 m asl (1982/83 core).

The Thalgut sequence also includes an erosional unconformity at the summit of the glaciolacustrine silts that is associated with pronounced weathering and pedogenesis, and is thought "to represent at least one well-developed warm period" (Preusser et al. 2011, p.288). It seems plausible that this warm period may correspond to the interglacial silts at Ried that may correspond to MIS 7 (cf. Section 3.1.9).

6.2.5 **Thungschneit-Räbeli, BE** (est. 2611 450/1182 750; silt: 549/560 m asl) **"Schürliacher", Bümberg, BE** (est. 2611 200/1183 400; surf.: c.565 m asl)

Up to 8 m of lacustrine silts and sands were documented and sampled by Welten in 1968/71 and by Schlüchter in 1971/72, between c.549 and 560 m asl in 6 cores taken before motorway construction at Thungschneit-Räbeli, while additional logs show that these silts were present from c.547 up to 562 m asl. The same silty unit could be observed at a similar altitude c.650 m to the north in a gravel quarry at Bümberg. Based on their pollen, Welten proposed that these lake sediments date from the late Riss until the Eemian (Welten 1982, diags. 8-10). Given a lack of clear biostratigraphic markers, however, they might be significantly earlier and based on their altitude may well correspond to the

Middle Pleistocene Jaberg-Seetone. A small, rather limited assemblage of aquatic molluscs was identified from Thungschneit by M. Wüthrich (Table 24) from a core also analysed by Welten (1982, diag. 9). They include *Unio* sp., in agreement with evidence from pollen and plant macroremains (*Abies*, *Acer* and *Alnus*) that these silts represent interglacial lake sediments. Unfortunately, only a few *Bithynia tentaculata* opercula remain, as the rest of the material seems to have been lost. A small molluscan assemblage from sandy-silts in the gravel quarry at Bümberg, sampled by Schlüchter in the early 1980's, consists solely of *Bithynia tentaculata* opercula.

6.2.6 Spiezberg, drill core RB 1-05, BE (2617 757/1171 488; c.592 m asl)

A 24.5 m geotechnics core extracted in 2005 from the northern flank of the Spiezberg NE of Spiezmoos, was described in the field and then the section between 10 and 18 m depth was boxed up and stored at the Institute of Plant Sciences, University of Bern (Zwahlen et al. 2021). This section of the core was sampled in detail for pollen, and the remaining sediments between 10.3 and 16.0 m were subsequently divided up into 0.2 m samples and sieved by Daniel Kälin. The core sediments consisted of basal moraine from 24.5 to 17.1 m depth, followed by dark grey laminated silts and sandy-silts with some stones from 17.1 to 16.45 m, beige silty-sandy gravels from 16.45 to 16.0 m, and then grey sandy-silt with some fine gravel from 16.0 to 15.6 m. Above this were grey laminated marly-silts up to 13.6 m, grey brown or brownish-grey organic silts up to 11.4 m, and then grey sandy-silts with some fine gravel and inclined bedding (40°) up to 10.3 m. The silts were then truncated by an erosion surface, above which was LGM basal moraine.

Pollen was analysed from 16.8 to 11.6 m depth. From 16.8 to 15.8 m the spectra are dominated *by Betula*, *Juniperus* and *Pinus* with abundant herbaceous pollen, thought to be typical of cold, late glacial conditions (Schläfli et al. 2021, Zwahlen et al. 2021). The remainder of the analysed sequence is dominated by tree pollen, including several thermophilous taxa, interpreted as being indicative of deciduous forest during the Eemian.

Varying frequencies of molluscs could be recovered from all of the sampled sediments between 16.0 and 10.3 m. Just 4.4% of the minimum number of 7731 individuals come from 28 terrestrial species (Table 25). These include several that are typical of warm interglacial periods. Of these, the most significant is *Helicodonta obvoluta*, which is nearly always present in Eemian assemblages but has never been found in MIS 7 faunas from Switzerland (cf. Section 5.6.2). The presence of *Carychium tridentatum* in the very lowest sample shows that this does not correspond to a cold late glacial climate, as thought by Schläfli et al. 2021, but instead represents an early phase of the Eemian, equivalent to the Preboreal at the start of the Holocene. Similarly, shells from *Discus ruderatus* in the lower part of the sequence (up to 14.6 m) also suggests that these deposits represent the earlier part of the Eemian, while the arrival of *Cochlodina fimbriata* in the upper part of the sequence, above 11.4 m, seems to indicate that this corresponds to the mid-phase of the Eemian (cf. Section 6.2.1, Table 20). The terrestrial molluscs suggest that beyond a fringe of marshy vegetation at the lake margin was damp, rather open, largely deciduous woodland with a rich understory of tall herbs and bushes/young trees.

Some 95.6% of the molluscs come from 19 aquatic species. Of note is the presence of several bivalve taxa (*Pisidium amnicum*, *P. henslowanum* and *P. moitessierianum*) commonly found in larger lakes with wave action, as well as *P. lilljeborgii*, which in lowland situations in Central Europe today is confined to larger lakes (Table 25). Given the altitude of the silty sediments with the molluscs, they seem to represent lacustrine deposits from a 20 m lake terrace of the Thunersee. Moreover, the great majority of the shells are fragmented, and although some of this was due to later compaction, the strong underrepresentation of shell apices, the high aquatic gastropod/bivalve ratio, and elevated *Bithynia tentaculata* shells/opercula ratio are all signs of accumulation through repeated wave action at the edge of a larger lake. There are few shells from taxa linked with aquatic plants, suggesting that the aquatic vegetation was rather modest, another sign of moderately energetic wave action. Estimations of the water depth based on the molluscs suggest that the lake-level may have risen from around 577 to c.580 m asl (cf. Thew 2016, p.2/19-2/24). It also seems possible that the gravelly sediments at 17.1 to 16.0 m depth in the core may represent lake beach deposits from the early Eemian.

6.2.7 **Flurlingen/Feuerthalen, ZH** (est. 2689 907/1282 078; c.460 m asl)

The shells from this site were found within a sequence of partially cemented tufas that bear the imprints of leaves from tree species such as *Acer*, *Buxus*, *Corylus*, *Fraxinus*, *Taxus* and *Tilia* (Guyan and Stauber 1941), typical of full interglacial conditions, while Ludi (1953, p.108-113) confirmed this with pollen analysis. This tufa, which used to be 12-15 m thick, was located within a depression near the summit of the Hochterrasse of the Hochrhein. The tufa overlay a basal till and was covered by another glacial till dating from the LGM. This outcrop has since been largely destroyed during road construction, so only remnants in the form of displaced blocks are still present today. U-Th dating of a sample from one such block gave an age of 102 ± 8 ka BP, which must be considered to be a minimum age given the floral and faunal evidence (cf. Graf 2009b, p.43, 47).

The few molluscs that could be extracted from the tufas were first studied by Wehrli (1894), Gutzwiller (1894) and Penck (1902). Wehrli's material was sadly destroyed by American bombing of Schaffhausen during WWII, while the whereabouts of the molluscs collected by Penck are unknown. The shells collected by Gutzwiller were twice reanalysed by Forcart (Erni et al. 1943, Forcart 1963), but despite this attention some questions remained, so the material has been re-examined by the author.

The biostratigraphical marker species *Aegopinella ressmanni* and *Discus perspectivus* are both typical of full interglacial conditions (Figures 8 and 10), while the Eemian marker taxon *Daudebardia brevipes* is also present, with all three species also being found at Niederweningen (cf. Sections 5.5.3, 5.6.2, 6.2.1). This evidence seems to confirm the Eemian age for this tufa deposit, in keeping with its stratigraphical position and the U-Th date. This is the first time that *Trochulus caelatus* has been recovered from sediments outside of the limited area of the Birs Valley in the Swiss Jura where it lives today. The small fauna (Table 26) indicates that the shells seem to have accumulated in small spring or seepage-fed pools that were prone to drying out and bordered by marshy ground, and which were overshadowed by damp, fairly dense, largely deciduous mature woodland.

6.2.8 **Bürgerspital, Basel, BS** (est. 2610 811/1268 144; c.255 m asl)

This rich molluscan assemblage was found beneath 3 m of coarse gravels that represent the Niederterrasse of the River Rhine, which is reliably dated to the LGM (Kock et al. 2009). The molluscs were found within a series of fluvial sands with some fine gravel, rare ostracods, *Chara*, wood fragments and plant debris that included *Corylus* nuts. The assemblage was first studied by Woltersdorf (1954) aided by Forcart, but has been completely reanalysed, including numerous unidentified shells and fragments that represent around two-thirds of the total fauna.

The assemblage includes a number of species typical of warm interglacial periods (Table 27). Biostratigraphical markers include *Acicula lineata*, which first appeared in Switzerland during the Eemian, and *Aegopinella ressmanni* (Figures 8 and 10), which is characteristic of full interglacials and was last present during the Eemian. Taken together with its stratigraphical position, it is clear that this rich molluscan assemblage dates from the Eemian. The absence of other biostratigraphical markers suggests that the fauna probably dates from the early to middle phases of the Eemian, before the classic marker species seen at Niederweningen arrived (cf. Section 6.2.1).

The terrestrial molluscs indicate damp, rather open largely deciduous woodland with a rich understory of tall herbs and bushes/young trees, together with small patches of open ground with low herbaceous vegetation (Table 27). The varied assemblage of aquatic molluscs shows that accumulation took place near the edge of the Rhine, slightly above the level with permanent water, where it was slow-flowing and had a rich aquatic flora. The numerous shells from taxa typical of springs and subterranean aquatic habitats must have entered the river nearby in spring-fed streams. When the shells accumulated the level of the Rhine seems to have been around 5 m higher than it is today (245 m asl).

6.2.9 **Bad Zurzach, AG** (2664 350/1270 960; 341 m asl)

In 1994 a core was sunk near the centre of Bad Zurzach, which after 2.9 m of sandy-silts, went through 15.2 m of sandy fluvioglacial gravels (the *Rheintal Schotter*) that correspond to the Niederterrasse. Beneath this were 12 m of dark grey silts and fine sands with bands of gravel (from 18.1 to 30.1 m depth) with mollusc shells and pieces of wood, two of which proved to be too old for radiocarbon dating (>57,000 BP for 29 m depth, >53,000 BP for 26 m depth; University of Bern). Underneath were 2 m of sandy gravels (the *Weiach Schotter*), then molassic bedrock. The same silty sediments have been found in several other cores beneath the south-eastern part of Zurzach, extending ESE for at least 700 m towards the Rhine, where they reach c.20 m thick and clearly represent flood deposits (Graf 2009b, p.106, 109, 110).

The limited molluscan assemblages were extracted from two small samples taken at 24.60 and 24.00 m depth, just below the mid-point of the silty deposits (Table 28). It seems likely that only the larger and most complete shells were picked out, so it is unfortunate that no residues were available to re-sort for more shell material. The presence of several typical interglacial species, the radiocarbon dates and the stratigraphic position, comparable to that of Bürgerspital at Basel (cf. Section 6.2.7), all indicate that this fauna dates from the Eemian. The limited numbers of molluscs preclude any precise assessment about which part of the Eemian the shells belong to, but the fauna may represent the early to middle phases due to the absence of any typical Eemian marker species. The silty deposits were present from 311 m to 323 m asl in the cores, which suggests that the Rhine at Zurzach was flowing at a similar level to today (318 m asl).

The terrestrial molluscs indicate damp, fairly open woodland with a rich understory of tall herbs, which must have been growing within the floodplain adjoining the left bank of the Rhine (Table 28). No aquatic molluscs were picked out during sorting.

6.2.10 **Wolfbach, ZH** (2685 250/1247 810; 531 m asl)

In 2021 D. Kälin sampled silts with wood fragments, organic remains and some mollusc shells in the valley of the stream known as the Wolfbach, near Hottingen, east of Zürich. Up to 5+ m of silts with lignite layers have been documented from the incised course of the stream and nearby boreholes, overlying up to 10+ m of compact laminated lacustrine or glaciolacustrine silts and fine sands, which in turn overly up to 25+ m of glacial till. The silts with organic remains were covered by up to 80 m of glaciogenic deposits that consist mostly of basal till, as well as up to 10+ m of glaciolacustrine silts and up to 10 m of blocky gravels in a silty-sandy matrix (Pavoni et al. 2015, p.63-64, fig.17). A radiocarbon date of >45,000 BP on wood from the silts provides a minimum age.

Two bulk samples were taken and processed by D. Kälin. In addition to moderate frequencies of mollusc shells, organic remains include needles from *Picea*, plus seeds from *Rubus* sp. and the aquatic plant *Ranunculus* sect. *Batrachium* (identified by NT).

The molluscs include the interglacial marker species *Aegopinella ressmanni* and *Discus perspectivus*, as well as several other taxa typical of a warm interglacial periods. The stratigraphical evidence as well as the range of species present suggest that the silts most probably correspond to the Eemian. The terrestrial molluscs indicate fairly damp, rather open largely deciduous woodland with a rich understory of tall herbs and bushes/young trees, together with small patches of open ground with low herbaceous vegetation (Table 29). The aquatic and marsh molluscs suggest that the silts accumulated in a shallow marshy pool prone to a degree of seasonal drying out.

6.2.11 **Port Valais, VS** (2556 080/1135 780; 389 m asl)

In 1961, correction of a bend in the cantonal road 400 m west of Port Valais and 3.5 km SE of the Lac Léman, exposed a series of lake deposits overlying molassic bedrock. Documented by M. Burri between c.383 and 388 m asl, the sediments consisted of over 3 m of fine sands and silts with mollusc shells overlain by just under 2 m of silty-marls, silts, and clayey-silts, with this sequence being covered by a glaciogenic deposit described by Burri (1962) as “local moraine.” Burri took a single sample for molluscan analysis from the fine sands and silts, while in the early 1980’s L. Chaix took a further four samples from the upper part of these lake sediments. Burri noted that the fine sands and silts were full of mica redeposited from the molasse by the Rhône River, showing that they probably represent an early terrace of Lac Léman rather than the vestiges of a small palaeolake. While the shells analysed by Burri could not be found in the collection of the Musée cantonal de Géologie, Lausanne, the Chaix samples were available for reanalysis.

The aquatic shells seem to represent fairly shallow, rather gently moving water very near to where the Rhone River flowed into Lac Léman (Table 30). Most of the species suggest rather calm water, which towards the top of the sequence became increasingly shallow and had a rich aquatic vegetation, although *Pisdium tenuilineatum* and *P. subtruncatum* are indicative of some water movement. Similarly, the decreasing ratio of *Bithynia tentaculata* shells: opercula is a sign of the rising influence of wave action as the lake became shallower. The faunas suggest a mean lake-level of around 389-390 m asl, 17-18 m above the present level of the lake (372 m asl), linked with a 20 m lake terrace. This terrace is considerably higher than lacustrine deposits of the 8-10 m terrace, which seem to date from the Late Glacial until the Preboreal (cf. Section 6.4.1; Villaret and Burri

1965, Gaillard et al. 1983, Gallay and Kaenel 1983, Lahouze 1983). Moreover, the supposed '30 m terrace' appears to consist largely of glacial deposits, with the only known molluscan assemblages or biological material representing Late Glacial terrestrial or paludal faunas (Chaix 1983, Gabus et al 1987, Weidmann 1988, Schoeneich 1998).

The terrestrial molluscs include several that are typical of warm interglacial conditions, including some (*Acicula lineata*, *Cochlostoma septemspirale*, *Oxychilus glaber*) that are normally associated with the mid to later phases of an interglacial period. Given the height of the terrace, the interglacial indicators and the presence of moraine covering the sequence, it seems highly likely that these lake sediments date from the Eemian. Of note, however, is a high proportion of open ground molluscs (>70% in Sample 3), indicating that the local environment consisted of rather open, largely deciduous woodland with an understory of tall herbs, and significant patches of open ground with low herbaceous vegetation. A similar peak in open ground molluscs can be observed during the final stages of the Eemian at sites like Burgtonna in central Germany (Mania 1978), suggesting that the lake sediments at Port Valais may date from the late Eemian.

6.3 Late Pleistocene sites dating from the Würm (Birrfeld Glaciation)

6.3.1 Muntschemier-Gugglieracher, BE (2576 340/1205 310; surface 460 m asl)

A sample was taken by the author in 1996 from the infill of a buried channel in a gravel quarry at Muntschemier-Gugglieracher, BE. The upper part of the channel infill consisted of finely bedded fine sands with some silt, a little fine gravel and mollusc shells, while the lower part was not visible. The channel was covered unconformably by up to 9 m of fluvioglacial gravels and sands of the *Obere Seeland Schotter* (OSS), which were in turn capped by basal till dating from the LGM (Meyer-Wohlfarth 1986). The OSS, which is present down to 442 m asl at Ins-VLG, is widespread in the Seeland region and may correspond to the LGM or to MIS 4 (Pugin 1991). The buried channel was cut into the sandy gravels of the *Untere Seeland Schotter* (USS), which are 2 to 7 m thick and at this site are present from <445 up to 451 m asl, while 2 km to the west at Ins-VLG, the only other site with these gravels, they are present from <435 m up to 442 m asl. These localised gravels appear from their bedding structures and granulometry to have accumulated in a braided river. The sands of the buried channel seem to be contemporary with similar deposits infilling a channel in the gravel quarry at Treiten-Ryffli, 3.3 km to the north-east, which had mollusc shells, wood fragments and plant remains (Meyer-Wohlfarth 1986, fig.12, 14, 15). The finely bedded sands with silty and gravelly bands, were associated with horizontal and inclined bedding, medium-scale cross-bedding and small-scale trough cross-bedding. At Muntschemier the channel infill was conserved from <448.50 m up to c.450.50 m asl, while at Treiten-Ryffli the channel sands were present from c.446.0 up to 452.10 m asl and have a radiocarbon date on a wood fragment with a minimum age of 47,000 cal BP (UZ 2134). The course of this buried channel suggests that it probably continued north-eastwards to drain into the Aar.

The molluscs from the sandy channel are 90% aquatic (Table 30). The fragmented nature of the assemblage and paucity of bivalves suggest that the shells accumulated as a result of seasonal flow near the edge of the channel. As the sample was taken at c.450.0 m asl, the mean level in nearby Lake Neuchâtel at that time may have been around 449 m asl, some 20 m higher than today (429 m asl). The aquatic and paludal molluscs show that the river was slow-flowing, had a moderately rich aquatic vegetation, and was flanked by a fairly dense fringe of marsh plants. The presence of *Planorbis carinatus* and the thermophilous bivalve *Pisidium moitessierianum* indicate that the channel must have been active during a fairly prolonged period of rather mild climate, which given the rather restricted nature of the terrestrial molluscs and the stratigraphic context, was probably an interstadial. The presence of taxa like *Fruticola fruticum* and *Cepaea hortensis* indicate that this is likely to have been during the Early Würm, as they were absent from MIS 4 onwards in the Swiss Plateau and adjoining regions. The non-marsh terrestrial molluscs suggest a local environment dominated by tall herbs, with some trees and shrubs.

Beneath the USS are lake silts, which at Muntschemier become sandier with wood fragments above 444.0 m asl and continue up to 446.3 m asl, while at Treiten-Ryffli silts and sandy-silts with plant remains are present from <447.0 m up to c.450.50 m asl. At the former site, pollen from 13 samples between 438.55 and 443.80 m asl, taken in a core below the quarry floor, have spectra typical of a forested interglacial (B. Amman in Meyer-Wohlfarth 1986). *Pterocarya* is present in most samples, which might imply that the silts correspond to the first phase of MIS 7, similar to Grandson (cf. Welten 1988, diag. 13; cf. Section 6.1.8), but the additional presence of reworked *Carya* rather suggests that *Pterocarya* is also redeposited. At Treiten-Ryffli, spectra from 3 samples between 449.80 and 450.10 m asl are somewhat different as they have a strong representation of *Pinus* (35-44%) and *Picea* (7-28%), declining *Abies* (2-17%), a lower proportion of *Quercus mixtum* (3-9%) and there is no *Pterocarya*, although *Carya* is again present. If both silt deposits date from the Eemian, as local stratigraphy suggests (cf. Pugin 1991, fig.11, p.191-193), then the silts from Muntschemier may correspond to a late phase of the Eemian in the nearby sequence from Meikirch II (zone DA-14, Welten 1982, diag. 1a), while the silts from Treiten-Ryffli might be slightly younger (end of zone DA-15). Some 23 km to the south-west at Cortaillod-Les Pendantes, a land-slip in 1985 revealed a 3 m sequence of lacustrine silts, sandy-silts and silty-sands, with fairly abundant well-preserved wood and cones from *Picea*, from <445 up to >448 m asl. (2554 980/1198 975; Brochier 1986, p.27, 30-31). A single pollen sample from these silts has a spectrum dominated by *Picea* (64%), with *Abies* (10%), *Pinus* (5%) and c.6% of deciduous trees (1.6% *Buxus*, 0.6% *Carpinus*, 1.6% Fagus and 2.1 % *Quercus*; Hadorn 1986, p.43-44), similar to the samples from Treiten-Ryffli and the later Eemian at Meikirch II (first half of zone DA-15). Given their altitudes, the lake deposits with preserved organic remains at these three sites might suggest a mean lake-level of around 450/452 m asl (cf. the method used to estimate lake-levels in Thew 2016, 2/p.19-24). Nearby at Cortaillod-'Les Breguettes' (2555 280/1199 680) a sequence of probable Eemian lake deposits from <459.50 up to 472 m asl with silts, laminated silts, sands and three pebbly beach levels, which suggest mean lake-levels between c.462 and 469/470 m asl, have pollen spectra dominated by *Picea* and then *Pinus*, but no *Carpinus*, suggesting that they also belong to the late Eemian (Weber-Tièche 1998).

It thus appears that during the late Eemian the level of Lake Neuchâtel may have fallen from c.475 m (cf. Les Tuileries - Section 6.2.2) to around 450/452 m, but might then have rebounded to between c.462 and 469/470 m asl. During the Early Würm (possibly MIS 5d) it fell once more to <434 m asl, before rising to above c.445 m asl during the accumulation of the USS gravels, and then to c.449 m asl while the buried channel at Muntschemier and Treiten-Ryffli was active (possibly during MIS 5c). The site at Muntschemier has BT opercula that could be used for AAR Dating.

6.3.2 **Boudry-Champ le Sage West, NE** (2555 630/1200 650; 439 m asl)

During the construction of the A5 motorway to the west of Neuchâtel, a trench excavated across the delta of the River Areuse revealed lacustrine sediments beneath 6-7 m of deltaic foreset gravels (equivalent to *Unit c* in Pugin and Rossetti 1992). The lower 3-4 m of the gravels have a silty matrix and seem to be fluvioglacial gravels dating from the LGM (equivalent to *Unit b*), while the upper gravels (*Unit a*) are sandy braided river gravels that were deposited by the Areuse during the Oldest Dryas (Elmer and Thew 2016). There is a clear unconformity at the base of the gravels that marks an important sedimentary hiatus. Below this are c.2 m of gently dipping, darkish blue-grey detritic silts with some sand and pebbles, up to 433 m asl, underlain by c.1 m of blue-grey silty-sands with moderate fine to medium gravel up to c.431.50 m asl, and then >0.5 m of fine to medium sandy gravel from <430 m up to c.430.50 m asl.

A sample taken at c.431 m asl within the lacustrine silts produced a fairly restricted molluscan fauna that is 99% aquatic. Although the stratigraphic position of these silts suggests that they may date from the Early Würm (Birrfeld Glaciation), the presence of *Planorbis carinatus* and *Lymnaea stagnalis* indicate a fairly mild interstadial (Table 30). The fauna indicates gently moving water with a moderately rich aquatic flora, while the few terrestrial molluscs show that the lake was fringed with marsh vegetation. The mean lake-level for the silts seems to have been around 433/434 m, rising to c.435 m asl (cf. the method used to estimate lake-levels in Thew 2016, p.2/19-2/24), while the underlying silty-sands with pebbles suggest a level of around 430/431 m rising to c.431/432 m asl, and the gravels at the base of the sequence indicate a level below 430 m asl.

Around 1.8 km to the south, next to Petit Cortaillod, a series of cores taken in Lake Neuchâtel within the area of the lake village at Cortaillod-Est encountered sediments with similar pollen spectra to those from Cortaillod-Les Pendantes and Treiten-Ryffli (cf. Section 6.3.1). These were rightly interpreted by Hadorn (1986) as being from an interstadial, although the 10-20% of *Abies* is unlike spectra from other Würmian interstadial deposits across the Swiss Plateau. Cortaillod-Est is situated at the south-western margin of the Areuse Delta and 250 m south-east from the base of a steep escarpment that includes Eemian lake sediments. Of the five sedimentary units described by Bochier (1986), Unit I and the base of II seem to represent mass movement deposits from the nearby lake cliff (due to their chaotic nature plus the presence of soft clasts and pebbles down to 421 m asl), while there appears to have been further rapid deposition by mass movement at the base and summit of Unit III. Units IIb, III and V are very sandy and show a strong detritic input from the River Areuse. Lacustrine elements (calcareous concretions, molluscs, ostracods) are rare in Units I and II, more frequent in Unit III, but only become common in Units IV (grey marly-silts) and V. The strong input of redeposited pollen from the lake cliff and washed in by the Areuse, explains why the spectra closely resemble those from the late Eemian seen at Cortaillod-Les Pendantes and Treiten-Ryffli, as they include many reworked grains. Estimates for mean lake-levels vary from c.427 m asl for Units I and II, c.428 m asl for III, 430/431 m asl for IV and c.429 m asl for V (cf. Brochier 1986). These estimates suggest that after the period represented by the buried channel at Muntschemier (cf. Section 6.3.1), lake-levels may have fallen again sharply, leading to the sediments documented at Cortaillod-Est in Units I to III, possibly during MIS 5b. After rising lake-levels during Unit IV, it's possible that Unit V may correspond to the gravel deposit at the base of the sequence from Champ le Sage West, after which levels rose still further until to c.435 m asl, perhaps during MIS 5a. The same delta gravels that sit unconformably on the lacustrine silts at Champ le Sage West also truncate the sediments of Unit V in Cores 16, 25 and 26 at Cortaillod-Est.

To summarise, it appears that while the Untere Seeland Schotter may correspond to MIS 5d, and the buried channel sampled at Muntschemier might date from the interstadial MIS 5c, it is possible that the deposits documented at Cortaillod-Est may represent MIS 5b and the start of MIS 5a, while the lacustrine sediments at Champ le Sage West might correspond to MIS 5a. The Obere Seeland Schotter may date from MIS 4 or the LGM, while the lower gravels of the Areuse Delta and the basal till widely present in the area date from the LGM (Birrfeld Glaciation; cf. Meyer-Wohlfarth 1986, Pugin 1991). Boudry-Champ le Sage West has BT opercula that could be used for AAR Dating.

6.3.3 **Jakobsberg/Unteregg, Auenstein/Veltheim, AG** (Sample 2018: 2653 801/1252 549; surface 400 m asl; Sample 2010: est. 2653 800/1252 750; surface c.410 m asl)

In 2010, expansion in part of the Jura Cement quarry at Jakobsberg-Unteregg, Veltheim, AG, led to the discovery of mammoth bones (skull, mandible, long bones and tusks from at least two individuals) in a layer of reddish-brown silts that gave OSL ages of 64.6 ± 7.9 BP and 63.8 ± 5.1 BP (Gaar and Preusser 2012). These are among the oldest mammoth remains known from Switzerland, although elsewhere in Central Europe there are specimens of *Mammuthus primigenius* that date back as far as c.200k BP (Lister et al. 2005). In 2018 a deposit of darkish-grey silt with mollusc shells was sampled from a slightly lower stratigraphic level c.200 m away in the same quarry, but within the commune of Auenstein, AG.

The stratigraphic context for the mammoth bones given in Gaar and Preusser (2012) has some inaccuracies. Although the bones were found within a depression in the underlying limestone bedrock, this was not a doline but was caused by differential weathering of softer mudstone beds within the *Wildegg Formation* (part of the Oxfordian). Moreover, between the limestone bedrock and the reddish silts was a layer of up to 1 m of compact olive-grey basal till dating from MIS 6 (shown in photos of the excavation), which nearby was associated with a 60-ton erratic block of 'Walliser Kristallin' (cf. Jordan et al. 2011, p.76-77). The moraine was covered by up to 1 m of olive-grey-brown (reddish at summit) silty-sand with fairly abundant fine limestone gravel, moderate pebbles up to 8 cm and a few cobbles >10 cm at base. This was followed by up to 2 m of reddish-brown silt with some sand and fine limestone gravel, a few pebbles to 3 cm, rare limestone cobbles to 8 cm at base and moderate Fe-Mn concretions. The base of this layer had lenses of somewhat reddish beige loessic silt, which was also present inside the mammoth cranium and mandible. The reddish silts were covered by up to 8 m of gravelly sediments that probably correspond to the LGM (Birrfeld Glaciation - MIS 2). Gaar and Preusser (2012) describe these as being "fluvial sandy-silty gravels", but this is very unlikely given that the Hochterrasse fluvioglacial *Veltheim Schotter* is of MIS 6 age and is not present in the location of the mammoth bones, being found at c.350-385 m asl, c.520 m to the NE (geological map, sheet 1089 Aarau). Instead, these gravelly deposits are probably the silty solifluction/slope deposits referred to in the geological map as ‘Verlehmter Hangschutt, Solifluktionsschutt.’

Although the molluscs from the reddish silts are fairly abundant there are only 12 terrestrial species and include the cold-tolerant pioneer taxon *Columella columella*, which is typical for cold-period deposits (Table 31). Nevertheless, the presence of species such as *Abida secale*, *Cochlicopa lubrica*, *Trochulus villosus*, *Vallonia costata* and *Vitrea crystallina*, suggests that the silts and mammoth bones were accumulating during a time with fairly mild interstadial conditions. Nevertheless, the paucity of worm granules points to rather cold winters, while the presence of loessic silt at the same level as the shells and mammoth bones suggests a strongly continental climate.

The OSL dates of 64.6 ± 7.9 BP and 63.8 ± 5.1 BP correspond to the cold period MIS 4, which lasted from c.70,000 to 59,500 ice core years BP (GS 19 + GS 18), may well have coincided with glacier advances, and falls between the Early Würm and the start of the MIS 3 Middle Würm interstadial (Preusser et al. 2011, Rasmussen et al. 2014). The climatic indications given by the molluscs may suggest that the fauna possibly corresponds to interstadial GI-18 during the middle part of MIS 4 (the only interstadial during this period), which lasted for 260 years around 64,000 ice core years BP (Rasmussen et al. 2014). During this time conditions would have been somewhat milder, allowing the local vegetation to flourish and possibly encouraging mammoths to proliferate. Certainly, similar climatic and environmental conditions during early-mid MIS 3 coincided with the notable presence of mammoths at Niederweningen, ZH (cf. Section 6.3.5; Coope 2007, Drescher-Schneider et al. 2007, Furrer et al. 2007, Hajdas et al. 2007, Preusser and Degering 2007, Tütken et al. 2007).

The shells and mammoth bones from the reddish silts seem to have accumulated within a shallow marshy depression prone to regular episodes of drying out (Table 31), but not in a “still-water pond” as suggested by Gaar and Preusser (2012). The fauna also indicates that this marshy depression was bordered by significant patches of open ground with low herbaceous vegetation, surfaces with abundant tall herbs, and limited patches of bushy scrub, probably with some scattered trees.

The lower sample was taken from darkish-grey laminated silts with some clay and sand and a little fine gravel, found below the same layer of compact MIS 6 basal till that underlay the mammoth bones. The small molluscan assemblage has just 3 aquatic species (Table 31), all of which are climatically tolerant, suggesting that this fauna probably corresponds to a cold period. When combined with the stratigraphic position beneath a MIS 6 basal till, this suggests that the fauna may well date from an earlier phase of MIS 6. The aquatic molluscs, together with some ostracod valves, indicate a permanent water body such as a large pond, with rather oligotrophic conditions and a poor aquatic flora.

6.3.4 **Riehen, BL** (2616 250/1270 030; 305 m asl)
Allschwil, BL (2608 025/1265 750; 335-341 m asl)
Fuchshag, Bottmingen, BL (est. 2609 430/1263 840; c.345 m asl)

Several profiles were documented in trenches at Riehen in 1999, with Profile 3 being sampled for molluscan analysis and dating, while Profiles 1 and 3 were sampled for micromorphology (Jagher et al. 2003). A series of 17 bulk samples were taken in Profile

3 through calcareous loessic sediments with preserved shells. The lowest sampled level, Layer 5a, consisted of up to 0.9 m of light brownish-grey moderately humic colluvionated loessic silt with some sand and fine gravel, while Layer 3 was up to 0.25 m of light brown somewhat humic loessic silt affected by pedogenesis, and Layer 2 was up to 1.3 m of finely banded, pale yellow/light grey loessic silt that in its upper 0.5 m was slightly humic and less clearly banded. Layer 4 (up to 2.9 m of yellow-brown faintly banded loessic silt) was missing from Profile 3. Beneath this sequence, Layer 5b was up to 0.5 m of brown partially decalcified soliflucted loessic sandy-silt with abundant fine to medium gravel, affected by pedogenesis, below which was an orange-brown gravelly soil at the summit of Hochterrasse gravels (Layer 6a). An ESR date of c.48 ka ± 5 ka BP on mollusc shells from Layer 5a1 suggests an age during the Middle Würm (early-mid MIS 3), which equates to the Middle Pleniglacial. By contrast an OSL date of 17.9 ± 2.9 ka BP from Layer 5a1, plus OSL dates of 19.6 ± 3.3 and 17.5 ± 2.8 ka BP from the base Layer 2c, suggest an age during the Late Würm (MIS 2b), which corresponds to the Upper Pleniglacial. The basal palaeosol seems to have formed during the Eemian, while Layer 5b is thought to date from the Early Würm (MIS 5d-5a; Early Glacial; Jagher et al. 2003). A Palaeolithic chopper tool from Layer 5b is clearly redeposited.

In 1989/90 a 17.5 m profile through a series of loessic deposits with intercalated soil horizons was documented at Allschwil, c.9.3 km south-east of Riehen by G. Zollinger (1991). Although much of the sequence was decalcified, three samples were taken for molluscan analysis, of which the two first analysed by K. Münzing have been re-examined. The lowest sample was from up to 1.5 m of brownish-beige rather humic colluvionated loessic sandy-silt with some gravel (Layer 15), thought to represent the 'Niedereschbacher Zone' of the early Middle Pleniglacial (early Mid Würm interstadial, early MIS 3), while the upper sample was from up to 0.6 m of pale grey-beige loessic silt (Layer 20), thought to correspond to Erbenheimer Böden E2 or E4 of the Upper Pleniglacial (Late Würm, MIS 2). The middle sample came from brownish rather humic loessic silt that infilled an erosional gulley c.5 m deep, located c.100 m downslope, which has a radiocarbon date on the shells of 25.8-22.65 ka cal BP (Late Würm, MIS 2e-2c) The stratigraphic appellations used above refer to a well-established regional loessic sequence elaborated for the state of Hessen, west-central Germany (Semmel 1968). Beneath this sequence was up to 2 m of brownish decalcified silty palaeosol thought to represent the Eemian (Layer 14), while above Layer 15 was up to 0.6 m of beige loessic silt (Layer 17), followed by up to 0.4 m of a brownish loessic palaeosol (Layer 18), then up to 0.3 m of beige banded loessic sandy-silt (Layer 19). This sequence was truncated by major erosion at the base of Layer 20.

The sequence at Fuchshag, Bottmingen was sampled by Prof. M. Reinhardt of Basel during the late 30's or 1940's, in a sandpit dug into loessic silts at the western side of the Birsig Valley. No detailed records were made during sampling, but from the map the sand pit seems to have been up to c.5 m deep. The lower sampled layer consisted of pale yellow-grey-beige loessic silt with some fine sand, while the upper layer was pale yellow-olive-grey loessic silty fine sand with some medium-coarse sand. Some of the shells were provisionally examined by J. Favre, but all the material has been reanalysed.

At Riehen, the presence of the forest and shaded species *Clausilia dubia*, *Discus ruderatus*, *Ena montana*, *Eucobresia nivalis* and *Trochulus villosus*, the tolerant taxa *Euconulus fulvus*, *Nesovitrea hammonis* and *Vertigo substriata*, plus the open ground species *Vertigo pygmaea* (Table 32) suggest that Layers 5a, 3 and 2 all correspond to the early-middle parts of the Middle Würm interstadial (early-mid MIS 3) that equates to the Middle Pleniglacial (59-32 ka BP). This is based on a correlation with the well-studied sequence at Nussloch in south-western Germany (Antoine et al. 2001, 2009, Bibus et al. 2007, Moine et al. 2002, 2005, 2008), where these species all disappeared before the start of the Upper Pleniglacial. The molluscan evidence therefore suggests that the ESR age is correct, while all three OSL dates are significantly too young. The molluscs also suggest that Layer 3 cannot be the Lohner Boden, as proposed by Jagher et al. (2003), as this coincides with the end of the Middle Pleniglacial. At Allschwil, the presence of *Vertigo pygmaea* in Layer 15 (Table 32) seems to confirm the stratigraphic attribution proposed by Zollinger (1991) that puts this layer within the early Middle Pleniglacial. By contrast, the low diversity of the faunas from Layers 16 and 20 (6 species) places them firmly within the Late Würm (MIS 2), equivalent to the middle to late Upper Pleniglacial. It seems possible that Layer 5a from Riehen might correspond to Layer 15 from Allschwil, while Riehen Layers 4, 3 and 2 may correlate with Allschwil Layers 17, 18 and 19. The two samples from Fuchshag, Bottmingen still have some of the marker species present at Riehen, such as *Clausilia dubia*, but are missing others such as *Vertigo pygmaea*, while the lower sample has taxa such as *Abida secale*, *Euconulus fulvus*, *Trochulus villosus* that are absent from the upper sample (Table 32). It seems possible that these two samples correspond to the later part of the Middle Würm Interstadial (late MIS 3; 32-27.5 ka BP), which represents the start of the Upper Pleniglacial. They would therefore come after the faunas at Riehen and Layer 15 from Allschwil, but predate the faunas from Allschwil Layers 16 and 20.

The faunas from Riehen suggest a landscape of rather open scrub woodland with some mature trees and an understory rich in tall herbs, plus patches of damp open ground with low herbaceous and/or marshy vegetation (Table 32). The upper two samples from Layer 2b appear to show a decline in shade-loving species, possibly due to a modest deterioration in the climate. The lower sample from Allschwil indicates patches of open scrub woodland with an understory of tall herbs, interspersed with patches of damp open ground with low herbaceous and/or marshy vegetation. The two faunas from Bottmingen suggest a marked decline in trees and bushes, at the expense of surfaces with tall herbs and open ground with low herbaceous vegetation. The upper sample has aquatic shells that may have been redeposited from earlier Quaternary sediments. The upper sample from Allschwil suggests a largely open landscape of damp marshy ground with low herbaceous and paludal vegetation, together with limited patches of low bushy scrub.

6.3.5 **Grand Casino, Baden, AG** (est. 2665 549/1259 272; c.382 m asl)

The sample from this site was taken in October 1919 by the renowned geologist, Professor A. Heim. The unprocessed sediment was darkish blue-grey silt from near the bottom of a deep doline that descended through the Niederterrasse above the west bank of the River Limmat, just to the north of historic Baden below Martinsberg.

The fauna (Table 33) is abundant and well-preserved but is not very diverse and has the cold-tolerant pioneer taxon *Pupilla alpicola*, making it typical of an interstadial. Of note is the presence of the forest species *Ena montana*, *Eucobresia diaphana*, *Trochulus clandestinus* and *Trochulus villosus*, the tolerant taxa *Euconulus fulvus* and *Nesovitrea hammonis* and the open ground molluscs *Vallonia pulchella* and *Vertigo pygmaea*. These, plus an absence of species like *Fruticola fruticum* that were still present during the Early Würm interstadials and a similarity to the faunas from Riehen (cf. Section 6.3.3) suggest that the assemblage dates from early to mid MIS 3, during the Mid Würm interstadial. If correct, this implies that the doline predates the formation of the Niederterrasse during the LGM (cf. Graf 2009b).

The fauna indicates rather open, largely coniferous scrub woodland with some mature trees and an undergrowth of tall herbs, young trees and low bushes, as well as patches of open ground with low herbaceous vegetation. There was also damp marshy ground that was probably within the doline itself.

6.3.6 **Niederweningen, ZH - upper levels** (2670 825/1262 095)

The samples were taken by T. Bolliger in 1990 in a construction trench for the new schoolhouse. The three samples represent the upper part of a series of silty sediments beneath the 'Upper Peat' (the 'Mammoth Peat') and the base of the Upper Peat itself (cf. Section 6.2.1). OSL and radiocarbon dates show that these sediments date from the Middle Würm (Birrfeld Glaciation), during early-mid MIS 3 (Furrer et al. 2007, Hajdas et al. 2007, Preusser and Degering 2007, Anselmetti et al. 2010 and Dehnert et al. 2012.).

Unsurprisingly, the mollusc faunas (Table 21) have no typical interglacial taxa, but do include the cold-tolerant pioneer species *Columella columella* and *Pupilla alpicola*. Nevertheless, the aquatic molluscs include the taxa *Bithynia tentaculata*, *Stagnicola palustris/corvus* and *Unio* sp., which indicate interstadial conditions as they have never been found in cold stadial or full glacial contexts. The fauna indicates a terrestrial environment of shrubs and tall herbs behind a marshy area that borders a shallow lake with a rather abundant aquatic flora, fed by a nearby stream.

6.3.7 **Creux d'Enfer, Bertigny, Pont-la-Ville, FR** (est. 2574 660/1173 120; c.720/735 m asl; top of sequence c.790 m asl)

During the mid-1940's molluscs were found by L. Mornod (1947) within silty-sands at the eastern side of the Sarine Valley, c.1 km to the NW of Pont-la-Ville. The site was sampled by Mornod and A. Jayet and then provisionally studied by J. Favre. All of the material has been reanalysed, including numerous previously unidentified fragments, as well as shell material recovered from 0.7 kg of previously unprocessed sediment.

Overlying the Upper Marine Molasse, at the base of the sequence documented by Mornod (1947), was c.40 m of basal till, followed by 8 m of partially cemented fluvioglacial gravels with striated clasts. Above this came 1 m of sand, then 5 m of silts and sandy-silts, capped by 0.4-0.6 m of compact laminated lignite with wood pieces. There followed 5 m of dark-grey, grey and blue-grey organic-silts, silts and silty-sands with molluscs and organic debris, then c.1 m of sands and fine to medium gravel with striated clasts, 2.5 m of yellowish silty-sands with molluscs, 1 m of sands and fine to medium gravel with striated clasts, then 3 m of ochre silty-sands. These were covered by 16 m of partially cemented fluvioglacial gravels with striated clasts, 10 m of LGM basal till and finally c.30 m of LGM gravelly moraine. The site was revisited by Dorthe (1962), who documented a similar sequence (2574 600/1173 100). Between the two units of fluvioglacial gravel he noted 4 m of blue-grey sandy-silt and dark grey sand with organic debris, then 0.5 m of compact lignite, 6.5 m of blue-grey silts and sandy-silts with some organic debris, 1 m of grey-brown organic silty-sands, blue-green silty-sands and bands of lignite up to 5 cm thick, with molluscs and abundant organic debris, 6.5 m of partially cemented ochre sands with scattered pebbles and molluscs, and finally 3.5 m of sands with gravel and large pebbles, including striated clasts.

The sequence seems to have been deposited within a trough eroded into the Molasse, with the glacial deposits at base thought to date from MIS 6, while the succeeding layers are believed to represent a mix of lacustrine, marsh and fluviatile sediments with an additional glaciogenic input (Pugin 1989, p.314, Weidmann 2005, p.32-35). Pollen analysis on the main lignite layer and the preceding silts by Ludi (1953, p.35-39) and more recently by E. Bezat suggests that they date from the Eemian, but the overlying silts and sands have not been studied (Weidmann 2005, p.32-35). Nevertheless, their stratigraphic position and the presence of striated clasts in the upper levels of the silts/sands indicates that they date from the Early to Middle Würm.

From dark grey silty-sand adhering to the shells and the unprocessed sample sediment, all of the molluscan material seems to come from the lower of the two levels with shells indicated by Mornod. Like Petit Saconnex, the fauna is of limited diversity, has no interglacial species and includes the cold-tolerant pioneer taxa *Columella columella* and *Vertigo genesii* (Table 34). Nevertheless, the abundance and excellent preservation of the fauna, together with the presence of the marsh snail *Succinea putris*, similar to Sihlbrugg, and the aquatic prosobranch *Bithynia tentaculata*, also found at Niederweningen, suggests that it represents an interstadial. From the stratigraphic position and the species present, this is likely to have been during the Middle Würm interstadial, early-mid MIS 3.

The 5% of aquatic molluscs, 70% of marsh snails, ostracod valves and the seeds from aquatic and marsh plants, show that the shells accumulated within shallow, gently-moving water that was prone to seasonal drying out, had a fairly rich aquatic flora and was fringed by a dense marsh vegetation (Table 34). This may have been an area of sheltered water at the edge of a river or a small lake fed by a stream. The non-marsh terrestrial molluscs point to fairly damp, very open, bushy scrub with scattered trees, surfaces covered by tall herbs and some patches of better drained more open ground with low herbaceous vegetation.

6.3.8 **Sihlbrugg, ZH** (est. 2686 160/1229 990; c.590 m asl)

The gravel quarry at Sihlbrugg was visited by T. Bolliger in 1989/1990. He took a small sample in a compact layer of dark brownish-grey organic silt with plant and insect remains and large pieces of wood, which was both underlain and covered by several metres of sandy fluvioglacial gravel.

The small molluscan assemblage (Table 35) includes the marsh snail *Succinea putris* and the cold-tolerant pioneer *Vertigo genesii*, like the fauna from Bertigny/Pont-la-Ville. These species together with the good shell preservation but low faunal diversity, is typical of interstadial conditions, which given the stratigraphic position may correspond to the Middle Würm interstadial, early-mid MIS 3, although it is also possible that this fauna may represent an interstadial of MIS 6.

The molluscs indicate very damp marshy ground, behind which was a zone with tall herbs and perhaps some small bushes and young trees. The presence of insect remains and abundant seeds from aquatic and marsh plants indicate that the shells accumulated in a body of calm, shallow, permanent water.

6.3.9 **Münsingen, BE** (2608 425/1192 330; 522 m asl)

A gravel quarry that used to lie around 80 m to the NE of the Psychiatric Centre at Münsingen (now filled in) was visited and documented by C. Schlüchter in 1971/72. He sampled a discontinuous layer of grey silty-sand and sandy-silt at the summit of the *Wichtrach-Schotter*, which forms the Niederterrasse to the east of the River Aar. The base of the silts was irregular due to the undulating surface of the underlying gravels, while the summit was truncated by Holocene colluvial gravels.

The shells were first examined by M. Wüthrich in 1972, but they have been completely reanalysed, including numerous previously unidentified shells and fragments. The low diversity and excellent preservation of this assemblage is typical for an interstadial with fairly mild conditions (Table 36). The fauna appears to correspond to the Late Glacial Bølling-Allerød Interstadial, in keeping with the stratigraphic position of the sampled sediments. The presence of *Clausilia dubia* together with an absence of other forest and shade-loving species, suggests that the molluscs probably date from the late Bølling or early Allerød (cf. Section 6.3.9).

The fauna is typical of damp stable grassland with some tall herbs and a few scattered shrubs/trees, which surrounded a marshy depression or shallow pond prone to seasonal drying out (Table 36). Ostracod valves found with the molluscs were identified by H.J. Oertli as being *Candona neglecta*, which is present in a wide variety of aquatic habitats.

6.3.10 **Räffelstrasse, Binz, Zürich, ZH** (2681 120/1346 370; 422.50 m asl)

In 2013 a construction trench at Räffelstrasse, Binz, in Zürich revealed a sequence of grey to olive-grey finely bedded silts with varying proportions of clay and fine sand, plus sporadic thin (2-8 cm) layers of silty fine sand, overlying grey sandy fine to coarse (to 20 cm), poorly sorted fluvioglacial gravels that correspond to the Niederterrasse. At the southern margin of the parcel the silts were 3.5 to 4.5 m thick and covered by 4.5 to 5.5 m of modern backfill, while in the west-central part they were up to c.6 m thick and covered by c.1 m of Holocene colluvium. In the southwestern part of the parcel, where the silts were 4 m thick, the upper 3 m had wood fragments and *in situ* stumps of pine trees (*Pinus sylvestris*). The silty sediments seem to have been deposited by slope-wash from the eastern flank of the Uetliberg, formed largely of Upper Freshwater Molasse, which lies just 1.3 km to the south-west (Reinig et al. 2018). A 2 kg sample was taken for molluscan analysis among the roots of a tree stump at c.422.50 m asl, 2.3 m from the top of the silts, in blue- to olive-grey silt with clay and a little fine sand.

There were several horizons with tree stumps, and the sample was taken next to one of the lowest found. Radiocarbon dates on the pine stumps span from 13,900 to 11,400 cal BP (12,037 ± 30 BP to 9,872 ± 30 BP), which corresponds to from the end of the Bølling until the early Preboreal. A peak in the number of dated stumps at 12,800 to 12,500 cal BP, represents the end of the Allerød to the first part of the Younger Dryas (Reinig et al. 2018). The mollusc sample appears to correspond to the earlier part of the Allerød.

The moderately abundant, well preserved molluscan fauna is of rather low diversity, typical for an interstadial. The molluscs include *Nesovitrea petronella*, which after the

LGM seems to have reappeared in the Swiss Plateau during the early Allerød (cf. Liniger and Thew 2008), but they are missing taxa that appeared later on in this period (cf. Section 6.3.9). This suggests an early Allerød date, in good agreement with the pine stumps and radiocarbon dating. The fauna indicates that the surrounding area had fairly damp, rather open, largely coniferous woodland, with an understory of tall herbs and young trees/bushes, together with significant patches of open ground with low herbaceous vegetation (Table 37).

6.3.11 **Dättnau Valley, ZH** (2694 125 / 1260 463; 487.5 m asl)

During a project studying sub-fossil tree stumps of *Betula* and *Pinus sylvestris* found in a loam pit in the Dättnau Valley, west of Wintherthur, ZH, in the late 1970's, K.F. Kaiser also took a column of 77 samples for molluscan analyses. In addition to radiocarbon-dated dendrochronological data from the pine stumps, there was a pollen profile for a nearby core (by M. Kuttel and M. Welten), and isotopic analyses on *Vallonia* sp. and *Trochulus sericeus* shells (Kaiser 1979, 1989, 1993. Kaiser and Eicher 1987). A complete reanalysis of the material has revealed 33 terrestrial and 5 aquatic taxa (Table 38). Molluscan preservation is mostly very good. The pollen shows that the mollusc sequence covers from the *Betula* phase of the Bølling until near the end of the Preboreal.

Throughout the sequence, the deepest part of the valley seems to have been occupied by a shallow pond or small lake. During the *Betula* phase of the Bølling, the location where the mollusc column was taken was within the marshy area around this water body, apart from a fairly brief interval when it was under water. The 21 terrestrial species indicate that at first the sides of the valley were covered by tall herbs, possibly with some scattered trees and bushes, plus surfaces of open ground with low herbaceous vegetation, but later on there were patches of open woodland with a rich understory of bushes/young trees and tall herbs (arrival of *Discus ruderatus* and *Trochulus montanus*). During the Allerød the sampling location was at times very marshy and at others somewhat drier, while the marsh vegetation became taller and denser. The 27 terrestrial species include the newly arrived forest taxa *Ena montana*, *Eucobresia diaphana*, *Trochulus villosus*, as well as the tolerant snail *Columella edentula* and the marsh taxon *Carychium minimum*. The fauna indicates that the valley sides were covered by rather open, largely coniferous woodland with mature trees and an understory of bushes/young trees and tall herbs, although patches of open ground with low herbaceous vegetation persisted. The Younger Dryas may have seen a shrinking or partial infilling of the valley bottom pond. The 19 terrestrial species suggest a significant opening out of the woodland and an expansion in the surfaces of open ground. During the Preboreal the sampling location remained rather marshy. Although the faunas are less abundant, the 24 species include new forest taxa like *Clausilia dubia* and *Aegopinella nitens*, as well as the Holocene marker *Carychium tridentatum*. The molluscs point to rather open largely coniferous woodland with mature trees, although this seems to have become increasingly deciduous, while patches of more open ground with low herbaceous vegetation continued to be present.

6.4 Holocene sites

6.4.1 Sous-Terre, GE - upper level (2499 175/1117 750)

Two samples were taken by A. Jayet in 1967 from the ‘upper level’ at Sous-Terre, in a grey marly silty-sand with moderate gravel to 3 cm, succeeded by grey sandy marly-silt with some fine gravel (cf. Section 6.1.2). This site is located on the right bank of the Rhône c.0.5 km from where the river exits Lac Léman, with the samples being taken between 376.30 and 377.0 m asl, 7-8 m above the present level of the Rhône (369.30 m asl; Jayet and Amberger 1969). Given the strong aquatic component, this deposit seems to represent a 9-10 m terrace, that is contemporary with the 10 m terrace from Lac Léman (cf. Schoeneich 1998). The molluscs from the lower sample include the terrestrial marker species *Discus ruderatus* but no other forest taxa, as well as the aquatic gastropod *Gyraulus albus*, which indicate that this fauna probably dates from the earlier part of the Preboreal (Table 12). AAR Dating of BT opercula gives a value that agrees with an early Holocene date for this deposit (cf. Section 5.7; Figure 9; Penkman et al. 2024). The upper sample includes several new forest and tolerant species, notably *Aegopinella nitens*, *Cochlodina laminata*, *Discus rotundatus*, *Fruticicola fruticum* and *Macrogastra ventricosa*, which indicate that the fauna probably dates from the late Preboreal.

The rich assemblages of aquatic molluscs indicate that the shells accumulated in moderately shallow but permanent gently-flowing water with a fairly rich aquatic vegetation, near the edge of the Rhône, with flow being gentler and the aquatic flora richer in the upper sample. A few still-articulated pairs from the bivalve *Pisdium casertanum* and the presence of *Chara* in the upper sample strengthen this impression. Abundant paludal snails show that the river was fringed by dense, fairly low marshy vegetation. The non-marsh terrestrial molluscs show that the area adjoining the river had fairly damp, rather open, largely coniferous woodland with an understory of tall herbs, bushes and young trees, with new deciduous tree species arriving during the upper sample.

6.4.2 Coupy, Bellegarde-sur-Valserine, France – upper level (315-320 m asl)

During the 1970’s L. Chaix visited Coupy, east of Bellegarde, and took two samples from the edge of the Rhône in silty sandy sediments revealed by a low level of the artificial lake created in 1948 by the dam at Génissiat, 5.5 km downstream of Bellegarde. To flush out accumulating sediment, the level of this lake was periodically lowered from its usual 330 m asl, to 315 m in 1972 and 1975 and exceptionally to 278 m in 1978 (Guertault 2015). This led to the level of the Rhône above the ‘Perte du Rhône,’ a waterfall just below Coupy that was sadly hidden beneath the artificial lake, falling to 315 m in 1972 and 1975, and to c.310 m in 1978. A mean level of c.310 m asl was the original altitude of the Rhône before a dam raised it to c.315 m around 1900, then to 330 m asl in 1948. Although Chaix conducted a preliminary analysis, the rather fragmented shells have been completed reanalysed.

The presence of modern aquatic shells indicates that the samples were taken between 315 and 330 m asl, as from 1960 onwards the lake level was lowered to 315 m every 3-5 years (Guertault 2015), meaning that aquatic organisms were unable to colonise. Rare aquatic shells (indicative of rather calm, fairly shallow water) and 11-15% of marsh snails among the terrestrial molluscs, suggest that the silts accumulated as flood deposits at the marshy fringe of the Rhône. The only suitable location for this seems to have been at the right bank, next to the Perte du Rhône, below and 150-180 m SE of Coupy. Allowing for a seasonal fluctuation of 2-3 m (based on photographic evidence) before the construction of the dam around 1900 that raised the water-level to c.315 m, it seems likely that the flood silts accumulated within a localised terrace deposit at least 5 m above the surface of the Rhône before any dams were built.

The modest assemblages suggest a date during the late Preboreal or early Boreal, prior to the arrival of certain forest species that appeared across the Swiss Plateau during the mid to late Boreal (cf. Section 6.4.6, 6.4.). The proposed terrace deposit may therefore be contemporaneous with the 8-10 m terrace deposit of the Rhône documented c.25 km upstream at Sous-Terre (cf. Section 6.4.1). The molluscan faunas indicate that at the time of accumulation, the river was adjoined by rather open, largely deciduous woodland with some mature trees and a rich understory of tall herbs, and modest patches of open ground with low herbaceous vegetation.

6.4.3 **Abri Unterkobel, Oberriet, SG** (2759 659/2242 699)

Abri Unterkobel is a rock-shelter in the Alpine Rhine Valley with Mesolithic to Roman archaeological levels (Wegmüller et al. 2013, Wegmüller 2022). The shells come from Middle Mesolithic layers dating from the later Boreal, which have a rich molluscan assemblage dominated by forest and shade-loving species (Thew 2022).

Unfortunately, AAR Dating of AA and FF shell fragments gave several anomalous values (cf. Section 5.7; Figure 9; Penkman et al. 2024), which seem to be due to the occupation levels being heated by hearths during Mesolithic times, and later on by the burning of dung during Middle Neolithic times when the shelter was used to stable sheep/goats.

6.4.4 **Boppelsen-Cholholz, ZH** (2673 800/1258 850; c.680 m)

In 1948 A. Jayet visited an outcrop of the Höhere Deckenschotter at Wakern, near Boppelsen and noticed mollusc shells in the upper part of the gravel sequence. Under 1 m of Holocene soil and colluvium were 3 m of brown gravelly tufaceous sity-sands, which had both charcoal fragments and mollusc shells. Beneath this were over 6 m of fluvioglacial gravels and sands that corresponded to the Höhere Deckenschotter (Jayet 1949). The site was revisited and resampled by H.R. Graf in the early 1990’s, but he failed to find any deposits with shells (Graf 1993, p.66-68), and neither did R. Loepfe and D. Kälin when they reinvestigated and resampled the site in 2017 (cf. Section 3.4).

The molluscan material was first analysed by Jayet (1949), but it has been completely reanalysed for this study (Table 39). Jayet believed that the shells may date from the Late Glacial because of their stratigraphic position, their excellent preservation with little fragmentation, the absence of species typical of the ‘*Quaternaire inférieur*’ and the presence of large charcoal fragments. His arguments were partially correct, as there are no biostratigraphic marker species typical of the Early, Middle or Late Pleistocene, but the assemblage rather appears to date from the early Boreal by comparison with well-dated Late-Glacial/Holocene sequences in Switzerland (cf. Liniger and Thew 2008, 2016, Thew 2022). The sediment in which the shells were found seems to represent the infilling of an erosional gully, cut into the summit of the Höhere Deckenschotter gravels, which was c.3 m deep but of limited spatial extent. This would explain why neither Graf, nor

Loepfe and Kälin were subsequently able to locate it. AAR Dating of fragments of AA is in good agreement with a Holocene age for this molluscan assemblage (cf. Section 5.7), meaning that it should no longer be considered when discussing HDS deposits.

The molluscs indicate a fairly open mixed coniferous and deciduous woodland, with some mature trees and an understory of tall herbs and bushes/young trees, although some patches of more open ground with low herbaceous vegetation were also present.

6.4.5 **Wildbach, Embrach, ZH** (2686 036, 1263 999; 400 m asl)

Just 2.5 km to the south-west of the Irchel Plateau, near the northern edge of Embrach, a sequence of deposits that forms a 5 m terrace at the west bank of the stream known as the Wildbach was sampled by D. Kälin in 2022. At the base, up to 1.75-2 m above the stream surface, are medium-coarse clast-supported gravels with horizontal to somewhat inclined clasts, above which are 0.4-0.65 m of grey-black organic silts with tufaceous concretions (lower sample from base of layer), then 0.75 m of grey silts, then 1.70 m darkish grey silts with frequent pisoliths (upper sample 0.25 above base of layer), capped by 0.5 m of colluvium and 0.1-0.15 m of modern forest soil.

The lower sample has a very similar fauna to that of Boppelsen-Cholholz (cf. Section 6.4.3) and seems to date from the early Boreal, while the appearance of several new forest species shows that the upper sample probably dates from the mid to late Boreal (Table 40). There are no species present to suggest that the faunas may date from the Eemian, despite their position within a 5 m terrace.

Aquatic shells in the lower sample suggests that accumulation occurred within a fairly shallow, stream-fed pond or small lake bordered by a marshy area with fairly tall marsh plants. The abundant aquatic shells in the upper sample suggest a similar situation, but with slightly deeper water and aquatic plants, while the surrounding marshy fringe may also have included some trees. The clear implication from the molluscs is that during the earlier Holocene the stream known as the Wildbach was partially blocked downstream by a natural dam that allowed a small ribbon lake to extend for c.400 m upstream (where crossed by the 400 m asl contour line). Downstream, the most likely point for a natural dam is c.550 m to the north, west of Geissenrain. At some later point during the Holocene, the stream breached the dam and the ribbon lake was drained, leading to progressive down-cutting by the stream.

The non-marsh terrestrial molluscs indicate rather open mixed coniferous and deciduous woodland, with some mature trees and an understory of tall herbs and bushes/young trees plus patches of more open ground, which then became fairly dense, largely deciduous forest with mature trees plus a rich understory and limited patches of more open ground.

6.4.6 **Oberbipp/Steingasse, BE** (2616 765/1234 395; 487 m asl)

During the excavation of a Late Neolithic dolmen at Oberbipp in 2011/12, mollusc shells were observed both within the burial chamber and in tufaceous sediments that lay beneath the dolmen. Samples were taken for molluscan analysis and the study of other biological material, with the latter samples being processed in Basel. The dolmen was constructed at the foot of the Jura Mountains within the south-western part of a small delta formed by the stream known as the Dorfbach (Ramstein 2014, Ramstein et al. 2020, 2022).

The molluscan faunas from beneath the dolmen can be reliably attributed to the early to mid-Boreal by comparison with well-dated Holocene sequences in Switzerland (cf. Liniger and Thew 2008, 2016, Thew 2022). This is due to the presence of the Boreo-Alpine pioneer taxon *Discus ruderatus*, which disappeared during the Older Atlantic, and forest species like *Acicula lineata*, *Aegopinella pura*, *Clausilia cruciata*, *Macrogastra attenuata Platyla polita*, which arrived during the early Holocene. Also, the absence of other woodland taxa like *Helicigona lapicida*, *Helicodonta obvoluta*, *Isognomostoma isognomostomos* and *Monachoides incarnatus*, which appeared between the late Boreal and the end of the Older Atlantic in the eastern part of the Swiss Plateau (Table 41). The latter group were all present, however, in Late Neolithic deposits within the dolmen, in addition to the open ground species *Vallonia excentrica* that appeared during the early Subboreal. The latest arrival in the sequence was the edible snail *Helix pomatia*, which was an intrusive element among shells that accumulated in disturbances within the dolmen during the Early to Late Bronze Age. *H. pomatia* arrived in the Swiss Plateau during the Late Bronze Age (Liniger and Thew 2008, 2016). AAR Dating carried out on SP and WG from the sediments beneath the dolmen, as well as fragments of AA, FF and CH from Late Neolithic/early Subboreal layers within the dolmen itself (cf. Section 5.7; Figure 9; Penkman et al. 2024), make Oberbipp/Steingasse a key site for the new aminostratigraphy for Switzerland. This material gave values that are consistent with an Early/Mid Boreal to early Subboreal date for these deposits.

The tufaceous sediments beneath the dolmen include aquatic and paludal molluscs that show that the shells accumulated within a shallow marshy pond, liable to seasonal drying out (Table 41). Around this, was moderately dense mostly deciduous woodland with mature trees, and an understory of tall herbs and bushes/young trees, although limited patches of more open ground with low herbaceous vegetation were also present. The dolmen was constructed and functioned within a relatively small cleared area, surrounded by deciduous woodland with mature trees that persisted after the dolmen fell into disuse. The presence of marsh and aquatic shells after the dolmen was constructed shows that this monument was affected by episodic flooding from the stream.

6.4.7 **Steffisburg, BE** (2613 655/1179 895; c.562 m asl)

During the construction of an underpass beneath Bernstrasse and the railway for the Thun-Nord/Steffisburg motorway feeder road, at the start of the 1970's, C. Schlüchter documented and sampled a c.15 m thick sequence beneath the floodplain of the River Zulg, a tributary of the Aar. At the base of the sequence was at least 1 m of weathered gravels and blocks, consisting largely of molassic material, which Schlüchter (1976) interpreted as a debris flow deposit. This was succeeded by c.2 m of sandy-silts with molluscs, wood pieces and macroremains from *Abies*, *Alnus*, *Fagus*, *Fraxinus* and *Quercus*, at the summit of which was a peaty layer associated with an *in-situ* tree stump of *Alnus* with a radiocarbon date of 3376-2873 cal BC (4420 ± 110 BP), which corresponds to the Subboreal. There followed c.8 m of unweathered gravels and molassic blocks thought to represent more debris flow deposits, which were covered by 3-4 m of silty fine sands with mollusc shells. Preliminary analysis was undertaken by M. Wüthrich, but all the shell material has been re-examined, including numerous previously unidentified shells and fragments.

The faunas from the basal part of the lower level of fine deposits seem to date from the Older Atlantic, as they include the Boreo-Alpine pioneer taxon *Discus ruderatus*, together with the forest species *Helicodonta obvoluta*, *Isognomostoma isognomostomos*, *Monachoides incarnatus* and *Trochulus edentulus* that first appeared in the western part of the Swiss Plateau between the late Boreal and the end of the Older Atlantic (Table 42). These faunas correspond to the gap in the sequence documented at Oberbipp/Steingasse (cf. Section 6.4.4). The appearance of the open ground taxon *Vertigo pygmaea* in the upper part of the sandy-silts might possibly be due to local Neolithic clearance activity. The molluscs in the upper level of fine sediments seem to be fairly typical of the Subboreal, as there had been a loss of some forest species since the Older Atlantic, while open ground taxa are better represented, including *Truncatellina cylindrica*.

The molluscs from the lower level of fine sediments indicate fairly damp, rather open largely deciduous woodland with mature trees, and a rich understory of tall herbs and bushes/young trees, with possible indications of localised clearance in the upper part of these sandy-silts. The faunas in the upper level again suggest fairly damp, rather open mostly deciduous, probably secondary woodland. There are indications of fairly permanent open ground nearby that seems to be more extensive during the upper part of these silty-sands. Although accumulation of both levels of fine sediments took place within the floodplain of the Zulg, it was only during the final part of the upper level that the presence of aquatic molluscs, ostracods and *Chara* suggests that local conditions became much wetter.

The upper body of debris flow gravel is of considerable interest as it suggests that during the Subboreal there may either have been an extreme event such a major land-side or a period of notable surface instability within the local area.

6.4.8 **Belp-Neumatt, BE** (2604 600/1194 220; c.513 m asl)

During construction of a new primary school at Belp-Neumatt at the start of the 1970’s, a 2.4 m sequence beneath the floodplain of the River Gürbe, a tributary of the Aar, was documented and sampled by C. Schlüchter. At the base of the sequence was a peaty layer, which has a radiocarbon date of 6779-6335 cal BC (7680 ± 110 BP) corresponding to the Older Atlantic. Above this were c.2 m of silts and sandy silts with mollusc shells, which interfinger with peaty-silts with wood pieces and macroremains from *Corylus*, *Fagus* and *Picea*. The peaty-silts and silts seem to date from the Subboreal, as *Picea* only became well established in the Swiss Plateau during this period (Hadorn 1994). First analysed by M. Wüthrich, all the molluscs have been re-examined for this study and a small sample of unprocessed sediment was sieved to recover more shell materiel.

The molluscs from the greater part of the silts are in accord with a Subboreal date, as forest molluscs are not well represented and there are species indicative of permanently open ground (Table 42). The presence of *Helix pomatia* in the upper part of the silts suggests that they may date from the Subatlantic, as this species seems to have appeared in the Swiss Plateau during the Late Bronze Age (Liniger and Thew 2008, 2016).

Significant frequencies of aquatic and marsh molluscs, together with ostracods, suggest that accumulation took place in a stream-fed marshy pond prone to seasonal drying out. This may have been a channel cut-off of the Gürbe, as shells typical of deeper water seem to have regularly been brought in by flood waters. Nearby was rather open, largely deciduous, probably secondary woodland with some mature trees and a rich understory of tall herbs and bushes/young trees, together with patches of permanently open ground.

6.4.9 **Taubenhalde, Bern, BE** (est. 2600 150/1199 120; 505 m asl)

During construction of a new office block at Taubenhalde, just south of central Bern, a profile was sampled by C. Schlüchter at the start of the 1970's. The site lies c.350 m to the west of the River Aar (surface at 501 m asl), within what used to be the marshy floodplain. Dark grey silts with sandy bands and rather abundant organic remains, which included *Fagus* and *Picea* (identified NT), were present within a series of peaty layers ('Torfkomplex'). This suggests that the silts cannot be older than the Subboreal, as *Picea* only became well established in the Swiss Plateau during this period (Hadorn 1994). The molluscs were first analysed by M. Wüthrich, but all shells have been re-examined for this study and a small sediment sample was sieved to recover more shell materiel.

The molluscan fauna (Table 42) would support a Subboreal date for the silts, as marker species for the Subatlantic are missing and there are no open ground molluscs. The aquatic and marsh molluscs, together with ostracods, suggest that accumulation took place in a stream-fed shallow marshy pond prone to seasonal drying out. Bordering this was fairly damp, moderately open, largely deciduous, possibly secondary woodland with mature trees and a rich understory of tall herbs and bushes/young trees.

6.4.10 **Bavois-en-Raillon, VD** (2533 800-890/1170 880-905; 500-511 m asl)

The archaeological site at Bavois-en-Raillon was excavated in 1977-78 under the direction of J.-L. Voruz. Archaeological structures and material dating between the Bell Beaker period and the Roman era were found within a gully 20-35 m wide eroded into the LGM basal moraine and the underlying Molasse (Vital and Voruz 1984). A detailed sedimentological investigation was undertaken by J.-L. Brochier (1984). The molluscs from 28 samples were first analysed by L. Chaix (1984), but all of the material has been re-examined, including numerous previously unidentified fragments.

The creation of the gully is undated, like two other similar features in the Bavois area revealed during the construction of the A1 motorway (Brochier 1984). The earliest gravelly infill (Layer 17) seems to date from the Younger Dryas, due to a lack of Holocene marker species but the presence of *Cepaea sylvatica* that after the LGM first appeared during the Allerød (Table 43). The presence of aquatic shells shows that the gully already had a small stream flowing through it. The following sandy sediments (Layers 16-15) appear have begun accumulating during the early-mid Preboreal, due to the presence of Holocene marker species like *Carychium tridentatum*, a paucity of forest taxa, and frequent shells from the cold-tolerant pioneers *Columella columella*, *Vertigo genesii* and *V. geyeri*, and the pioneer shade-loving snails *Discus ruderatus* and *Nesovitrea petronella*. The presence of *Pisidium amnicum* among the aquatic molluscs shows that the stream was now perennial. The molluscs suggest that the floor of the gully was marshy, while the sides were largely covered by low herbaceous vegetation. Bordering the gully was a mix of rather open, largely coniferous woodland and patches of more open ground. Sandy sedimentation continued during the Boreal and the Older Atlantic (Layers 16-15), as the area bordering the gully became colonised by increasingly dense, largely deciduous forest with large mature trees (new forest species *Helicigona lapicida* and

Helicodonta obvoluta, while pioneer species largely disappeared). The denser forest cover led to a decrease in stream flow, which was no longer active throughout the year. During the later Older Atlantic to the Younger Atlantic, a dense, fully mature forest led to the gully becoming largely overgrown (Layer 14), while pedogenesis caused decalcification and the loss of shells. By contrast, nearby forest clearance and woodland exploitation during the Neolithic (Layer 13=12b, early Subboreal), which intensified during the Bell Beaker period (Layer 12a), led to a reactivation of the stream, which again became perennial and caused both erosion and the redeposition of eroded shells, although the area bordering the gully remained wooded (new forest species *Isognomostoma isognomostomos* and *Monachoides incarnatus*). Local clearance expanded during the Early Bronze Age, with occupation activity affecting the southern side of the gully for the first time (Layers 11 to 9), while the stream was more active than ever, causing further erosion and redeposition of eroded shells. Although much of the surrounding area remained forested, the arrival of species like *Vallonia excentrica*, and the reappearance of *Pupilla muscorum* and *Vertigo pygmaea* suggest that for the first time some of the cleared land was fairly permanent. Forest recovery during the Middle Bronze Age led to a major reduction in stream flow and much siltier sediments (Layers 8 to 7), as the gully became largely overgrown and soil development led to decalcification. Renewed forest clearance during the first part of the Late Bronze Age was linked with habitation structures at its northern margin. Increased silty sedimentation within the gully led to the preservation of low frequencies of shells, which show that forest continued to be well represented at the southern side of the gully (new shade-loving species *Cochlostoma septemspirale*), although there were areas of fairly permanent open ground (newly appeared *Chondrula tridens*) and the stream still flowed intermittently. Subsequently, as the gully became more or less filled in the stream ceased to flow and no shells were preserved in the silty and clay-rich colluvial sediments.

There are comparable sequences from the same region as Bavois, notably in the presence of cold-tolerant pioneer and shade-loving pioneer species during the early Holocene. Around 20 km to the north-east, in former marshy areas just west of Onnens, *Columella columella*, *Vertigo genesii*, *V. geyeri*, *Discus ruderatus* and *Nesovitrea petronella* could all be seen in Preboreal to early Boreal sediments (Stucki and Thew 2011). Similarly, some 15 km further to the north-east in former ponds and marshes at Bataillard near Bevaix, the same five species were accompanied by *Pupilla alpicola* in Preboreal to Boreal layers (Liniger and Thew 2008).

6.4.11 Hauterive-Champréveyres, NE (2564 480/1206 390; 428.50 m asl)

The BT opercula used for AAR Dating come from a late 19th century beach deposit at Hauterive-Champréveyres at the north-western margin of Lake Neuchâtel, which was sampled by the author in 1986 prior to motorway construction. This beach was formed when the level of Lake Neuchâtel fell suddenly by c.3 m during the late 1870's as a result of the *Premier Correction des Eaux du Jura*, causing severe erosion around the lake that led to the truncation of earlier lake sediments (Moulin 1991). It is therefore no surprise that the AAR Dating values show that both recent (late 19th/20th century) BT opercula and older (possibly Older Atlantic) redeposited opercula were present within this beach deposit (cf. Section 5.7; Figure 9; Penkman et al. 2024).

7 Conclusions concerning the study of molluscs from Deckenschotter deposits and other Quaternary sediments in Switzerland

7.1 Conclusions for the Irchel sites

- The study of the molluscan remains from all of the Irchel sites investigated between 1955 and 2022 (Tables 5, 6a, 6b) has yielded a minimum number of c.75,280 identified individuals, which include c.71,890 (95.5%) terrestrial molluscs coming from 89 species and 3,390 (4.5%) aquatic molluscs from 28 taxa. This represents an exceptional assemblage for both Switzerland and for Europe as a whole, as it matches the most important European sites for Pleistocene molluscan palaeontology. The Hasli Formation (HF) has 83 terrestrial and 27 aquatic species from 99 samples. Of the five principal sites studied from the HF (Hasli, Steig, Amselboden, Hochwacht and Wilemerirchel), Hochwacht proved to have the most diverse faunas, for both terrestrial (71 species) and for aquatic molluscs (19 taxa), although the fine sediments from the 'upper channel' at Hochwacht have the most diverse faunas of all, with 72 terrestrial and 18 aquatic species, coming from just 4 samples.
- As the majority of significant molluscan biostratigraphic marker species are present at all four study sites (Figure 3), while the faunas and the sediments indicate very similar environmental, depositional and climatic conditions, this suggests that these sites are all more or less contemporary and that the HF probably represents a single stratigraphic entity. The shells of the HF seem to have accumulated within the flood plain of a sizeable lowland meandering river. Sandy and gravelly deposits at the base of the sequences at Hochwacht and Amselboden suggest that these locations lay somewhat nearer the active channel than Hasli and Steig and that the river probably flowed to the south-west of the Irchel Plateau. These deposits also suggest that the channel probably had bed deposits dominated by gravels and sands.
- There is evidence from both the molluscs and sediments that the sequence through the HF at Hasli can be divided into four stratigraphic 'Parts.' These units represent four upward-fining sedimentary cycles, with sandier deposits at the start of each cycle indicative of more rapid accumulation, succeeded by siltier sediments, and then by silts with clay accompanied by signs of pedogenesis and poorer shell preservation as accumulation slowed at the end of each cycle. Cycles 2 and 3 ended with thin layers of humified lignite, showing a virtual cessation of sedimentation. These cycles appear to be linked to variations in the intensity of flood activity. The thicknesses of the four cycles at Hasli are 1.20, 1.70, 1.45 and 1.85 m, which might suggest a certain periodicity. The sedimentary and molluscan sequences at Steig and Hochwacht can similarly be subdivided into 'Parts,' which also seem to represent sedimentary cycles, although erosion has made these cycles more difficult to recognise.
- Molluscan assemblages and lithological evidence have been used to correlate between the sequences at Steig West and Steig East and between Hochwacht East and Hochwacht West with a fairly high degree of confidence (Figures 5 and 6), although correlations between Hasli, Steig and Hochwacht are much more tentative. At all three sites forest molluscs increased during Part 2, while Part 3 saw significant increases in the percentages of open ground and marsh molluscs, a decline in the proportion of

forest species and notably better shell preservation, and Part 4 was marked by a sharp decrease in molluscan numbers.

- The terrestrial molluscs from the HF give an overall image of a floodplain environment with fairly damp, rather dense, mainly deciduous woodland with large trees and a rich understory of tall herbs and young trees, with increasing proportions of marsh molluscs nearer to the main channel. At Hasli the gradual arrival of new woodland and shade-loving taxa shows a biosuccessional progression during Parts 1 to 3, as the forest became denser, more mature, more diverse, and increasingly deciduous. The faunas from Hochwacht and Amselboden show a similar progression in the forest, but this was notably more rapid, achieving maturity by the end of Part 2. A similar progression can be seen at Steig, although the local environment seems to have been significantly more open and retain an understory of abundant tall herbs throughout the sequence. The differences in the rapidity of forest development between the sites may have been related to the degree of dampness at the floodplain surface, with Steig being somewhat wetter.
- The molluscs from all four study sites at Irchel are typical of warm interglacial conditions. Moreover, the climate at the time when the HF was accumulating seems to have been significantly warmer than today, as the molluscan faunas included a number of species with modern or palaeodistributions that lie far to the south and east, indicating higher summer temperatures, and taxa with distributions that lie far to the west signifying considerably milder winters.
- There is also evidence from both the molluscs and the sediments for longer term changes in local conditions that may have been linked to more important variations in the climate. Most of Part 2, for example, seem to have been notably warmer and drier, allowing more diverse forest faunas and encouraging pedogenesis. By contrast, Part 3 at Hasli, Steig and Hochwacht seems to have been notably cooler and wetter, which led to increases in open ground, tolerant and marsh molluscs while forest and shade-loving taxa declined, saw the appearance of the cold-tolerant pioneer *Columella columella*, and allowed the shells to be better preserved. This is supported by pollen evidence and the presence of *Lemmus* sp. among the small mammals from Part 3 at Hasli, which is typically found in moist, relatively open habitats in areas with a rather cold climate.

- Around 4.5 m of fluvial gravel that succeeds the HF at Hochwacht includes in its upper part several silty soft clasts and a large lens of finely-bedded silts and fine sands. These are the deposits of the ‘upper channel.’ Both the soft clasts and the silty-sand lens yielded rich molluscan faunas which show that the river was bordered by a floodplain covered by dense, largely deciduous woodland with large mature trees and a rich understory of young trees, bushes and tall herbs, and very little open ground. The soft clasts represent flood silts that accumulated in a floodplain setting. The silty-sand lens also has a fairly varied aquatic fauna indicative of gently moving water with a relatively rich aquatic vegetation, indicating that the gravels and the lens accumulated within a gravelly meandering channel, which seems likely to have been the same river that generated the flood silts of the HF.

- The assemblages from both the soft clasts and the silty-sand lens have the same species as the HF and are typical of significantly warmer conditions than today. The presence of 6 new terrestrial species since the HF with modern or palaeodistributions that lie significantly to the west, south and east of Switzerland, suggests that conditions may have been equally warm as during the HF, or that the climate may have been slightly warmer. Biostratigraphically, the faunas include all of the major marker species already present in the HF, showing that they are of a similar age and part of the same chronostratigraphic period. Nevertheless, the presence within the lens of 5 new terrestrial species not found in the HF suggests that the 'upper channel' deposits are slightly younger.

- The molluscan faunas from the HF encompass many species that have never previously been recorded from Quaternary deposits in Switzerland, including several that have long been extinct and represent important biostratigraphic markers. The most important of these are the East-Central European species *Clausilia stranzendorfensis* and the Western European taxon *Cochlostoma salomoni*, which both disappeared around 1.8 My at the end of the older Early Pleistocene (EP1). Other characteristic markers are *Triptychia* sp. and *Neostyriaca dehmi*, two Central European species that also went extinct around 1.8 My, *Macrogastra sessenheimensis*, an East-Central European taxon that disappeared during the middle Early Pleistocene (EP2), *Archaegopis acutus*, an East-Central European species that went extinct at the end of EP2 and *Serrulella* sp. that disappeared after EP3. Hasli, Amselboden and Hochwacht also share the species association *Cochlostoma salomoni - Spermodea lamellata*, which in Central Europe has only ever been found at sites dating from EP1. Species new for Switzerland also include extant taxa that have distributions that lie far to the west, south or east of the Swiss Plateau. Some of these have been found in neighbouring countries in contexts that are also restricted to EP1. The presence of these molluscan marker species throughout the HF, as well as within the fine sediments of the 'upper channel' at Hochwacht, indicates that all of these deposits probably accumulated before 1.8 My.
- The small mammal remains recovered from the upper part of the HF at Irchel Hasli have several key biostratigraphic markers, including *Mimomys pliocaenicus*, that became extinct in Western-Central Europe around 1.8 My, as well as *Pliomys episcopalis/simplicior* that first appeared in Central Europe during the Olduvai Subchron after 1.934 My. The small mammals therefore suggest a date between c.1.93 and 1.8 My for the upper part of the HF. The presence of *Fagus* (beech) pollen at Hochwacht and Hasli is also important as *Fagus* was well represented during the Tiglian, but became rare during the remainder of the Early Pleistocene, again suggesting that the HF probably dates from the Tiglian. Palaeomagnetic data from Hochwacht and Hasli gives a clear signal for reversed polarity in the lower part of the HF and a strong signal for normal polarity in its upper levels. Given the biological data, this change in polarity should correspond to the Olduvai Subchron between 1.934 and 1.775 My (Raffi et al. 2020). The HF together with the deposits of the 'upper channel', therefore seem to date from between c.2.1/2.0 and 1.78 My, which in the MIS curve would represent MIS 75 to 63, from 2.04 to 1.76 My.

- As the HF and the deposits of the 'upper channel' may have accumulated during an interval of mainly warm interglacial conditions between 2.04 and 1.76 My, while the thick fluvioglacial gravels that preceded the HF represent truly cold conditions, it seems reasonable to correlate the accumulation of the Irchel-Schotter and the Steig-Schotter with MIS 78-76 in the MIS curve, which spans from 2.09 to 2.04 My. This interval seems to have been colder and lasted for longer than most other 'cold periods' during EP1, while there is convincing evidence across lowland Europe for glacial activity at this time.
- Before the cold period linked with the Irchel and Steig gravels, there was an interval of warm interglacial conditions during MIS 81-79, from c.2.145 to 2.09 My, that includes the Réunion (Feni) Subchron with normal polarity from 2.155 to 2.120 (Raffi et al. 2020) or 2.140 to 2.116 My (Ogg 2020). It seems possible that this warm interval coincided with the silty deposits with biological material at Irchel Ebni, because palaeomagnetic data suggests that the Ebni silts coincided with an episode of normal polarity. These silts seem to have been deposited by a meandering river bordered by a marshy floodplain during a period of warm climate.
- Preceding the warm interval that may include the Ebni silts, there was an earlier period of notably colder climate during MIS 82, which although somewhat shorter, from 2.17 to 2.145 My, was nevertheless associated with strong evidence for glacial activity across Europe. It is this interval that may correspond to the Langacher-Schotter.

7.2 Conclusions for Albishorn-Bürglen 2

- Altogether, the 13 samples analysed from sandy and silty levels within the fluvial gravels of the Albisboden-Schotter yielded a minimum of 6,054 individuals, which include 5,985 terrestrial molluscs (98.9%) from 58 species, but just 69 aquatic molluscs (1.1%) from 10 taxa (Table 8).
- Despite their impressive thickness (13-17 m), the molluscs show that the fluvial gravels that constitute Albishorn-Bürglen (A-B) 2 accumulated within a meandering river during a period with warm interglacial conditions. The local environment was of rather damp fairly open mixed deciduous-coniferous forest, with an understory of tall herbs and young trees, which by the top of the gravels had evolved into denser, largely deciduous, more mature and diverse woodland with a richer understory. The poor aquatic fauna suggests that flow was probably rather energetic in much of the river, in keeping with the gravelly nature of the sediments. Nevertheless, there were several aquatic species present which show that the meandering channel had stretches of quieter water where aquatic plants could flourish. Terrestrial species with modern or palaeo-distributions that lie far to the west, south and east of Switzerland show that the climate was significantly warmer than today.
- The molluscan faunas include several important biostratigraphical marker species (notably *Acicula parcelineata*, *Archaegopis acutus*, *Clausilia stranzendorfensis*, *Cochlostoma salomoni*, *Macrogastra sessenheimensis*, *Poiretia dilatata dilatata*) which indicate that these gravels date from EP1 and are of a similar age to the faunas from the Hasli Formation, in keeping with their comparable stratigraphic position

within the HDS complex. The lower part of the fluvial gravels at A-B 2 has reversed palaeomagnetic polarity (Graf 2019), like the lower half of the HF.

7.3 Conclusions for Albishorn-Bürglen 1

- The up to 1.4 m of overbank silts that constitute Albishorn-Bürglen (A-B) 1 lie within the upper part of the HDS sequence at this site. They are separated from the underlying fluvial gravels of A-B 2 by up to 6m of fluvioglacial gravels with large boulders followed by 9-12 m of compact glacial moraine (Bürglen Till). They are overlain by 24-30 m of fluvioglacial gravels with intercalated layers of glacial till (Albiswald Schotter-Till; cf. Section 3.3.2). The sequence terminates with 2-9 m of basal moraine and gravels that probably date from the Middle Pleistocene.
- From the 5 samples taken in the silts, a minimum of 239 individuals could be identified, including 98 (41.0%) terrestrial molluscs from 31 species and 141 (59.0%) aquatic molluscs from 10 taxa (Table 8), with all of the shells coming from thin bands of tufaceous silt within the sandy-silts and organic silts.
- The assemblages accumulated within a floodplain near the margin of a large, slow-flowing meandering river with aquatic plants and a marshy border. The local terrestrial environment seems to have consisted of fairly damp, rather dense, largely deciduous woodland with mature trees and a fairly rich understory of tall herbs and young trees, with very little open ground. Pollen in the silts also shows largely deciduous woodland with a strong coniferous element (Knipping pers. comm.).
- The presence of warm stenotherm species shows that the silts of Albishorn-Bürglen 1 represent a second interglacial period within the HDS sequence at this site. The organic and tufaceous nature of the flood silts suggests relatively low sedimentation rates due to only moderate flooding, suggesting that the climate may have been rather warm and fairly dry.

- The sequence implies an important stratigraphic break after the notable warm period represented by the thick fluvial gravels of A-B 2, when a major advance by the Linth-Rhine Glacier led to the formation of fluvioglacial gravels and thick basal moraine. Then, after the interglacial period represented by the silts of Albishorn-Bürglen 1, a further glacial advance led to the deposition of the second thick glaciogenic unit. The A-B 2 gravels seem to represent the first and second sub-units of the HDS in northern Switzerland (Graf 2019, fig.16, p.21-23; cf. Section 5.1), which dates from EP1 (Section 5.8.1), while all of the deposits above these gravels, including the A-B 1 silts, belong to the third sub-unit of the HDS. As there appears to be no evidence in any of the HDS sequences across northern Switzerland for a prolonged interruption between the second and third sub-units of the HDS, it seems plausible that the two glacial periods and the intervening A-B 1 interglacial may correspond to EP2, between 1.8 and 1.2 My.

- The molluscan faunas are significantly younger than those of the Irchel sites and A-B 2, as all of the most important biostratigraphical markers for EP1 have disappeared and only three Early Pleistocene marker species continue to be present. Instead, there are four new taxa that became typical elements within Swiss interglacial molluscan faunas from then onwards. Furthermore, all of the species present in the HF and at A-B 2 with modern or palaeo-distributions that lay far to the west or to the south have also disappeared, as well as most of those with distributions that lay far to the east, indicating that there had been a period with much colder conditions since then, which must have occurred after EP1. Taken together, the evidence suggests that these faunas date from EP2 or EP3. As the faunas are nevertheless younger than those from Hungerbol 2 that seem to belong to EP3 (see below), this rather suggests that A-B 1 probably dates from EP2.

- Pollen from the Albishorn-Bürglen 1 silts includes a number of thermophile tree species typical of a warm interglacial, but there is no sign of *Fagus* despite many thousands of grains being counted. *Fagus* pollen is rather common in EP1 contexts, but is rare in deposits dating from EP2 and EP3. As *Fagus* seems to have been found in the HF at Hasli and possibly Hochwacht, this gives another firm indication that the Albishorn-Bürglen 1 silts are significantly younger than the deposits at Irchel and Albishorn-Bürglen 2, and suggests that they probably date from EP2 or EP3.

- Around 1.76 My there was a major cooling that marked the transition from the Tiglian warm stage to the Eburonian cold stage in the North-West European Chronology. This major change took place just after the end of the Olduvai Subchron (at 1.78 My; Ogg 2020) and denotes the transition from the older Early Pleistocene (EP1) to the middle Early Pleistocene (EP2). The middle Early Pleistocene (EP2) incorporates two stages from the North-West European Chronology: the Eburonian cold stage, from 1.76-1.49 My, and the Waalian warm stage from 1.49-1.22 My. During EP2, the periods with the clearest evidence for significant glacial activity in Europe seem to have been MIS 58 at 1.67-1.64 My, MIS 52 at 1.545-1.525 My and MIS 50 at 1.51-1.49 My (cf. Section 5.3), all of which lie within the Eburonian. There was relatively little glacial activity in lowland Europe during the Waalian, which suggests that the glaciogenic deposits that envelope the silts of Albishorn-Bürglen 1 may date from the Eburonian. Of the Eburonian cold periods, the MIS curve suggests that MIS 58 lasted for somewhat longer, MIS 52 was slightly colder, while MIS 50 had a similar climate to MIS 58 but came after a warmer interval (MIS 51) that was both brief and not very temperate. If the first glacial advance that deposited the fluvioglacial boulder layer and Bürglen Till might possibly correspond to MIS 58, then the later advance that led to the Albiswald Schotter-Till complex may perhaps represent MIS 52-50. Such correlations are plausible as both glacial advances imply notably colder conditions, and these were the two coldest periods during EP2.
- If the suggested correlations for the glacial deposits are valid, then the interglacial silts of A-B 1 might represent MIS 57-55, or possibly MIS 57-53, between 1.64 and 1.545 My. The MIS curve suggests that MIS 57-55 may have been the longest and warmest interglacial period during EP2, making it a credible candidate for the interglacial silts, while MIS 53 was one of the shortest. If the silts at A-B 1 do indeed date from EP2, this would make them the first deposit with biological material from this period known in Switzerland.

7.4 Conclusions for Hungerbol 2 and Hungerbol 1

- The remains from a minimum of 19,064 individuals have been identified, which include 18,449 (96.8%) terrestrial molluscs from 61 species, and 615 (3.2%) aquatic molluscs from 16 taxa (see Table 10). Hungerbol 2 has 60 terrestrial and 16 aquatic taxa, while Hungerbol 1 has 21 terrestrial and 2 aquatic species.
- The up to 2.8 m of banded silts of Hungerbol 2, together with the underlying 1.2 m of finely bedded gravels and sands, were deposited by a fairly large lowland meandering river with a bed of sand and gravel, during a period with temperate conditions. These deposits lie at the base of a TDS terrace, within a channel eroded into the Molasse.
- The local landscape was composed of fairly damp, moderately open, largely deciduous woodland with mature trees and a dense understory of tall herbs and young trees, as well as small patches of open ground with low herbaceous vegetation. The forest became somewhat denser, more diverse and with significantly more large mature trees later in the sequence, although small patches of open ground remained, probably at the margins of the river channel.
- There are remains from steppe lemmings within the upper levels of the silts, which typically live in rather dry, open habitats where they can dig burrows. It seems likely that both these and the 3-6% of open ground molluscs were taking advantage of local habitats such as dry sandy banks linked with the river channel.
- Variations in shell frequency and the texture of the sediments show that there were fluctuations in both water-levels and flooding activity during the accumulation of the Hungerbol 2 silts. At the base (Part 1), sandier sediments together with the aquatic molluscs show that accumulation was taking place at the margin of a large, slow-flowing, meandering river with a fairly rich aquatic flora, while during Part 2 a rise in water-levels saw siltier sediments and accumulation in rather calm water with a rich aquatic vegetation, possibly in a sheltered embayment at the edge of the active channel. After a fall in water-levels, Part 3 consists of flood silts that accumulated at the floodplain surface near to the active channel.
- Above the Hungerbol 2 silts are up to 0.9 m of finely bedded gravels that may have been deposited by the same meandering river after a significant rise in water-levels. The summit of these gravels has signs of intense rilling erosion due to run-off water, which implies a sharp fall in water-levels.
- Above this were up to 2.2 m of banded flood silts that constitute Hungerbol 1. At the western side of the Hungerbol exposure these silts are largely decalcified. At the eastern side, the preserved shells indicate that they accumulated in a marshy area within the floodplain, probably near to the margin of the same lowland meandering river. *Nymphaea* pollen shows that the river had slow-flowing reaches rich in aquatic plants.
- The local terrestrial environment during Hungerbol 1 was characterised by rather damp, fairly well-established woodland with some mature trees and a dense understory of tall herbs, although this woodland was notably more open and less diverse than previously, and there were larger patches of open ground with low herbaceous vegetation.

- The diverse molluscan fauna in the silts of Hungerbol 2 includes a number of species typical of a warm interglacial climate, while the high diversity (60 terrestrial species) is also typical of interglacials and is compatible with the faunas from the Irchel sites. The continued presence of eastern species like *Macrogastra densestriata*, *Monachoides vicinus* and *Trochulus filicinus*, which were already present in the Irchel sites and Albishorn-Bürglen 2, suggests that the climate is likely to have been rather warm, with somewhat higher summer temperatures than today.
- By contrast, the upper silts of Hungerbol 1 have just 21 terrestrial species and none of the interglacial forest and shade-loving taxa of Hungerbol 2, while the fauna newly includes the cold-tolerant pioneer *Columella columella*, all of which points to a major climatic cooling since the time of the lower silts. Nevertheless, the presence of several woodland species, including *Clausilia bidentata*, a Western European taxon that does not tolerate very cold winters, indicates that the silts of Hungerbol 1 accumulated during a mild interstadial early on in the succeeding glacial period.
- The silts were truncated by an erosion surface, which was followed by up to 3 m of slope-deposits that include imbricated clasts typical of gelifluction in a cold climate situation. These were succeeded by up to 5.5 m of the fluvioglacial *Bannholz-Schotter* with boulders up to 1.2 m, capped by up to 0.6 m of glacial diamicton, which signify truly cold, full glacial conditions.
- The molluscan faunas from Hungerbol 2 clearly belong within the Early Pleistocene due to the continued presence of eastern species like *Macrogastra densestriata*, *Monachoides vicinus* and *Trochulus filicinus* and an absence of marker taxa for the Middle Pleistocene like *Helicodonta obvoluta*. Nevertheless, they include newly arrived biostratigraphic markers that subsequently became regular elements of Swiss interglacial molluscan faunas. This evidence suggests that Hungerbol 2 probably dates from EP2 or EP3. AAR Dating shows that *Bithynia* opercula from Hungerbol 2 are considerably older than those from Ecoteaux that seem to date from the early Middle Pleistocene, while shells from *Arianta arbustorum* are clearly younger than those from the Irchel sites.
- The small mammal remains recovered from the silts of Hungerbol 2 represent two unidentified species of rootless Lagurid that may well have been *Lagurus arankae* and *Prolagurus pannonicus*. If correct, this would suggest a date between 1.8/1.7 and 1.1/1.0 My, spanning EP2 and the first part of EP3.

- In the TDS sequence for the Schiener Berg (D; Graf 2009a) at base there are several channels eroded into the Molasse, with possible remains of glaciogenic deposits in places. At Hungerbol the base of one of these channels is succeeded by interglacial fluvial gravels, sands and silts (Hungerbol 2), which are covered by cold period deposits (Hungerbol 1) that include the fluvioglacial *Bannholz-Schotter*. In places the Bannholz-Schotter is up to 15 m thick and includes bands of glacial diamict, striated clasts and large boulders, indicating that a glacier front lay nearby. This unit seems to be contemporary with the up to 30 m of coarse fluvioglacial *Bohlingen-Schotter*, which is followed by warm period bedded fluvial gravels, silts and sands with calcareous nodules, capped by a palaeosol. These are succeeded by up to 50 m of the *Schrotzburg-Till* then c.15 m of fluvioglacial *Schrotzburg-Schotter*, which represent a single glacial period. The Schiener Berg sequence thus includes erosional channels with possible glaciogenic sediments, then interglacial fluvial sediments at Hungerbol, followed by glaciogenic deposits linked with a nearby ice front, then warm period alluvial sediments capped by a palaeosol, and finally thick glacial deposits formed by a major glacier advance. Around 3 km W of Hungerbol the fluvioglacial *Wolkensteinerberg-Schotter*, formed at a somewhat lower level after moderate incision, represents the *TDS unteres Niveau*, the final phase of the TDS complex.

- Both the episodes of incision at the start of the TDS at sites like Iberig and the Schiener Berg and the deposits that make up much of the TDS complex in northern Switzerland and southern Germany, seem likely to have been formed by glacial activity. This may well have taken place during EP3 as there is abundant evidence for glacial activity across much of Europe at this time, including the Rhine Glacier in southern Germany. By contrast there is little evidence for glacial activity in lowland Europe during the preceding Waalian warm stage, that forms the latter part of EP2. During EP3 there seem to have been up to four periods with notable glacial activity in North-Western, Northern and Central Europe.
- The periods associated with the most widespread evidence of glacial activity across Europe during EP3 seem to have been MIS 34-32 (1.145-1.09 My), MIS 30 (1.065-1.035 My), and especially MIS 24-22 (0.935-0.865 My), which has been called the '*0.9 My super-cooling event*.' There are also signs of more localised glacial activity during MIS 20 and possibly MIS 36. For the warm periods, MIS 35 seems to have been only moderately warm, MIS 31 appears to have been a 'super-interglacial' due to significantly high temperatures, MIS 29-25 was moderately warm for around 100k years, and MIS 21 was both warm and fairly prolonged (50k years).
- At the Schiener Berg, the glacial deposits of the Schrotzburg-Till/Schrotzburg-Schotter seem most likely to correlate with MIS 24-22, the '0.9 My super-cooling event,' due to their impressive thickness, while the fluvioglacial Wolkensteinerberg-Schotter of the TDS unteres Niveau might correspond to MIS 20. The small mammal remains from the silty-sands of Hungerbol 2 argue for an age before 1.1/1.0 My (see above). Palaeomagnetic data from the silty-sands of Hungerbol 2 and Hungerbol 1 shows normal polarity for both levels, although the signal is patchy (Scheidt et al. 2023). The only example from the later Early Pleistocene for a warm period with normal polarity being succeeded by a cold period with normal polarity is the second part of MIS 31 followed by MIS 30 (cf. Cohen and Gibbard 2022), meaning that the interglacial deposits of Hungerbol 2 might represent MIS 31, while the interstadial sandy-silts of Hungerbol 1 may correspond to early MIS 30. If correct, the fluvioglacial gravels of the Bannholz-Schotter/Bohlingen-Schotter would represent MIS 30, as this cold period correlates with the first part of the Jaramillo Subchron (1.076-1.008 Ma), the warm period gravels, sands/silts and palaeosol of the Bohlinger Gorge might correspond to MIS 29-25, while initial incision and the earliest glaciogenic deposits may equate to MIS 34-32. If the sandy-silts of Hungerbol 2 represent MIS 35 (1.195-1.145 My) or MIS 31 (1.09-1.065 My), this would give a total time window for Hungerbol 2 between 1.2 and 1.06 My, as both periods fit with the small mammal data. If the palaeomagnetic data is credible, however, this might narrow the date for Hungerbol 2 to between 1.1 and 1.06 My.

- In the reference sequence for the TDS in northern Switzerland at Iberig (AG), the three units of glacial deposits may represent MIS 34-32, MIS 30 and MIS 24-22. These are separated by a well-developed palaeosol that might correlate with MIS 31 and 8 m of alluvial silts with biological remains that may correspond to MIS 29-25. Palaeomagnetic data from layers of sterile silty-sand within the *Iberig-Schotter* shows normal polarity (Scheidt et al. 2023), suggesting that this unit of fluvioglacial gravels may correspond to MIS 30, during the early part of the Jaramillo Subchron, and supporting the above chronostratigraphic proposition.
- The combined evidence suggests a total time window for the formation of the TDS gravel/till units between 1.145 and 0.865 My, which extends to 0.79 My if the TDS unteres Niveau is included. The episode of incision that preceded accumulation seems to have taken place during MIS 34-32, although some incision may already have occurred during MIS 36, with c.50 m of incision at the Schiener Berg (Graf 2009). In some locations, however, incision may have taken place progressively, linked with the successive units of glaciogenic/fluvioglacial deposits that constitute the TDS.
- There is additional evidence for more intense glacial activity in Switzerland after 1.0/0.8 My, with accelerated glacial erosion in the Rhône Valley between Visp and Martigny (VS) and in the Aare Valley near Interlaken (BE). Moreover, deposits of glacial till and glaciolacustrine silts with reversed polarity at Ecoteaux (VD) indicate that a glacial advance reached this location during EP3.

7.5 Conclusions for the Middle Pleistocene to Holocene deposits

- The sedimentary basin at Ecoteaux (VD) has a series of lacustrine silts and sands with biological material that have normal polarity corresponding to the Brunhes Chron. Pollen analysis shows two interglacials that are separated by only a moderately cold phase, the lower of which has up to 2% *Carya* pollen indicating that it dates from the early Middle Pleistocene, in agreement with the AAR signal. Looking at the MIS curve for this time, the most suitable two warm stages separated by a moderately cold interval are MIS 15 to 13. The molluscs come from the lower part of the earlier interglacial, so they might well represent MIS 15. The underlying glacial deposits with normal polarity may therefore correspond to MIS 16, while the lowest glaciogenic sediments with reversed polarity seem to represent a significant glaciation during EP3, which may have been MIS 24-22. The mollusc faunas have several terrestrial and aquatic species typical of interglacials. These include the bivalve *Pisidium clessini*, which became finally extinct in Western Europe after MIS 7, but may have disappeared from Central Europe after MIS 15-13. *Pagodulina pagodula* seems to have first appeared in Central Europe during the early Middle Pleistocene, but aside from Ecoteaux has only been found at Eemian sites in Switzerland. Similarly, *Acicula lineolata* and *Acicula lineata* have otherwise only been found at Eemian sites in Switzerland. The faunas from the two samples taken at Location A indicate that accumulation took place in shallow, rather calm water near the edge of a lake that was bordered by dense marsh vegetation, while a stream entered the lake nearby. The lake became notably shallower in the upper sample, while the aquatic vegetation and that of the marshy fringe became much richer. The molluscs from Location B are similar, but seem to have accumulated in somewhat deeper water. Of note is the presence in one sample of moving water taxa typical of large lowland rivers and larger lakes with moving water. This suggests that the basin may have been somewhat larger than thought up until now. The lake then became notably shallower in the uppermost sample, while the aquatic flora and that of the marshy fringe became very rich. At both locations, behind the marshy edge of the lake was an area of damp ground dominated by tall herbs, and beyond this was rather open woodland that became more diverse and deciduous in the upper samples.

- The interglacial molluscan faunas at Montfleury and Sous-Terre (GE) appear to correspond to MIS 11, due to their biostratigraphic marker species, their AAR values, and their stratigraphic position overlying thick glacial deposits that correspond to the '*Moraine basale inférieure*' and may well represent MIS 12. The terrestrial molluscs from Sous-Terre are rather diverse and include several species and subspecies that are now extinct. Those from Montfleury are less varied and somewhat different, possibly because they represent a slightly earlier stage of MIS 11. The interglacial sediments at both sites were succeeded by cold-period deposits that may represent MIS 10. At Montfleury these have an abundant molluscan fauna typical of an interstadial during a cold stage, while at Sous-Terre the assemblage is poor. At Sous-Terre the sequence was truncated by an unconformity, followed by massive fluvioglacial gravels that represent the 'Alluvion ancienne.' At Montfleury, however, there is another unit of silts and organic silts with biological remains that might represent MIS 9, although the molluscs in these deposits were not retained for analysis. These silts were then truncated by the same 'Alluvion ancienne' gravels as at Sous-Terre, which may date from MIS 6 (cf. Section 6.1.4). The interglacial terrestrial faunas at both sites indicate fairly damp, largely deciduous woodland with mature trees and a rich undergrowth of tall herbs and young trees, while the aquatic molluscs suggest accumulation near the margin of a large, slow-moving meandering river, probably the Rhône. The modest molluscan fauna from Coupy, near Bellegarde (France), seems to be contemporary with those from Montfleury and Sous-Terre due to its stratigraphic position (covered by the 'Alluvion ancienne' and underlain by basal moraine) and the occurrence of the extinct marker species *Aegopis klemmi* at both Coupy and Sous-Terre. Coupy also has specimens of Retinella elephantium, which seems to have become extinct after MIS 11. The fauna indicates a local environment with moderately open, largely deciduous woodland with mature trees and a rich understory of tall herbs. The sands that contain the shells may have been formed by slope wash.
- Based on stratigraphic and pollen evidence, the faunas from Nuolen (SZ) and Grandson (VD) both seem to date from MIS 7, in good agreement with their AAR values. At Nuolen, sediments from ponds and marshy areas linked by flowing water are underlain by fluvio-deltaic deposits from the Hochterrasse, while at Grandson lacustrine silts and lignites accumulated at the edge of a greatly-enlarged Lake Neuchâtel when the mean level was c.50 m higher than today. The fauna from Ried (BE) also seems to correspond to MIS 7 due to its stratigraphic position, a strong resemblance to the molluscs from Nuolen and an absence of marker species typical for Eemian deposits. The silts at Reid were found within a sequence of fluvioglacial gravels equivalent to the Hochterrasse, and appear to include the transition from MIS 7 to the start of MIS 6. The faunas from MIS 7 are very different to those of MIS 11 as they include no extinct taxa, have just three species that no longer live in

Switzerland and seem to be significantly less diverse. They are also much less diverse than those from the Eemian (MIS 5e), and lack key Eemian marker species.

- The faunas from Petit Saconnex and WHO in Geneva (GE) come from similar silty sediments that lie below the fluvioglacial gravels of the 'Alluvion ancienne' and sit unconformably over the same 'Moraine basale inférieure' as the interglacial levels at Montfleury and Sous-Terre. The silts appear to have been deposited after a major episode of erosion led to the removal of earlier sediments dating from MIS 11 to MIS 9. The fairly abundant, well preserved molluscan faunas within these silts are of fairly low diversity and include the cold-tolerant pioneers *Columella columella* and *Vertigo genesii*, although they also include several species indicative of scrub woodland. This together with their stratigraphic position suggests an interstadial early in MIS 6, or possibly MIS 8, which is supported by AAR values from both these sites. The assemblages from two Geneva boreholes are important because they show that the mean level of Lac Léman was at that time c.15 m below its present level. The fauna from 'Parc de La Grange' is very similar to those of Petit Saconnex and WHO, comes from silts with the same stratigraphic position and seems to be of a similar age. The fauna from 'la Petite Boissière' has fewer species and comes from a silt layer within the 'Alluvion ancienne' gravels, so is probably somewhat younger and may correspond to the mid part of MIS 6 when the landscape seems to have been more open. The assemblages from fluvial sands at Fisibach (AG), linked with the Hochterrasse of the Hochrhein, are of similarly low diversity, so probably date from a mid or later phase of MIS 6, after an interval of truly severe climate had greatly impoverished both the local vegetation and its associated molluscan fauna. By contrast, the faunas from Herteren, Sulperg, Wettingen, AG, show rising diversity due to improving conditions during the final phase of MIS 6, as the local environment had increasing frequencies of bushes and trees.

- Unsurprisingly, molluscan faunas from the last interglacial are better represented than those from earlier warm periods, with shell material from eleven sites. By far the richest and most complete sequence comes from Niederweningen (ZH), which has 5 interglacial marker species absent from the Holocene as well as 3 other interglacial taxa typical for the Eemian. The faunas from the ten other sites are less rich, either because of limited sampling (between 60 and 120 years ago for several sites), the way they were processed (sieves with over-large mesh sizes), or because the sequences were truncated by erosion during the last glacial period. Only Niederweningen appears to include the so-called 'climax phase' of the Eemian when faunas were at their most diverse, although the fauna at Flurlingen (ZH) may have come from not long before this phase. By contrast, those from Thalgut (BE), Les Tuileries (VD), 'Giez'/Grandson (VD), Bürgerspital (BS) and Wolfbach (ZH) all appear to represent early to mid-phases of the Eemian. The faunas from Zell (LU) vary somewhat according to where they come from within the very large gravel quarry, with the Kälin samples corresponding to an earlier phase of the Eemian, while the Forcart and Jayet samples represent a mid-phase of the Eemian, shortly before the 'climax phase.' The small assemblage from Zurzach (AG) may also correspond to an early to mid-phase of the Eemian. The molluscs from Les Tuileries and 'Giez'/Grandson come from sediments that seem to have been linked with Lake Neuchâtel when it was much larger and its mean level stood at c.475 m asl. Similarly, the molluscs from Spiezberg (BE) seem to represent a 20 m lake terrace of the Thunersee, with assemblages that accumulated in shallow water near the lake shore as the mean level rose from around 477 to c.480 m asl between early to mid-phases of the Eemian. By contrast, although the faunas from Port Valais (VS) appear to represent a 20 m terrace of Lac Léman, the notable component of open ground species among the terrestrial molluscs might suggest that the assemblages correspond to a late phase of the Eemian.

- The faunas from Muntschemier-Guggleracher (BE), and Boudry-Champ le Sage West (NE), are dominated by aquatic molluscs and include species indicative of mild interstadial conditions. Both appear to represent Early Würm interstadials due to their stratigraphic positions and the presence of terrestrial and aquatic marker species. The shells from the former site seem to have accumulated within a meandering channel that flowed north-eastwards from Lake Neuchâtel towards the Aar when the mean lake-level stood at c.449 m asl, perhaps during MIS 5c. The assemblage from Champ le Sage West accumulated in Lake Neuchâtel when its mean level was at c.433/434 m, rising to c.435 m asl, possibly during MIS 5a.
- The molluscan faunas from a cement quarry at Jakobsberg/Unteregg (AG) come from two levels. The lower level, located within the commune of Auenstein, has darkish-grey silts with a small aquatic assemblage that seems to date from an early phase of MIS 6. The upper level, found within the commune of Veltheim, consists of fairly abundant terrestrial molluscs, found with the remains of *Mammuthus primigenius* within a layer of reddish-brown silts with OSL ages of 64.6 ± 7.9 BP and 63.8 ± 5.1 BP. The rather restricted fauna (12 species) includes the cold-tolerant pioneer taxon *Columella columella*, as well as several taxa which show that the reddish silts accumulated during an interstadial with a fairly mild climate, although the presence of loessic silt at the same level suggests strongly continental conditions. The OSL dates suggest that this interstadial may correspond to GI-18, which lasted for 260 years around 64,000 ice core years BP, during the middle part of the cold period MIS 4 that spanned from c.70,000 to 59,500 ice core years BP. The shells and mammoth bones within the reddish silts seem to have accumulated in a shallow marshy depression prone to regular episodes of drying out. This was bordered by significant patches of open ground with low herbaceous vegetation, surfaces with abundant tall herbs, and limited patches of bushy scrub, probably with some scattered trees.
- The abundant, well-preserved faunas from Riehen (BL), the lowest level at Allschwil (BL) and from Baden (AG), have marker species, including several forest species, which suggest that they represent the early to middle phases of the Middle Würm interstadial (early to mid MIS 3; 59-32 ka BP), which equates to the Middle Pleniglacial. The faunas also include the cold-tolerant pioneers *Columella columella* and *Pupilla alpicola*, which are typical for this period. The faunas indicate a landscape of rather open scrub woodland with some mature trees and an understory of abundant tall herbs, young trees and bushes, as well as patches of damp open ground with low herbaceous and/or marshy vegetation. By contrast, the faunas from the two levels sampled at Fuchshag, Bottmingen have fewer forest and other marker species, and seem to correspond to the late phase of the Middle Würm interstadial (late MIS 3; 32-27.5 ka BP), which equates to the start of the Upper Pleniglacial. These faunas show a marked decline in trees and bushes, at the expense of surfaces with tall herbs and open ground with low herbaceous vegetation. The two upper levels from Allschwil have significantly lower diversity and a lack of any marker species, indicating that

they date from the Late Würm (MIS 2), equivalent to the Upper Pleniglacial. These faunas suggest a largely open landscape of damp marshy ground with low herbaceous and paludal vegetation, together with patches of low bushy scrub.

- The faunas from Bertigny/Pont-la-Ville (FR), Sihlbrugg (ZH) and the upper levels at Niederweningen (ZH) are fairly similar, having the limited diversity typical of cold periods, the presence of cold-tolerant pioneers like *Columella columella*, *Pupilla alpicola* and *Vertigo genesii*, and a few shade-loving species. Nevertheless, the assemblages are fairly abundant and rather well-preserved, showing that they correspond to interstadial conditions. The Niederweningen fauna is OSL and radiocarbon-dated to the Middle Würm interstadial (early to mid-part of MIS 3). Bertigny/Pont-la-Ville has a similar stratigraphic position, while comparable species suggests that Sihlbrugg may also be of the same age. These faunas are thus of similar age to those from Riehen and Baden, but are somewhat different as they have more marsh species due to a wetter sedimentary environment.

- The abundant, well-preserved, but low diversity fauna from silts found at the summit of Niederterrasse fluvioglacial gravels at Münsingen (BE) is typical of interstadial conditions during the late Bølling or early Allerød of the Late Glacial. There are few forest or shade-loving species, indicating that the local vegetation was still rather open despite mild conditions. Molluscs from Räffelstrasse, Binz, Zürich (ZH) and the Dättnau Valley (ZH) also date from the Late Glacial Bølling-Allerød Interstadial, but the Binz fauna, which seems to date from the early Allerød, is typical of rather open, largely coniferous woodland, although significant patches of open ground were also present. The sequence from the Dättnau Valley covers from the *Betula* phase of the Bølling until near the end of the Preboreal. During this time the local vegetation progressed from tall herbs, possibly with some scattered trees and bushes, through open woodland with a rich understory of tall herbs and bushes/young trees (Bølling), to fairly open, largely coniferous woodland with mature trees and an understory of bushes/young trees and tall herbs (Allerød), although patches of open ground persisted throughout. During the Younger Dryas there was a significant opening out of the woodland and an expansion in the surfaces of open ground, while the Preboreal saw a return to fairly open largely coniferous woodland with mature trees.

- The faunas from the upper level at Sous-Terre (GE) come from an 8-10 m terrace of the Rhône, which from the terrestrial molluscs and AAR data seems to date from the Preboreal. The faunas are dominated by aquatic species that accumulated in shallow but permanent gently-flowing water with a fairly rich aquatic vegetation, near the edge of the Rhône. The area adjoining the river had fairly damp, rather open, largely coniferous woodland, that during the time of accumulation became denser, mixed deciduous-coniferous forest with more mature trees. The faunas from Coupy, near Bellegarde (France) seem also to come from a localised terrace of the Rhône. The area near the river had rather open, largely deciduous woodland with some mature trees and a rich understory of tall herbs.

- The abundant, well-preserved faunas from Boppelsen-Cholholz (ZH) and from next to a stream known as the Wildbach, near Embrach (ZH), appear to date from the early Boreal and the early to the mid/late Boreal. The shells at the former site accumulated within an erosional gully c.3 m deep that was cut into the summit of HDS gravels, while at the latter, the molluscs seem to have accumulated in a former small stream-fed ribbon lake. The faunas from Boppelsen-Cholholz and the lower level at Wildbach are very similar and suggest fairly open mixed coniferous and deciduous woodland, with some mature trees, while the upper level from Wildbach indicates fairly dense, mostly deciduous forest with large mature trees.

- Molluscs dating from the early to mid-Boreal, have also been recovered from beneath a Neolithic dolmen at Oberbipp/Steingasse (BE) that was constructed on the delta of a stream. The Boreal shells accumulated within a shallow marshy pond that was liable to seasonal drying out, around which was moderately dense, mostly deciduous woodland with mature trees. The Late Neolithic dolmen was constructed within a small clearing surrounded by similar deciduous woodland with mature trees, and was subject to episodic flooding from a nearby stream.
- At Steffisburg (BE), sandy-silts from the floodplain of the River Zulg, a tributary of the Aar, yielded a molluscan fauna indicative of moderately dense largely deciduous woodland dating from the Older Atlantic. Above subsequent peaty layers dating from the Older Atlantic and Subboreal were floodplain silts and sands of Subboreal age that show permanently cleared land in addition to the continued presence of deciduous woodland. At Belp-Neumatt (BE), within the floodplain of the River Gürbe another tributary of the Aar, peats of Older Atlantic age are succeeded by silts and sandy-silts that interfinger with peaty-silts. The silts have a fauna of Subboreal age with strong aquatic and marsh components that suggest accumulation within a stream-fed marshy pool that may have been a channel cut-off, around which lay rather open largely deciduous woodland. A few kilometres to the north at Taubenhalde, Bern (BE), dark grey silts interbedded with peaty layers in the floodplain of the Aar have a fauna of Subboreal age that accumulated within a shallow stream-fed marshy pond, bordered by fairly damp, moderately open, largely deciduous, possibly secondary woodland with mature trees. These three sites from the Aar system therefore suggest that a period of stability with peat accumulation from the Older Atlantic until the Subboreal, was followed by more silty sedimentation possibly linked with human activities, after which silty-sandy sediments coincided with increased signs of forest clearance.
- The molluscan faunas from Bavois-en-Raillon (VD) were preserved within the infill of a gully through which a stream flowed either perennially or intermittently. Beginning with the Younger Dryas, the preserved sandy infill continued through the Preboreal until the Older Atlantic, during which time the surrounding landscape passed from open, largely coniferous woodland with patches of open ground to fairly dense, largely deciduous forest with large mature trees. Of note are the continued presence of the cold-tolerant pioneers *Columella columella*, *Vertigo genesii* and *V. geyeri* during the early-mid Preboreal. After a rupture in sedimentation due to the development of dense forest within the gully, sandy sedimentation resumed during Neolithic times due to forest clearance, causing the stream to be reactivated. Forest clearance intensified during the Early Bronze Age, linked with occupation structures and more permanently open ground, although forest continued to be present nearby. Forest regeneration during the Middle Bronze Age saw stream flow greatly diminish and much siltier, more clay-rich sediments. Renewed forest clearance linked with settlement activity during the early part of the Late Bronze Age coincided with the final sediments to have preserved molluscs, although forest continued to be present nearby. After this the gully became infilled and the stream ceased to flow.

7.6 Conclusions for the value of Quaternary molluscan analysis

- A significant number of mollusc species have been identified during this study that have never previously been found in Swiss Quaternary deposits. Some of these are important biostratigraphic markers that have long been extinct, such as *Clausilia stranzendorfensis, Cochlostoma salomoni*, *Neostyriaca dehmi* and *Triptychia* sp., which disappeared c.1.8 My after the end of the Tiglian, *Macrogastra sessenheimensis*, which died out between c.1.5 and 1.3 My, plus *Archaegopis acutus* and *Oxychilus steiningeri*, which became extinct c.1.2 My. Others include *Neostyriaca corynodes ornatula* that became extinct after MIS 13, *Clausilia rugosa antiquitatis* and *Retinella (Lyrodiscus) elephantium* that disappeared after MIS 11, *Aegopis klemmi* and *Zonitoides sepultus* that went extinct after MIS 9, and finally *Pisidium clessini* that disappeared after MIS 7. There are also existing species that have modern distributions that lie far to the west, such as *Azeca goodalli* and *Spermodea lamellata*, far to the south, such as *Poiretia dilatata dilatata*, and several that lie to the east or south-east, such as *Acicula parcelineata*, *Helicopsis striata*, *Macrogastra densestriata*, *Monachoides vicinus*, *Soosia diodonta*, *Theodoxus danubialis*, *Trochulus filicinus* and *T. leucozonus*, which disappeared from Switzerland between the close of EP1 and the end of EP3, as well as *Aegopinella ressmanni*, *Aegopis verticillus*, *Clausilia pumila*, *Perforatella bidentata* and *Urticicola umbrosus*, which vanished from Switzerland between the end of MIS 11 and the termination of MIS 5e.

- By contrast, there are species that are absent from the Irchel sites and Albishorn-Bürglen 2 that subsequently became regular elements among Swiss interglacial molluscan faunas. These include *Cochlodina fimbriata*, *Macrogastra attenuata*, *M. plicatula* and *Monachoides incarnatus*, which first appeared at Albishorn-Bürglen 1 (EP2), *Clausilia cruciata* and *Platyla polita*, which were first present at Hungerbol (EP3), plus *Cepaea sylvatica*, *Cochlostoma septemspirale*, *Helicodonta obvoluta* and *Sphyradium doliolum*, which were first recorded from MIS 11 but may have arrived somewhat earlier. The development of a fairly detailed molluscan biostratigraphy for much of the Quaternary in Switzerland may potentially provide a useful relative dating tool for future studies.

- Molluscan faunas provide a credible indicator of past climates, and given reasonably well-preserved assemblages of a certain abundance can easily distinguish between faunas from interglacial, interstadial and stadial contexts. There are a number of forest species that can be considered to be typical for past interglacials, while interstadial and stadial faunas are normally of rather low diversity and often include cold-tolerant pioneers like *Columella columella*, *Pupilla alpicola* and *Vertigo genesii*. These species could also sometimes survive at the start of subsequent interglacial periods until vegetational development led to their disappearance (cf. Bavois-en-Raillon), but in this case interglacial markers like *Carychium tridentatum* would also be present.

- Molluscs can also furnish reliable information about local terrestrial and aquatic palaeoenvironments, and how these have evolved through time. As many sedimentary contexts include both terrestrial and aquatic molluscs, assemblages can often provide information about both domains.

- Molluscan assemblages can also give important evidence about the sedimentary context. For example, the absence of molluscs from silty-sands (not decalcified) within the TDS Iberig-Schotter at Iberig (AG), is entirely in keeping with field observations that these deposits were formed by a dynamic braided river system within a cold-climate setting. By contrast, although the fluvial gravels of Albishorn-Bürglen 2 were interpreted by Graf (2019) as being fluvioglacial due to their thickness, coarseness and petrography, the molluscs present within several silty/sandy layers demonstrate that these gravels were deposited by a meandering river during a warm interglacial period. Similarly, several silty soft clasts and a large lens of silty fine sand located within a series of fairly finely bedded and moderately well sorted gravels (the Hochwacht-Schotter) at Hochwacht West, 1.2-1.5 m below the summit and c.3 m above the Hasli Formation, have molluscan faunas typical of a forested floodplain environment during a warm interglacial, while indicating that these gravels accumulated within a meandering river. Likewise, the shells in gravelly sand levels at the base of the lower silts of Hungerbol 2 confirm that the underlying series of finely bedded sands and gravels also accumulated within a meandering river during a period of warm interglacial climate. These three examples illustrate why it is important to take the biological content of gravelly fluvial deposits into account when seeking to understand their climatic, environmental and chronological context.

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Appendix 1: Tables 1 to 45

Table 1 : The Stratigraphy and Sampling of Irchel Hasli 2018-2019

Irchel Hasli 2018-19				**Sampled 24/05/2018 Resampled 21/02/2019**	**Prepared, documented and sampled by Gaudenz Deplazes, Daniel Kälin + Nigel Thew in May 2018**		**Sample processing NT October and December 2018, plus January 2020 Topmost (2019) samples processed in January 2020**				**Richness of molluscan material**	**Small mammal remains**
TOP		**Layer number**	**Thickness (cm)**	**Colour**	**Lithology and sedimentary structures**	**Clast lithology, diagenetic features + biological remains**	**Samples 2019**	**Samples 2018**	**Sampling remarks**	**Sample processing and biological remains**		
modern soil		**1**	15	dark grey-brown	modern forest soil	decomposing organic matter						
glaciogenic		**2**	46-50	olive-brown	silty sand with some clay + moderate pebbles (10-20%), up to 11 cm; rounded to angular clasts; orientations from horizontal to vertical (cf. Hochwacht Col. 1, Layers 3 +2)	moderetaly weathered diamicton; **glaciogenic**						
Amselboden Schotter		**3**	20	slightly reddish brown	fine to medium gravel (30-40%) in silty-sand + some coarse up to 8 cm, poorly sorted, matrix supported, sub-rounded to sub-angular clasts; orientations from horizontal to vertical; **erosion surface at base**	strongly weathered, iron staining + small black patches of Mn; with frequent decomposed sandstone clasts; slope deposit						
Hasli Formation	**Part 4b**	**4**	60	orangey-grey (top) to olive-grey (bottom)	very sandy silt, very diffusely banded, with a little very fine gravel + rare stones up to 1.5 cm **erosion surface at base**	top strongly weathered, but whole layer with significant iron staining + black from Mn + frequent small Fe-Mn concretions	-4	bottom 20 cm of layer		-4: 2.90 kg sieved; no molluscs, no other biological remains found, apart from *Cenococcum*		
		5	35	olive-grey (top) to olive-brown (bottom)	fairly sandy silt, more sandy at the bottom, silty at the top, very diffusely banded, with a little very fine gravel + rare stones up to 1 cm **erosion surface at base**	moderate iron staining + fairly frequent very small Fe-Mn concretions	-3	middle 20 cm of layer		-3: 3..15 kg sieved; no molluscs, no other biological remains found, apart from *Cenococcum*		
		6	20	olive-grey to olive-brown	silt with some fine-medium sand alternating with silt with some clay, diffusly banded, with a little very fine gravel + rare stones up to <1 cm	some iron staining + moderate very small Fe-Mn concretions	-2			-2: 2.70 kg sieved; no molluscs, no other biological remains found apart from a few *Cenococcum*		
		7	30	olive-brown	sandy silt, diffusly banded, with a little very fine gravel and rare stones up to 1.5 cm **erosion surface at base**	some iron staining	-1			-1: 3.85 kg sieved; no molluscs, no other biological remains found		
	Part 4a	**8**	20	olive-grey	clay rich silt with several bands of nodules up to 3 cm (somewhat coroded)	uppermost layer with flame structure, at the top irregular cemented layer		1		1: 2.25 kg sieved; some molluscs, fairly coroded and rather fragmented; some granules; rare ostracods (mica platelets); more open environement?		
		9	15	greyish to brown (iron staining)	interbanded sandy silts, silts and clayey silts, clearly banded at the top, with a few small stones up to <1 cm	in the middle partially cemented, at bottom white, carbonate-rich lenses		2		2: 1.75 kg sieved; some molluscs, coroded and very fragmented, some granules, few *Cenococcum* (Fe-Mn concretions)		
		10	5	olive-grey	clay silt + thin silty bands with some fine sand, diffusely banded	few small calcareous nodules (<1 cm), iron staining in sandier bands; charcoal frags up to 1 cm		3	Layers 10 + 11 taken together	3: 2.5 kg sieved; in Layer 10 moderate molluscs, extremely fragmented; some granules; rare ostracods; in Layer 11 only moderate charcoal frags, a few larger up to 1 cm	▤	
	Part 3b	**11**	2-5 mm	black	finely laminated lignite							
		12	10-15	dark grey to grey, bottom darker than top	diffusely laminated clay silt **erosion surface at base**	few small calcareous nodules (<1 cm), iron staining + possible gleying in upper part?; charcoal frags up to 1 cm	DK12	4 + DK12	additional pollen sample	4: 3.8 kg sieved; no molluscs, no granules, no small mammals found, but some charcoal DK 12: 17.3 kg sieved; rare molluscs, rare granules, several **small mammal** teeth + some charcoal		🟦
		13	30	grey	silt with some clay + bands with some sand; diffusely banded; rare small stones up to 1.5 cm, especially in lower part; + small **soft clasts** of eroded detritic peat up to 1 cm in lower part	numerous rootlet concretions, especially in upper part; iron staining and Fe concretions, especially in upper part; **gastropod shells**	DK13upper DK13lower	5 6	5: top part of Layer 13 6: lower part of Layer 13	5: 3.75 kg sieved; 6: 3.8 kg sieved; fairly abundant molluscs (esp. in 6), moderately fragmented; some granules; some ostracods; rare **small mammals**; fairly frequent aquatic molluscs (*Anisus leucostoma, Gyraulus laevis, Stagnicola* sp., *Valvata piscinalis, Pisidium casertanum, P. obtusale, P. subtruncatum*); fauna typical of the middle part of an interglacial, sporadically active channel; open damp woodland in a marshy floodplain environment; *Aegopinella ressmanni, Azeca goodalli, Clausilia* spp., *Cochlostoma* sp., *Perforatella bidentata, Urticicola umbrosus*	🟩 🟩	🟦 ▥
		14	30	light to dark grey	sandy-silt and silty-sand, finely laminated; with rare stones up to <1 cm	some small calcareous nodules (<1 cm), plus few sandy concretions up to 1 cm; **gastropod shells**	DK14	7		7: 5.35 kg sieved; moderate molluscs, fairly fragmented; some granules; some ostracods; fairly frequent aquatic molluscs; *Aegopinella ressmanni, Azeca goodalli, Clausilia* spp., *Cochlostoma sp., Perforatella bidentata, Urticicola umbrosus*	▤	
		15	15	grey	silt with some fine sand + bands of silty fine sand with reddish iron staining; mm laminations; rare small stones up to 0.6 cm **erosion surface at base**	some small calcareous nodules (<1 cm), plus few small sandy concretions (<1 cm); **gastropod shells**		8		8: 3.7 kg sieved; abundant molluscs, rather fragmented; some granules; rare ostracods (moderate mica platelets); fauna dominated by marsh and open ground species, with indicators of standing water (*Pisidium casertanum*); relatively few woodland snails (*Aegopinella*)	■	
	Part 3a	**16**	15	grey (creamy grey marly bands)	silty fine sand with bands (up to 3 cm) of marly silt **erosion surface at base**	bands show deformation; **gastropod shells**		9		9: 3.4 kg sieved; moderate molluscs, moderately fragmented; few granules; rare ostracods (mica platelets); fauna dominated by marsh species, with indicators of standing water (*Pisidium casertanum*); a few woodland snails (*Clausiliids, Aegopinella*)	▤	
		17	25	grey	fine sand with some silty bands + few stones up to 2.5 cm	moderate sandy concretions up to 4 cm		10		10: 4.6 kg sieved; some molluscs, some granules (mica platelets); fairly frequent aquatic molluscs, fauna typical of the middle part of an interglacial, sporadically active channel; open damp woodland in a marshy floodplain environment; *Aegopinella ressmanni, Azeca goodalli, Clausilia* spp., *Cochlostoma* sp., *Monachoides vicinus, Perforatella bidentata, Urticicola umbrosus*		
		18	10-15	grey (creamy grey: marly bands)	silty fine sand with bands (up to 2 cm) of marly silt	moderate calcareous nodules up to 2 cm and some sandy concretions up to 2 cm		11		11: 3.25 kg sieved; some molluscs, moderately fragmented, few granules; fauna dominated by marsh species (no woodland snails); **significantly wetter**		
		19	5	reddish to orange grey/grey/light grey	interbanded clay-silt, silt, marly-silt and silt with some fine sand; finely laminated	numerous calcareous rootlet concretions; intense iron staining in sandier bands		12	Layers 19 + 20 taken together. Note 1	12: 2.35 kg sieved; in Layer 19 rare molluscs, rare granules, in Layer 20 fairly common micro frags of charcoal		
	Part 2b	**20**	1	black	finely laminated lignite	completely humified, with no distinguishable plant remains						
		21	10-15	grey to reddish	silt with some fine sand; mm laminations and cm banding **erosion surface at base**	iron staining of certain bands		13		13: 3.4 kg sieved; rare molluscs (mostly slug plates), some granules; some charcoal, *Cenococcum* (mica platelets)		
		22	5	reddish to reddish-brown	silt with some clay and a little fine sand; mm laminations and cm banding **erosion surface at base**	notable iron staining of certain bands		14		14: 1.95 kg sieved; no molluscs, rare granules, rare **small mammal** remains		🟦
		23	15-20	grey, with reddish brown and black mottling in upper part	silt with some clay; with small black organic lenses	frequent small Fe-Mn concretions plus iron staining, especially in the upper part; **gastropod shells** in the lower part		15 + DK23upper 16	15: top part of Layer 23 Additional large sample 23 upper by DK 16: lower part of Layer 23 Additional very large sample 23 lower taken by MB, processed by DK	15: 1.8 kg sieved; very few molluscs (2 slug plates), rare **small mammal** tooth fregs, rare *Cenococcum* (very frequent Fe-mn concretions) DK23upper (= sample 15) 7.4 kg sieved by DK; some molluscs, v fragmented corroded and coated (Fe-Mn), moderate granules but corroded, rare small mammals; (freq Fe-Mn concretions, some mica platelets); molluscs include a few larger *Cepaea hortensis* 16: 3.35 kg sieved; moderate molluscs, corroded, v fragmented and coated (Fe-Mn), freq granules (freq Fe-Mn concretions linked to pedogenesis, some mica platelets); very rare **small mammals**; few *Cenococcum* ; few aquatic molluscs, *Aegopinella ressmanni, Azeca goodalli,* Clausiliids, *Cochlodina laminata, Cochlostoma sp., Perforatella bidentata, Urticicola umbrosus;* freq *Ena montana* DK 23lower (=sample 16) 30.5 kg sieved by DK; as sample 16 (note: this very large sample may include the summit of Layer 24)	 ▤	🟦 ▥
		24	8	light olive-grey	silt with clay; at the top more calcareous	moderate small Fe-Mn concretions; **gastropod shells**		17		17: 1.8 kg sieved; abundant molluscs, rather fragmented; freq granules; few aquatic molluscs, fauna typical of the middle part of an interglacial, fairly open, moderately damp woodland in a somewhat marshy floodplain environment, but getting drier; *Aegopinella ressmanni, Azeca goodalli,* Clausiliids, *Cochlostoma sp., Perforatella bidentata, Trichia edentula/unidentata, Urticicola umbrosus;* abundant *Ena montana*	■	
		25	7-13	light olive-grey	silt with moderate fine sand; **soft clasts** up to 1.5 cm of redeposited brown detritic silty peat **erosion surface at base**	in the middle an undulating band of small calcareous nodules up to 2 cm; **gastropod shells**		18		18: 1.55 kg sieved; moderate molluscs, rather fragmented and coroded, moderate granules, rare charcoal, few *Cenococcum* (mica platelets)	▤	
	Part 2a	**26**	18-23	olive-grey	silt with moderate fine sand + two sandy bands with frags of cemented sand up to 4 cm	the two bands with frags of cemented sandy layer: one very ondulating, + fairly frequent calcareous nodules up to 3 cm; microbanded at the top and base, some orange Fe nodules		19		19: 2.1 kg sieved; some molluscs, fragmented and coroded; moderate granules; some ostracods (mica platelets); very rare **small mammals**		▥
		27	31-33	light grey - light olive-grey, orangey in places	interbanded fine sand and silty fine sand **erosion surface at base**	frequent calcareous nodules up to 5 cm in horizontal/subhorizontal bands; fairly frequent small Fe-Mn concretions; Fe coated roots		20 21	20: top part of Layer 27 21: lower part of Layer 27	20: 2.05 kg sieved; some molluscs, fragmented and coroded; some granules; some ostracods (mica platelets) 21: 2.75 kg sieved; some molluscs, fragmented and coroded; moderate granules; some ostracods, 2 *Chara* (mica platelets)		
		28	20	grey, orangey in places	interbanded fine sand and silty fine sand, with some medium to coarse sand and a little very fine gravel	frequent small calcareous nodules up to 2 cm in the more sandy bands (more freq than in layer 27) and moderate sandy concretions up to 4 cm; Fe coated charcoal/ancient roots		22		22: 1.9 kg sieved; very few molluscs; some granules; rare ostracods (mica platelets)		
		29	1-5	grey	cemented sandy layer **erosion surface at base**			no sample				
		30	21	grey	interbanded sand, silty sand and sandy silt; wedging out towards the west	cemented in places, sandy at the bottom; moderate calcareous nodules up to 6 cm, and some sandy concretions up to 4 cm; freq Fe coated charcoal/ancient roots		23		23: 2.15 kg sieved; rare molluscs, very fragmented and corroded; few granules; rare ostracods, 2 *Chara* (freq mica platelets)		
		31	22-25	grey, sometimes orangey	interbanded fine to medium sand, silty sand, sandy silt and some marly silt; includes one orangey-red silty **soft clast** 1.5 cm across **erosion surface at base**	in upper part: a few calcareous nodules up to 2 cm, some sandy concretions up to 4 cm in lower part: moderate calcareous nodules up to 3 cm, moderate sandy concretions up to 5 cm; Fe coated charcoal/ancient roots		24 25	24: top part of Layer 31 25: lower part of Layer 31	24: 1.65 kg sieved; few molluscs, fragmented and very coroded; fairly frequent granules; rare ostracods, 1 *Chara* (mica platelets) 25: 2.35 kg sieved: no molluscs; few granules; rare ostracods (freq mica platelets) **significantly wetter, water movement (much sandier); rapid accumulation**		
	Part 1c	**32**	20	grey	finely interbanded fine sand, silty sand and silt (more silt than sand); marly bands at top and bottom	one discontinuous band of cemented sand, three bands of white calcareous nodules up to 4 cm, + some sandy concretions up to 2 cm; Fe coated charcoal/ancient roots		26		26: 1.5 kg sieved; no molluscs, few granules, rare ostracods (mica platelets)		
		33	6-8	olive-grey	interbanded slightly sandy silt and silt **erosion surface at base**	very cemented sand lenses at top and bottom; sandy concretions up to 4 cm; iron staining; Fe coated charcoal/ancient roots		27		27: 1.85 kg sieved; rare molluscs (only slug plates), few granules, some ostracods (mica platelets)		
	Part 1b	**34a**	20	light grey	interbanded silt and clay silt	very compact; Fe coated charcoal/ancient roots		28		28: 2.45 kg sieved; some molluscs, fragmented and very coroded (mostly slug plates), some granules, moderate ostracods (few mica platelets)		
		34b	18	light grey (slightly yellowish)	laminated silts with some fine sand; rare small stones up to < 1 cm **erosion surface at base**	very compact, with one lense of calcareous nodules; Fe coated charcoal/ancient roots; Fe concretions up to 1.5 cm; **gastropod shells**		29		29: 2.3 kg sieved; moderate molluscs, rather fragmented and coroded; fairly frequent granules, frequent ostracods **significantly wetter**	▤	
	Part 1a	**35**	15	grey	alternating bands of silty fine sand and silt, silt predominating, with rare small sub-rounded pebbles up to 3 cm	Fe coated charcoal/ancient roots; frequent very small Fe-Mn concretions; **gastropod shells**		30		30: 2.2 kg sieved; fairly abundant molluscs, rather fragmented and coroded; fairly freq granules; moderate ostracods, few aquatic molluscs (moderate mica platelets); fauna typical of the earlier part of an interglacial, rather open fairly damp flood plain environment with some trees, tall herbs, rocks and some open ground; fairly frequent Clausiliids	🟩	
		36	10	grey, orangey in places	finely interbanded silty fine sand, sandy silt and silt, with some pebbles to 1.5 cm (+ rare up to 4 cm) at base	significant iron staining + Fe coated charcoal/ancient roots; with cemented sand lenses; some sandy concretions up to 4 cm; frequent very small Fe-Mn concretions; **gastropod shells**		31		31: 2.15 kg sieved; abundant molluscs, very fragmented and rather coroded; very frequent granules (moderate mica platelets); some ostracods; few small pyrite crystals; frequent Clausiliids	■	
		37	26-28	grey, orangey in places	interbanded fine sand and silty fine sand, plus a few bands of silt, with some sub-rounded to sub-angular pebbles up to 5 cm, becoming notably more common at base	pebbles show evidence of frost-shattering; significant iron staining - especially at base; very compact and partially cemented at base; **gastropod shells**,		32 + DK37upper 33	32: top part of Layer 37 (upper 12 cm) Additional large sample 37 upper by DK 33: lower part of Layer 37 (lower 14-16 cm)	DK37upper (= sample 32): 7.6 kg sieved by DK; moderate molluscs, very fragmented and rather coroded; v frequent granules (moderate mica platelets); rare ostracods; few aquatic molluscs; fauna typical of the earlier part of an interglacial, rather open fairly damp flood plain environment with some trees, tall herbs, rocks and some open ground; *Vitrinobrachium breve* , fairly frequent Clausiliids 33: 1.7 kg sieved; moderate molluscs, very fragmented and severely coroded, v frequent granules; rare ostracods; fauna as above	▤ 🟩	
Höhere Deckenschotter Gravels		**38**	25-40		medium sandy gravel, clast-supported, pebbles up to 8 cm; sub-rounded to sub-angular	very strongly cemented (secondary calcite)						
			>80		fine to medium sandy gravel with some silt, clast-supported, pebbles up to 6 cm, sub-rounded (incl. disk-shaped) to sub-angular	partially cemented, pebbles include alpine limestones, radiolarites, ?dolomites, sandstones						

BOTTOM The gravels of Layer 38 continue downwards for at least another 8 m, are clast-supported, massively bedded, have sub-rounded to sub-angular pebbles, plus some boulders up to >0.5 m across

Total profile approx. 850 cm

Note 1: two pollen samples were taken, just above and below the lower lignite, to the right of the gastropod samples

▒ No sample possible
🟥 Samples processed by NT in 2018 + 2020
🟧 Samples processed by DK 2019

☐ Low frequencies of molluscs or sterile
▤ Moderate frequencies of molluscs
🟩 Fairly abundant molluscs
■ Abundant molluscs

▥ Rare, unidentifiable fragments of small mammals
🟦 Small mammal remains include identifiable tooth frags

Table 2a : The Stratigraphy and Sampling of Irchel Steig West 2018-2019

Irchel-Steig West 2018-2019			**Documented and sampled by Gaudenz Deplazes, Daniel Kälin + Nigel Thew 24.05.2018; resampled 21.02.2019**										**Sample processing by NT October 2018 to January 2019**		
Stratigraphic units		**Layer number**	**Layer descriptions**							**Samples 2019**	**Samples 2018**	**Sampling remarks**	**Sample processing**	**Richness molluscan material**	**Small mammal remains**
			East side of profile - Column 1				**Centre - Column 2**	**West of centre**	**West side of profile**						
TOP			**Thickness (cm)**	**Colour**	**Lithology**	**Additional remarks**									
modern soil		18	25	darkish grey-brown	modern fairly organic silty soil with some stones		25 cm of darkish grey-brown modern silty soil	25 cm of darkish grey-brown modern silty soil	25 cm of modern silty soil						
?	**?**	17	c.100 cm of undocumented stratigraphy; covered by recently displaced material				c.80 cm of undocumented stratigraphy; covered by recently displaced material	c.120 cm of undocumented stratigraphy; covered by recently displaced material	undocumented stratigraphy; covered by recently displaced material	**Column 2 samples**					
stratigraphic connections uncertain? fluvial deposits	**seems to come after the Hasli Formation**	16					up to 15 cm of light grey silt with some fine sand; becomes grey + with some fine to medium stones up to 3 cm in upper 5 cm; some iron staining **in situ?**			C2-5			2-5: 2.9 kg sieved by DK; no molluscs, rare granules		
		15.2					up to 25 cm of olive-brown sandy fine to medium gravel up to 5 cm								
		15.1					up to 30 cm of olive-brown sand with some fine to medium gravel up to 5 cm + silty lenses + lenses of gravelly sand **important erosion surface at base**								
		14.2	>45	olive-brown	fine to medium sand with some fine gravel at base **erosion surface at base**		up to 30 cm of grey silt with fine sand + sandy bands and thin bands/lenses of sand with some fine gravel up to 2 cm; some small calc. nodules <0.5 cm + gastropods)	up to 30 cm of grey-brown sandy-silt with some stones		C2-4	C2 0	0 at centre	2/0: 2.1 kg sieved, fairly frequent molluscs, v fragmented, frequent granules, rare **small mammals**, fauna typical of the earlier/middle part of an interglacial, sporadically active channel, open damp woodland; *Azeca goodalli, Urticicola umbrosus*	🟩	🟦
		14.1					up to 10 cm of brown sand with some fine to medium gravel up to 5 cm	few cm of brown sand with some fine to medium stones							
		13.2	10-20	olive-brown	fine to medium sands with thin bands of grey sandy-silt and fine gravel, notably at base **important erosion surface at base**		up to 30 cm of light grey silt with some clay + bands of fine sand and thin bands/lenses of sand with fine gravel + rare larger stones up to 3 cm; moderate calc. nodules up to 2 cm + some sandy-calcareous concretions up to 3 cm + **molluscs**	up to 20 cm of grey-brown sandy-silt with some stones			C2 4, 1, 2, 3	1 top part to west 4 basal part to west 3 top part at centre 2 basal part at centre	2/3: 1.9 kg sieved, moderate molluscs, v fragmented, fairly frequent granules; *Urticicola umbrosus* 2/2: 3.2 kg sieved, rare molluscs; some granules, so rapid accumulation	▤	
		13.1					up to 15 cm of brown sand with some fine to medium stones up to 5 cm **important erosion surface at base**	few cm of brown sand with some fine to medium stones							
		12.3	15 (east) -25- 15 (west)	olive-brown	fine to medium sand with thin bands of fine gravel in the middle and at the top		up to 40 cm of light grey silt with some fine sand + some small stones to 2 cm, sandier at base; frequent calc. nodules up to 7 cm, especially in the upper part + **molluscs**	up to 40 cm of fine to medium silty sand with some scattered stones + lenses of grey silt			C2 5, 6, 8, 9	6 to west, 5 top part at centre, 8 middle part centre 9 lower part centre	2/6: 2.1 kg sieved; rare molluscs, rare granules, rare ostracods, (some mica platelets); so rapid accumulation		
										C2-3			2/5: 2.5 kg sieved, some molluscs (v fragmented), some granules, so rapid accumulation;		
													2/8: 2.8 kg sieved; moderate molluscs, v fragmented, rather corroded, fairly frequent granules, rare ostracods, (mica platelets); fauna as below, *Cochlostoma* sp., *Urticicola umbrosus*	▤	
										C2-2			2/9: 3.6 kg sieved; fairly frequent molluscs, v fragmented, frequent granules, fairly frequent ostracods, rare **small mammals** (also found by DK), (mica platelets); fauna typical of the earlier part of an interglacial, sporadically active channel, open damp woodland; *Urticicola umbrosus*	🟩	🟦
		12.2					up to 10 cm of grey-brown/olive-brown fine to medium sand with +/- fine to medium gravel to 3 cm	up to 5 cm of grey-brown/olive-brown fine to medium sand with +/- fine to medium gravel							
		12.1					up to 30 cm of light grey/grey silt with some clay and fine sand + thin bands /lenses of sand with fine gravel (up to 3 cm) + a discontinuous cemented sandy band (frags to 5 cm) + sandy band at top; frequent calc. nodules to 4 cm + **molluscs**	up to 40 cm of fine to medium silty sand with some fine to medium stones + lenses of grey silt			C2 7	at west	2/7: 4.9 kg sieved; moderate molluscs, v fragmented, moderate granules, rare ostracods; fauna typical of the earlier part of an interglacial, sporadically active channel, open fairly damp woodland	▤	
		11	5 (east) -10 (west)	olive-brown	fine to medium sandy gravel up to 3 cm; wedging out towards the west **erosion surface at base**	with black Mn mineralisation	up to 30 cm of grey-brown/olive-brown fine to medium sand with +/- fine to medium gravel up to 5 cm	up to 40 cm of grey-brown/olive-brown fine to medium sand with +/- fine to medium gravel							
		10	5 (east) -10 - 10 (max west)	olive-grey	fine to medium sand with silt lenses	cross bedded, with black Mn mineralisation	up to 40 cm of light grey silt with some clay, with thin bands of sandy-silt + sand with some fine gravel (up to 2 cm), + c.5 cm of fine sand at summit; frequent calc. nodules to 4 cm, especially in the lower part + **molluscs**	up to 20 cm of fine to medium silty sand with some fine to medium stones + thin gravelly bands + lenses of grey silt		C2-1	C2 10, 11	at centre, 10 top part, 11 lower part	2/10: 4.7 kg sieved, fairly frequent molluscs, v fragmented, frequent granules, fairly frequent ostracods, v rare **small mammals**, (mica platelets) fauna typical of the early part of an interglacial, sporadically active channel, open damp woodland; *Urticicola umbrosus*; aquatic species: *Radix ovata, Armiger crista, Pisidium obtusale*	🟩	▤
													2/11: 4.8 kg sieved; moderate molluscs, v fragmented, frequent granules, moderate ostracods (mica platelets); fauna as above	▤	
Amselboden Schotter?		9	5 (east) -30 -60 (max west)	brown	very sandy fine to medium gravel up to 8 cm; matrix supported, **strongly weathered**; rounded to subangular clasts, some frost-shattered; to the west intercalations of slightly silty sand	some bands with black Mn, clasts include alpine pebbles + frequent decomposed sandstones	up to 20 cm of brown sandy fine to medium gravel up to 8 cm; matrix supported; **strongly weathered**; rounded to subangular clasts, some frost-shattered **marked erosion surface at base = stratigraphic break**	up to 40 cm of brown sandy gravel **marked erosion surface at base = stratigraphic break**		**Column 1 samples**					
Hasli Formation	**Part 4a**	8.2	10 (east) -0 (west)	light grey to olive-grey to darkish grey	interbanded clayey silt / silt with some fine sand + several thin bands of sandy-silt; thin horizon of sandy-calcareous concretions to 1 cm **erosion surface at base**	dipping westwards by 5-10°	lost to erosion when the central channel was incised into the deposits of Layers 2 to 8		the sequence here is the same as for Layers 2 to 8 at the western side of the channel		no sample				
		8.1	15 (east) -5 (west)	olive-grey to darkish grey-brown (to light grey)	interbanded sandy-silt / silt + few thin bands of clayey silt + thin horizons of sandy-calcareous concretions to 3 cm; one discontinuous strongly cemented band; intense iron staining; thin black bands (Mn) **clear erosion surface at base**	dipping westwards by 5-10° frequent small Mn concretions					C1 1		1/1: 1.8 kg sieved; very rare molluscs (single slug plate); very rare granules, rare ostracods, (mica platelets)		
		7	35 (east) -15 (west)	light grey to olive-grey to darkish grey	interbanded silt with some fine sand / silt with clay + several bands of silty fine sand + rare small stones to 1 cm; + some thin black bands (Mn); 5 horizons with calcareous nodules up to 5 cm **marked erosion surface at base = stratigraphic break**	irregular upper surface; frequent small Mn concretions					C1 2		1/2: 1.9 kg sieved; no granules, no granules, no ostracods, (mica platelets)		
	Part 3b	6.3	25 (east) -10 (west)	lightish grey	clayey silt with horizons of calcareous nodules up to 3 cm	irregular upper surface iron staining in the nodular horizons, **molluscs**				C1-3	C1 3	upper part of this layer to west not sampled	1/3: 2.35 kg sieved; fairly frequent molluscs, rather fragmented, frequent granules, some ostracods, (mica platelets); fauna indicates a sporadically active channel, open damp woodland; rare redeposited (grey) frags from earlier deposits	🟩	
		6.2	5-10	darkish olive-grey	the upper surface of Layer 6.1 has erosional pockets up to 10 cm deep filled with sandy-silts with frequent calcareous nodules up to 2 cm **irregular erosion surface at base**						no sample				
		6.1	22-28	lightish grey, light olive-grey at summit	inter banded silt / clayey silt, intermittent horizons, with frequent calcareous nodules up to 6 cm; some Fe nodules **erosion surface at base**	**molluscs**				C1-2	C1 4		1/4: 3.4 kg sieved; fairly frequent molluscs, rather fragmented, frequent granules, rare **small mammals** found by DK, moderate ostracods, (mica platelets) fauna indicates a sporadically active channel, open damp woodland; rare redeposited (grey) frags from earlier deposits	🟩	▤
	Part 3a	5	11-15	grey to darkish grey	silty fine sand, with moderate calcareous nodules up to 5 cm **erosion surface at base** giving an irregular contact					C1-1	C1 5		1/5: 3.2 kg sieved; some molluscs, v fragmented, f frequent granules, some ostracods, (mica platelets); fauna typical of the early part of an interglacial, sporadically active channel, open damp woodland; rare redeposited (light brown) frags from earlier deposits include *Cochlostoma* sp. , *Isognomostoma isognomostomos* + *Monachoides vicinus*		
	Part 2	4	15-20	light grey to grey, upper part reddish-yellow-grey (Fe staining)	clayey silt + some sand at base, + 3-4 horizons with fairly frequent calcareous nodules up to 5 cm **marked erosion surface at base**	iron staining in upper part the sediments below this surface are significantly more weathered and compact					C1 6	lower part of layer	1/6: 3.25 kg sieved; some molluscs, coroded and v fragmented (majority slug plates), some granules, moderate ostracods, (mica platelets); fauna typical of the early part of an interglacial, sporadically active channel		
	Part 1	3	20	reddish yellow-brown (Fe staining)	finely interbanded, silt / clayey silt + 2 horizons with fairly frequent calcareous nodules up to 6 cm **clear erosion surface at base**	lower part has thin black bands with Fe-Mn, irregular surface due to erosion					no sample				
		2.2	10-15	beige grey with yellowish bands (more clayey)	very compact silt with fine sand + some coarser sand + a little fine gravel + frequent sandy-calcareous nodules (up to 4 cm); a partially cemented band at 10-15 cm; wedging out towards the west **clear erosion surface at base** with some fine gravel and a thin layer of grey sand (just above first cemented band of Layer 2a)	fairly intense iron staining in places					no sample				
		2.1	30-35	beige grey with yellowish bands (more clayey)	very compact silt with fine sand + some coarser sand + a little fine gravel + frequent sandy-calcareous nodules (up to 4 cm); 3 strongly cemented bands (at 0-5 cm, 10-15 cm + 30-35 cm from top); wedging out towards the east	some pebbles between 1st and 2nd cemented layers, fairly intense iron staining in places	5-10 cm of yellowish-grey silt with some clay	5-10 cm of yellowish-grey silt with some clay			C1 7	between 2nd and 3rd cemented bands	1/7: 2.7 kg sieved; rare molluscs (mostly slug plates due to heavy disolution), frequent granules, some ostracods, (mica platelets); sporadically active channel?		
Höhere Deckenschotter Gravels		1	>400	massively bedded fine to coarse gravel, clast supported, strongly cemented at the surface, clasts up to 40 cm, subangular to rounded, irregular surface											

BOTTOM

Total profile approx. 900/910 cm

🟥 Samples processed by NT end 2018 - early 2019
🟩 Samples processed by DK in Mar-May 2019

Please note: the layers in Column 2 exposed during cleaning before sampling in 2019 were somewhat different than those of 2018, although the correlations between the two columns have since been confirmed by sample processing

Low frequencies of molluscs or sterile ☐
Moderate frequencies of molluscs ▤
Fairly abundant molluscs 🟩
Abundant molluscs ■

Rare, tiny unidentifiable fragments of small mammals ▤
Small mammal remains include identifiable tooth fragments 🟦

Table 2b : The Stratigraphy and Sampling of Irchel Steig East 2020

Irchel Steig East 2020

2688.542 / 1265.628

Documented and sampled by Gaudenz Deplazes, Daniel Kälin + Nigel Thew 19.05.2020

Stratigraphic Units **TOP**		**Layer no.**	**Thickness (cm)**	**Layer Descriptions**		**Additional remarks**	**Samples**	**Sample processing**	**Richness of molluscan material**	**Small mammal remains**
modern soil		1	25	darkish grey-brown	topsoil, including upper 10 cm humus; some scattered stones					
slope deposit or eroded remnants of a gravel unit?		2a	10-20	olive-grey-brown	silty-sand with fairly abundant fine to medium gravel + some coarse; sub-angular to rounded stones up to 8 cm; no clear orientation; matrix supported					
		2b	5-15		fine to medium gravel + some coarse up to 11 cm, in a sandy matrix; matrix or clast supported, sub-angular to rounded clasts; horizontal or slightly inclined orientation; reaches 20 cm thick to the left of the cleaned profile, and in the forest to the south of the site is over 2 m thick **clear erosion surface at base**					
glaciogenic deposits		3	25	reddish-brown, to reddish olive grey, mottled	fairly abundant fine to medium gravel (c.40%) + few coarse up to 7 cm, in a matrix of silty-sand; angular to sub-rounded clasts, moderate decomposed sandstones; intensely mottled due to iron staining, no dominant orientation, although vertical are common; **erosion surface at base**	strongly weathered gravelly diamicton?				
		4	25-31	reddish-brown to reddish olive-grey to light olive-grey, mottled	silty fine sand with some clay + moderate fine gravel (c.20%) + some stones up to 2 cm (incl. decomposed sandstones); heavily mottled by iron staining; the basal 5-7 cm is a fine gravel in a silty-sand matrix, and varies from clast to matrix supported **erosion surface at base**	strongly weathered gravelly diamicton? flame-like structure at base = cryoturbation?				
Hasli Formation	**Part 4b**	5	44-48	olive-grey to grey strongly mottled to reddish-brown	clayey silt with some fine sand + rare very small stones to 0.3 cm; band of sandy-silt at base; the base is strongly iron stained **clear erosion surface at base**		IS 20-1	3.7 kg sieved; no molluscs; no granules; abundant *Cenococcum*		
		6	10-12	darkish olive-grey	silt with some clay and fine sand + rare very small stones to 0.3 cm; strongly mottled to reddish-brown **clear erosion surface at base**		IS 20-2	1.45 kg sieved; no molluscs; no granules; fairly abundant *Cenococcum*		
		7	28	darkish olive-grey	interbanded silt with some fine sand / silt with some clay + rare very sma stones to 0.3 cm; mottled and heavely stained by Fe and Mn; occasional sandy-calcareous concretions to 1 cm		IS 20-3	1.85 kg sieved; no molluscs; no granules; very abundant *Cenococcum*		
		8	26	darkish olive-grey, interbanded with darkish olive-brown	clayey silt with some fine sand + rare very small stones to 0.4 cm; some **soft clasts of blackish-brown humified peat** up to 2 cm; fairly abundant calcareous rootlet concretions **clear erosion surface at base**	soft clasts	IS 20-4	3.35 kg sieved; no molluscs; some granules; moderate *Cenococcum*		
	Part 4a	9	15	light olive-grey, becoming light reddish-brown in the upper 5 cm	clayey silt with some fine sand + rare very small stones to 0.3 cm; frequent small white soft calcareous nodules; very abundant white calcareous rootlet concretions **clear erosion surface at base**		IS 20-5	3.65 kg sieved; rare molluscs; moderate granules; very rare ostracods		
		10	9-10	grey to light grey	two bands of silty fine sand + a marly band (2-3 cm) with some fine sand in the middle; fairly frequent Fe-stained sandy-caclareous concretions up to 6cm; abundant white calcareous rootlet concretions **clear erosion surface at base**		IS 20-6	2.80 kg sieved; no molluscs; some granules		
		11	22	light olive-grey to grey	interbanded silts / grey clay silts with some fine sand + a thin band of sandy-silt at base; mottled by iron staining; moderate calcareous nodules in upper part; moderate light grey sandy-caclareous concretions to 1.2 cm; abundant white calcareous rootlet concretions		IS 20-7	3.35 sieved; very rare molluscs; rare small granules; rare ostracods		
		12	9-10	darkish blue-grey	fine sand (little medium) with some silt / some thin bands of silt; a horizon of small calacreous nodules at base; moderate light grey sandy-calcareous concretions to 12 cm; fairly common Fe-stained sandy-caclareous concretions to 2 cm; some white calcareous rootlet concretions **clear erosion surface with some small stones at base**		IS 20-8	2.55 kg sieved; very rare molluscs; very rare small granules; rare ostracods		
	Part 3b	13	34	light olive-grey to grey	interbanded sandy silt / silt with clay and some fine sand + rare very small stones to 0.4 cm; some light grey sandy-calcareous concretions to 0.5 cm; some iron oxide concretions arround rootlets up to 2.5 cm; fairly abundant white calcareous rootlet concretions	**molluscs**	IS 20-9	4.60 kg sieved; fairly abundant molluscs; frequent granules; rare ostracods	🟩	
		14	15-16	grey to yellowish-grey to darkish grey at summit	interbanded silty fine sand / sandy-silt + some bands of silt with clay; few Fe-rich sandy concretions to 1.5 cm; moderate small grey sandy concretions up to 0.5 cm; rare white calcareous nodules up to 0.4 cm; a few iron oxide concretions arround rootlets up to 2cm; some white calcareous rootlet concretions **clear erosion surface at base**		IS 20-10	2.65 kg sieved; moderate molluscs; moderate granules; very rare ostracods	▤	
		15	26-30	light grey to light brownish-grey to yellowish-brown at base	silt with some clay and fine sand in lower part, becoming clayey silt with a little fine sand in upper part; a sandy band with some very fine gravel to 0.4 cm at base; some small calcareous nodules to 0.6cm; some white calcareous rootlet concretions; rare iron oxide concretions arround rootlets up to 0.5 cm; sub-angular **bioturbations** (tube-like) with a grey sandy filling **clear erosion surface at base**	**molluscs** bioturbations	IS 20-11 / IS 20-17 (large sample DK)	5.95 kg sieved; fairly abundant molluscs; frequent granules; very rare ostracods	🟩	
	Part 3a	16	6-12	grey/darkish grey to yellowish-brown at summit	irregularly interbanded sandy-silt / silt + very rare small stones to 0.3 cm; a few grey sandy-calcareous concretions to 2 cm; some white calcareous rootlet concretions **clear erosion surface at base**		IS 20-12	2.30 kg sieved; some molluscs, very fragmented and corroded; some granules; very rare ostracods		
	Part 2	17	32-36	light grey to olive-grey to reddish olive-grey; reddish olive-brown at summit (Fe staining)	silt with some clay and fine sand in lower part, becoming clayey silt in upper part; fairly frequent calcareous nodules up to 6 cm in horizons 6 cm and 26 cm above the base; **clear erosion horizon at base**		IS 20-13	3.75 kg sieved; some molluscs, very fragmented and corroded; frequent granules; some ostracods		
	Part 1	18	12-14	light olive-grey to reddish olive-brown at summit (Fe staining)	interbanded silty fine sand (+ little medium) / sandy-silt + some bands of silt with clay; 2 discontinous cemented bands at the top and base; moderate sandy-calcareous concretions to 4.5 cm; a few white calcareous nodules to 0.7 cm; few Fe coated charcoal/ancient roots		IS 20-14	2.90 kg sieved; very rare molluscs; frequent granules; very rare ostracods		
		19	14-18	dark grey	fine to medium sand (+ some coarse) with some silt; + some **soft clasts** of reddish grey silt with some clay up to 1.5 cm; some grey sandy concretions to 3.5 cm; some Fe coated charcoal/ancient roots; iron staining in places **clear erosion surface at base**		IS 20-15	3.00 kg sieved; very rare molluscs; some granules		
		20	12	light olive-grey to yellowish-olive-brown	interbanded sandy (mostly fine + little medium) silt / silt with some clay; the sandier bands are reddened by iron staining; at base some subangula to rounded pebbles to 4-5 cm; fairly frequent sandy-calcareous concretions to 5 cm; some iron oxide concretions to 1cm; Fe coated charcoal/ancient roots; sub-rounded **bioturbations** up to 3 cm across with a grey sandy filling	bioturbations	IS 20-16	3.35 kg sieved; very rare molluscs; fairly frequent granules		
Höhere Deckenschotter Gravels		21	>400	fine to coarse gravel, clast supported, clasts up to 10 cm, subangular to rounded, mostly horizontally bedded; strongly cemented in upper part, with an irregular surface						

BOTTOM

☐	Low frequencies of molluscs or sterile
▤	Moderate frequencies of molluscs
🟩	Fairly abundant molluscs
■	Abundant molluscs

Table 3a : The Stratigraphy and Sampling of Irchel Hochwacht East 2016-2019

Irchel Hochwacht East 2019

Commune: Berg am Irchel
Coordinates: c.686050/268300

Documentation and sampling

21.09.2016 - M. Büchi, G. Deplazes, R. Grischott, T. Gubler, S. Scheidt
29.03.2017 - S. Beetschen, G. Deplazes, S. Scheidt
05.06.2019 - M. Büchi, G. Deplazes, D. Kälin, N. Thew

Additional sampling October 2020 - D. Kälin

Lithostratigraphy and sampling Hochwacht East - 05.06.19

Stratigraphical Units TOP		Layer Numbers	Depth/Height (cm)		Thickness (cm)	Layer Descriptions	Additional characteristics (from sieving)	Sediment/ Interpretation	Sample	Sample processing	Richness molluscan material	Small mammal remains
modern soil		**1**	562	592	30	dark reddish-brown topsoil, roots, including c.5 cm of humus at top		topsoil				
glaciogenic deposits		**2**	502	562	60	olive-brown sand with some silt + moderate small stones (5-10%) + few to 4 cm, subangular to subrounded; layers dipping from right to left c.10° (cf. Hasli Layer 2)		diamicton glaciogenic deposit				
		3	484	502	18	olive-brown sand with some silt + moderate stones (20%) to 6 cm, axis of clasts from horizontal to vertical, subrounded to subangular, layers dipping from right to left c.10°; (cf. Hasli Layer 2)		diamicton glaciogenic deposit				
Amselboden Schotter?	**slope deposit?**	**4**	441	484	43	reddish olive-brown (top) to fairly dark reddish olive-brown (base) fine to medium gravel (c.50 % at base, 40% in top 15 cm) in a silty-sand matrix with a little clay, clasts to 8 cm (to 6 cm in top 15 cm); poorly sorted, matrix-supported; clasts from horizontal to vertical, angular to subrounded; <u>frequent decomposed sandstones</u>, some pebbles seem to be frost-shattered; layer diping from right to left c.10° **clear erosion surface at base**		<u>strongly weathered</u> slope deposit?				
'Hochwacht Schotter' (part of the Forenirchel Schotter complex) fluvial gravels		**5**	371	441	70	reddish olive-brown fine to coarse gravel, most < 3 cm, some up to 20 cm, patchy matrix: sometimes with fine sand and sometimes without (due to circulating water?), moderately sorted, clast-supported, moderate tendency for horizontal clast orientation, especially at base; <u>some decomposed sandstone</u> clasts; partially cemented at base, basal 15 cm more silty (due to infiltration?)		fluvial gravels				
		6	286	371	85	olive-grey-brown to darkish reddish-olive-brown at base very sandy fine to medium gravel + some coarse, slightly silty, clasts up to 8 cm; fairly poorly sorted, mostly matrix-supported but includes two bands 5-10 cm thick that are clast supported, 40-60% clasts, no dominant clast orientation but many horizontal, some imbricated, few vertical; sub-rounded to rounded, variable lithology (dark blue Alpine limestone, sandy limestone, calcareous sandstone, <u>some decomposed sandstone</u>)		fluvial gravels				
		7	271	286	15	olive-grey very sandy fine to medium gravel, very slightly silty, clasts up to 5 cm, fairly poorly sorted, matrix-supported, more or less horizontally orientated clasts, subangular to rounded, quite a lot of platey pebbles, dipping about 5°; <u>some decomposed sandstone clasts</u> **erosion surface at base**		fluvial gravels				
		8	267	271	4	almost black very sandy fine to medium gravel, slightly silty, clasts up to 5 cm; moderately sorted, rather matrix-supported, subangular to rounded pebbles; includes a 2-3 cm thick lens at the summit of light creamy-yellow silty fine sand, with some coarse + little fine gravel; thickness 3-5 cm		Mn-stained fluvial gravels				
		9	253	267	14	reddish-brown (at summit very reddish- iron staining) fine to coarse gravel, clasts up to 10 cm, moderately sorted, very sandy at the top with lenses of sand, rather matrix-supported, majority of clasts are imbricated, some are horizontal; thickness: 8-18 cm; <u>some decomposed sandstone clasts</u>; thickness 12-16 cm **irregular erosional contact at base**		Fe-stained fluvial gravels				
Hasli Formation	**Part 4b**	**10**	227	253	26	light olive grey mottled with reddish brown, especially in upper part (Fe-staining) interbanded silt /clayey-silt + thin bands of silty fine sand with iron staining, plus 3 bands with sandy concretions - top and bottom bands strongly cemented, thickness: 24-28 cm **clear erosion surface at base**	frequent sandy-calarceous concretions to 4 cm; moderate Fe coated rootlets + frequent small (<1 mm) Fe nodules; moderate small Fe-Mn concretions	overbank deposits	HOC19 C1 1(10a) HOC19 C1 2(10b)	1: 1.6 kg sived; no molluscs, some granules 2: 2.05 kg sieved; very few molluscs, moderate small granules, rare small bone fragments, mica platelets		
		11	216	227	11	light olive-grey clayey silt with a little fine sand + bands of silt and a few thin bands of sandy silt + rare small stones up to 0.4 cm, a creamy-yellow marly band in the middle, thickness: 9-12 cm **clear erosion surface at base**	moderate sandy-calcareous concretions up to 3 cm; moderate Fe coated charcoal/ancient rootlets		HOC19 C1 3(11)	3: 1.9 kg sieved; no molluscs; some granules		
	Part 4a	**12**	197	216	19	light grey with one reddish band, clayey-silt with a little fine sand; more sandy (fine) in lower part with <u>Fe staining</u>; 4 bands: top = band of sandy concretions, 3 more bands of calcareous nodules (irregular, "cauliflower" shape), nodular layers light-grey coloured; thickness: 16-19 cm **clear erosion surface at base**	fairly frequent calcareous nodules to 4 cm; moderate Fe coated charcoal/ancient rootlets		HOC19 C1 4(12)	4: 1.75 kg sieved; some molluscs, rather coroded and very fragmented; moderate small granules; rare **small mammal tooth** frags, rare ostracods		○
	Part 3	**13**	179	197	18	light olive-grey interbanded sandy-silt / silt with some clay and fine sand + rare small stones to 0.6 cm; with sandy concretions to 8 cm; with **molluscs** **clear erosion surface at base**	frequent sandy-calcareous nodules to 8 cm; moderate Fe coated charcoal/ancient rootlets		HOC19 C1 5(13)	5: 3.15 kg sieved; moderately frequent molluscs, fairly well preserved but rather fragmented; moderate granules	▒	
		14	174	179	5	grey sand, cemented, calcareous; this cemented layer is discontinuous and pinches out towards the right (west); thickness: 1-5 cm **clear erosion surface at base**			HOC19 C1 14 no sample			
		15	166	174	8	olive-grey interbanded silt with some clay and fine sand / few thin bands of clay-silt / sandy-silt, thicker at base + rare small stones up to 0.6 cm; little black and reddish dots (Mn, Fe), thickness: 6-9 cm, with **molluscs** **clear erosion surface at base**	some sandy-calcareous nodules to 3 cm; moderate Fe coated charcoal/ancient rootlets; fairly frequent small Fe-Mn concretions becoming very frequent in upper part		HOC19 C1 6(15)	6: 2.45 kg sieved; abundant molluscs, rather coroded and very fragmented; fairly frequent granules; rare **small mammal tooth** frags	█	○
	Part 2b	**16**	138	166	28	light olive-grey silt with some fine sand, becoming silt with clay and a little fine sand in the upper part; few thin sandy lenses in lower part; rare small stones to 1 cm in lower part; black + reddish spots (Mn, Fe; more than in the layer above), 1-5 cm from summit two black bands of small Mn concretions; **molluscs** seen, especially in the lower part **clear erosion surface at base**	Fe concretions, especially in upper part, moderate Fe coated charcoal/ancient rootlets; frequent small Mn concretions, especially in the upper part where some larger Fe-Mn concretions to 2 cm; some calcareous nodules to 3 cm, few sandy-calcareous concretions to 1.5 cm		HOC19 C1 7(16a) HOC19 C1 8(16b) HOC19 C1 DK16b	7: 4.45 kg sieved; fairly abundant molluscs, fairly coroded and rather fragmented; moderate granules; rare **small mammal teeth** fragments 8: 4.05 kg sieved, DK16B: 21.6 kg sieved; fairly abundant molluscs, well preserved but rather fragmented; fairly frequent granules; no small mammals	█ █	○
		17	131	138	7	olive-grey interbanded sandy-silt / reddish (<u>Fe-enriched</u>) silty fine sand + rare small stones to 1.3 cm; thickness: 7-9 cm; **molluscs** seen **clear erosion surface at base**	moderate small light grey calcareous nodules to 1.5 cm; some sandy-calcareous concretions to 2.5 cm; some Fe concretions; frequent small Mn concretions		HOC19 C1 9(17)	9: 3.65 kg sieved; abundant molluscs, well preserved but rather fragmented; fairly frequent granules; some ostracods	█	
		18	117	131	14	lightish olive-grey sandy-silt with some clay + some thin bands of silty-sand; some soft clasts of brick red clay-silt up to 3 cm; with **molluscs**; thickness: 14-18 cm **erosion surface at base**	frequent calcareous nodules up to 8 cm + light grey calcreous nodules; moderate Fe coated charcoal/ancient rootlets; moderate mica platelets		HOC19 C1 10(18)	10: 3.5 kg sieved; abundant molluscs, well preserved but rather fragmented; fairly frequent granules; some ostracods	█	
		19	103	117	14	olive-grey and lightish grey-brown (mottled) fine sand with moderate silt + bands and lenses of sandy-silt (fine); thickness: 14-16 cm; **molluscs** seen **clear erosion surface at base**	frequent sandy-calcareous nodules to 12 cm + light grey calcareous nodules; moderate Fe coated charcoal/ancient rootlets; frequent mica platelets		HOC19 C1 11(19-20)	11: 3.45 kg sieved; moderately frequent molluscs, somewhat corroded and rather fragmented; moderate granules; some **small mammal tooth** fragments; little charcoal	▒	●
		20	97	103	6	olive-grey to reddish ochre-brown (<u>intense Fe-staining</u>) interbanded silty-sand (fine to medium) / sandy-silt; the upper part is more sandy; thickness: 5-8 cm; **molluscs** **clear erosion surface at base**	dipping by a few degrees towards the west some sandy-calcareous nodules to 1 cm					
	Part 2a	**21**	87	97	10	grey silty-sand, with two strongly cemented sandy bands at top and bottom; calcareous nodules; thickness: 9-10 cm **erosion surface at base**			HOC19 C1 21 no sample			
		22	76	87	11	mottled olive-grey to olive-brown to reddish-brown (<u>intense Fe-staining</u>) very silty sand, with a thick lens of cemented sand, rare small stones to 0.5 cm; frequent calcareous nodules; thickness: 6-15 cm	frequent sandy-calcareous nodules to 7 cm; moderate Fe coated charcoal/ancient rootlets; frequent mica platelets		HOC19 C1 12(22)	12: 3.45 kg sieved; few molluscs, somewhat corroded and very fragmented; some granules		
		23	58	76	18	brownish-grey sand, with two thick cemented sandy bands at top and bottom; calcareous nodules; thickness: 16-20 cm **clear erosion surface at base**			HOC19 C1 23 no sample			
	Part 1c	**24**	36	58	22	olive-grey to rusty-red (<u>intense Fe-staining</u>) to light grey silty-sand (fine-medium) with reddish bands of sand + thin bands of silt, with a few small stones to 1 cm; lower 10 cm with inclined, fine and undulating bedding (= ? ripples), steeply inclined bedding in the middle, two horizons with sandy-calcareous nodules, small pebbles at base, base is cemented; thickness: 18-26 cm (just to the left reaches 42 cm and is intensely red at summit) **clear erosion surface at base**	fairly frequent sandy-calcareous nodules to 6 cm; moderate Fe coated charcoal/ancient rootlets; moderate small Fe-Mn concretions; frequent mica platelets		HOC19 C1 13(24)	13: 3.9 kg sieved; some molluscs, rather coroded and very fragmented; moderate granules; some **small mammal tooth** fragments; some charcoal		●
Hasli Formation - sandy facies fluvial sands + gravels	**Part 1b**	**25**	26	36	10	olive-grey sand with silt and some fine gravel /two bands of very sandy fine-medium gravel at top and botton, with clasts to 5 cm; cemented in places, subangular to rounded; thickness: 7 (east)-12 cm (west) **clear erosion surface at base**	top of layer is horizonzal, but base is dipping slightly towards the west (channel edge)	meandering river channel sediments	HOC19 C1 25 no sample			
		26	22	26	4	olive-brown sand with abundant fine gravel, clasts up to 3 cm, subangular to sub-rounded; includes a cemented band at western side; thickness: 3 (east)-8 cm (west) **erosion surface at base**	dipping c.5° towards the west (channel edge) moderate Fe coated charcoal/ancient rootlets		HOC19 C1 14(26-27)	14: 2.65 kg sieved; few molluscs, severely coroded and very fragmented; rare granules; some charcoal		
		27	12	22	10	grey to olive-grey to rusty red (Fe staining) interbanded sand (fine to coarse) with some silt / fairly silty sand, plus rare small silt lenses; steeply inclined bedding + cross-bedding, drape (?) structures (fluvial), cemented at the base, thickness: 4 (east)-11 cm (west) **clear erosion surface at base**						
	Part 1a	**28**	0	12	12	olive-grey interbanded very sandy fine-medium gravel, clasts to 6 cm / sand with abundant fine gravel; matrix-supported, subangular to rounded, horizontal clast orientation + some imbricated; two bands of pure sand with some silt near top and bottom of layer, cemented in places; some small <u>yellowish sandstone pebbles</u>; thickness: 6 (east)-18 cm (west) **clear erosion surface at base of layer**	dipping c.5° towards the west resembles the edge of a channel		HOC19 C1 15(28)	15: 3.15 kg sieved; few molluscs, severely coroded and very fragmented; some granules; rare charcoal		
Höhere Deckenschotter Gravels		**29**			>100	olive-brown fine to coarse gravel to 10 cm for the top 0.2 m, then bedded fine to medium gravel to 6 cm; clast-supported, rather horizontally orientated, subangular to rounded, partially cemented at top; excavated thickness: 70 cm, looking at entire outcrop >8 m of gravel		Höhere Deckenschotter Gravels				

BOTTOM

Total profile	**691 cm**
Hasli Formation	**216-225 cm**
gravelly sands (= HF)	**33-45 cm**

Analysed 🟥
No sample possible ▨

Low frequencies of molluscs or sterile ☐
Moderate frequencies of molluscs ▒
Fairly abundant molluscs ▓
Abundant molluscs █

Rare, small unidentifiable fragments of small mammals ○
Small mammal remains present, including identifiable tooth fragments ●

Lithostratigraphie 21.09.16						Paläomagnetik 21.09.16			Paläomagnetik 29.03.17			Palynologie 21.09.16			
Lagen Nr.	Tiefe (cm)		Mächtigkeit (cm)	Beschreibung	Sediment/ Interpretation	Tiefe (cm)	Probe (Label)	Palaeo-direction (mark)	Tiefe (cm)	Probe (Label)	Palaeo-direction (mark)	Tiefe (cm)	Probe (Label)	Resultat	Bemerkungen
14			*100*	siltiger Feinsand mit vereinzelten Geröllen	Verwitterungsschicht, komplett durchgewitterte Grundmoräne										
13			*250*	- Schotter - zweitunterste 5 cm: schwarz verfärbter lehmiger Schotter - rostfarbiger, lehmiger, verlehmter Schotter, Feinkies	Schotter										
12	164	198	34	gelbbraun, rost-gelb gefleckter, toniger Silt mit wenig Feinsand, etwas mehr Feinsand als darunger, darin schwimmend Fladen/Kalkkonkretionen mit Durchmesser bis 10 cm und 4 cm Dike, rundliche Fladen, bis eierförmig	Hochflutablagerung	194	06.07	#(4)&#(4)	194	08.06	+(3)	194 cm			Paläomagnetikprobe **6.07** bei 194 cm
11	144	*164*	20	hellbeige toniger Silt mit ganz wenig Feinsand (viel Ton), massig, mit sehr hellbeigen, mehligen Kalkkonkretionen	Hochflutablagerung	165	06.06	– (2)&-(3)					HOC 162 - 167 cm	na	Paläomagnetikprobe **6.06** bei 165 cm, Palynologieprobe an gleicher Stelle
10	126	144	18	braunbeiger, feinsandiger Silt mit wenig Ton, knetbar, mit vielen knollig zementierten Sandkalkknollen, **Schneckenschale**	Hochflutablagerung										
9	121	126	5	sandige Kalklage, knollig, brau-beige, harte Knollen, verkittete Sandbank, knollig zementierter Sandstein	Hochflutablagerung										
8	87	121	34	toniger Silt mit wenig Feinsand, zerstreut **Schneckenschalensplitter**, z.T. ganze Schnecken, massig, braun-grau	Hochflutablagerung	118	06.05	– (3)	118	08.05	- (3)&#(4)				Paläomagnetikprobe **6.05** bei 118 cm; Paläomagnetikprobe **6.04** bei 102 cm, Feldaufnahme 2016 und 2019 unterscheidet sich etwas in der Mächtigkeit, deshalb gewisse Restungewissheit bez. Zuordnung Paläomagnetikprobe
									108	08.04	#(4)&#(4)				
						102	06.04	#(4)							
									93	08.03	-(4)&+(4)		HOC 100 - 105 cm	keine Aussage möglich	
7	78	87	9	braun-grauer toniger Silt mit Feinsand und mit hellbeigen mehligen Kalkkonkretionenen, diese nehmen gegen oben ab	Hochflutablagerung	83	06.03	#(4)&#(4)	83	08.02	-(4)&#(4)		HOC 80 - 85 cm	na	Paläomagnetikprobe **6.03** bei 83 cm, Palynologieprobe an gleicher Stelle
6	67	78	11	hellbeige Kalkkonkretionsbank, sandig, in Zwischenräumen siltiger Feinsand	Hochflutablagerung										
5	61	67	6	ockerbrauner, rostbrauner siltiger Feinsand mit wenig Ton	Hochflutablagerung										
4	35	61	26	Kalknollen schwimmend in siltiger Feinsandmatrix, gelbbraun, Kalkknollen nehmen gegen oben ab, sie lösen sich in Flecken auf	Hochflutablagerung	50	06.02	+(3)&+(3)							Paläomagnetikprobe **6.02** bei 50 cm
3	19	35	16	Kalkkonkretioinen, Kalksand-Konkretioinen, knolliges Gefüge, bräunlich-beige, dazwischen siltiger Feinsand	Hochflutablagerung										
2	0	19	19	grober z.T. auch feiner/siltiger Sand, v.a. Feinsand, lagig geschichtet, beige-gelb ocker	Hochflutablagerung	4	06.01	+ (2)	4	08.01	#(4)&#(4)				Paläomagnetikprobe **6.01** bei 4 cm
1			*80*	Schotter	Schotter										Top des Schotters ist Basis der Abmessungen der Paläomagnetik-Proben

Total profile 628 cm

Legend 1 = top
2 = ok
3= uncertain
4 = useless
zwei Zahlen zeigen Geschwisterprober

+ = normal polarisiert
- = invers poloarisiert
= keine stabile Richtung

na = nicht analysiert

Table 3b : The Stratigraphy and Sampling of Irchel Hochwacht West 2019

Irchel-Hochwacht West 2019

Documentation and sampling 05.06.2019 - Gaudenz Deplazes + Daniel Kälin + Nigel Thew

Additional sampling November-December 2020 - D. Kälin
plus 25.08.2021 - D. Kälin and N. Thew

Stratigraphical Units TOP		Layer number	Depth/height (cm)	Thickness (cm)	Colour	Layer Descriptions	Additional remarks	Sediment/ Interpretation	Samples 2019	Samples 2021	Sample Processing 2020	Richness of molluscan material	Small mammal remains
modern soil		**23**	776	30	dark reddish-brown	stony topsoil, roots, with ca. 5 cm of humus at top		topsoil					
glaciogenic deposit		**22**	746	c.110	olive-brown	gravel, fine to medium + some coarse (20-40% in basal part, 20-30% in upper part), poorly sorted, silty-sand matrix, matrix supported, clasts up to c.20 cm, angular to rounded, no clear orientation (cf. Layers 2-3 in Col. 1); **includes pebbles with striations** **clear erosion surface at base**		diamiction glaciogenic					
'Hochwacht Schotter' (part of the Forenirchel Schotter complex) fluvial gravels		**21**	636	c.120	olive-brown to olive-grey-brown	gravel, mostly medium + some coarse up to 10 cm, moderately sorted, mostly clast supported but matrix-supported in places, clasts angular to rounded, most with +/- horizontal orientation, partially cemented (whitish) near summit		fluvial gravels with fairly massive inclined bedding					
		20	516	5-30	grey to olive-grey	olive-grey interbanded silty fine sand / sandy (mostly fine)-silt / some silty bands + bands of silt with some clay near the summit + bands of silty-sand with gravel to 4 cm at summit; few calcareous nodules to 2 cm + moderate sandy concretions to 3 cm olive-grey interbanded silty-fine sand / sandy (mostly fine)-silt + some silty bands, becoming grey and silty near base; a few stones to 4 cm; thin bands with fine gravel in places at base; rare calcareous concretions to 1 cm + moderate sandy concretions to 1.5 cm; small Fe-Mn concretions	this is a lens c.2.5 m wide by up to 0.4 m thick, which thins out rapidly towards the W and E; to the left (east) of the main profile, moderate calcareous-sandy condretions up to 3 cm; **molluscs seen**		🟥 HOC19 C2-20	🟥 HOC21 C2-1 🟥 HOC21 C2-2	C2 20: 2.95 kg sieved; abundant molluscs, rather fragmented and somewhat coroded; moderate granules; rare **small mammal** tooth frags C2-1: 5.20 kg sieved; as above, incl. rare **small mammal** tooth frags; very rare ostracods C2-2: 5.10 kg sieved; fairly abundant molluscs, rather fragmented and somewhat coroded; moderate granules	■	≡
		19sc	-	-	yellowish olive-grey	**soft clast** within the upper part of Layer 19 gravels, 0.06 to 0.36 m below the base of the sand lens; angular rhomboidal shape, 0.37 x 0.11 m; silt with some clay + some fine sand - very similar to the Hasli Formation; several other smaller soft clasts are also present 0.04 to 0.18 m below the base of the sand lens	some calcareous nodules up to 1 cm + few to 2 cm; moderate sandy concretions up to 1 cm + some calc rootlet concretions; **molluscs seen**			🟥 HOC21 C2-3	C2-3: 1.25 kg sieved; fairly abundant molluscs, well preserved but fragmented; moderate granules	■	
		19	499	40-80	olive-brown	gravel, mostly medium, moderately sorted, clast-supported, silty-sand matrix, strongly cemented in places, clasts subangular to rounded, with vanished pebbles, +a lens of olive-grey sandy-siltup to 5 cm thick, 10 cm from the summit							
		18	439	70-80	olive-brown	gravel, fine to medium + some coarse up to 20 cm; very cemented, lowermost 10-30 cm brownish and not cemented; moderately sorted, mostly clast-supported, but sometimes also matrix supported; clasts subangular to rounded	type "Löcherige Nagelfluh"						
		17	364	~15	olive-grey-brown	gravel, fine to medium, moderately sorted, matrix-supported, with light beige silty-sand matrix, cemented in places							
		16	349	~47	olive-grey	gravel, medium to coarse, moderately sorted, clast/matrix-supported, with imbrication, silty-sand matrix, cemented in places							
		15	302	11-15	olive-grey	gravel, fine to medium, moderately sorted, clast-supported, with light beige silty-sand matrix, presence of lenses of light beige silty fine sand							
		14	289	40-45	top reddish-brown, bottom brownish-grey	gravel, medium to coarse up to 12 cm, moderately sorted, clast-supported, clasts rounded to subangular, silty-sand matrix							
		13	246	2-3	blackish	gravel, medium, moderately sorted, clast-supported, clasts subangular to rounded, +/- horizontal orientation	stained by Fe-Mn						
		12	243	60	top grey-brown bottom olive-grey	gravel, medium + some coarse up to 10+ cm, moderately sorted, clast-supported, clasts subangular to rounded, +/- horizontal orientation, silty matrix with +/- clay **clear irregular erosion surface at base**	water circulation horizon						
Hasli Formation	**Part 4b**	**11b**	183	10	reddish ochre	silt with clay	intense Fe staining, frequent small Fe-Mn concretions	overbank deposits					
		11a	173	8	light olive-grey mottled orange	clayey silt with laminations **clear erosion surface at base**	strong Fe staining, small Fe-Mn concretions		🟪				
	Part 4a	**10b**	165	8	light olive-grey	silt with some clay and fine sand, + fairly frequent calcareous nodules to 4 cm	fairly frequent small white calcareous nodules up to 4 cm; moderate small Fe-Mn concretions, moderate Fe concretions, Fe coated charcoal/ancient roots		🟥 HOC19 C2-10		C 2 10: 2.55 kg sieved; some molluscs, rather coroded and very fragmented, moderate small granules, rare **small mammal** tooth frags, rare ostracods		≡
		10a	157	17	light grey (olive-grey at base)	clayey silt with some fine sand, more sandy at base + very rare small stones up to 0.5 cm; diffusely laminated; few small calacerous nodules to 2 cm; fine Mn mineralisation (black); **clear erosion surface at base**							
		9d	140	15	light olive-grey/grey	sandy-silt in lower part; with fine gravel at base, becoming a silt with some clay and fine sand towards the summit **clear erosion surface at base**	fairly frequent calcareous nodules up to 5 cm		🟪				
		9c	125	8	light grey	silt with some clay and some fine sand; band of grey-brown silty fine sand at base **clear erosion surface at base**	fairly frequent calcareous nodules up to 3 cm		🟪				
		9b	117	5	light grey	silt with clay and some fine sand	few small calcareous nodules		🟪				
		9a	112	7	light olive-grey	sandy-silt + some fine gravel at base + some scattered stones **clear erosion surface at base**	fairly frequent calcareous nodules up to 3 cm		🟪				
		8	105	10-12	grey	silt with some clay and moderate fine sand **clear erosion surface at base**	fairly frequent calcareous nodules up to 3 cm		🟪				
	Part 3	**7**	94	11-15	darkish olive-grey	silty sand (fine + some medium) + rare small stones up to 1.2 cm, + a band of gravelly sand at base; with a few thin bands of grey silt with some clay **clear erosion surface at base**	some sandy-calcareous nodules up to 2 cm; fairly frequent Fe concretions, Fe coated charcoal/ancient roots; moderate small Fe-Mn concretions; **molluscs seen**		🟥 HOC19 C2-7		C2 7: 4.65 kg sieved; fairy abundant molluscs, rather fragmented but some are excetionally well preserved moderate granules; some **small mammal** teeth fragments	▩	🟦
	Part 2b	**6**	81	10	grey	sandy (fine)-silt with silty bands, some very fine gravel at base + few scattered pebbles to 3 cm; fine Mn mineralization (black) **clear erosion surface at base**	some sandy-calcareous nodules up to 4 cm; moderate Fe concretions, moderate small Fe-Mn concretions; Fe coated charcoal/ancient roots; **molluscs seen** in L5 + at base of L6		🟥 HOC 19 C2-5 + 6		C2 5/6: 3.05 kg sieved; fairy abundant molluscs, rather fragmented; some granules; very rare ostracods	▩	
		5	71	5-7	light reddish grey/reddish ochre	silty fine sand with some medium + some stones up to 2 cm + silty bands; band of fine gravel at the base; fine Mn mineralization (black) in the middle - intense Fe-staining , especially at summit **clear erosion surface at base**							
	Part 2a	**4**	65	16-20	olive-grey	silty fine sand (some clay) with moderate stones to 4 cm, subangular to subrounded + lenses of strongly cemented sand **erosion surface at base**			🟪				
		3	47	16-20	darkish brownish-grey	silty-sand with fairly frequent fine gravel, especially at base and top; strongly cemented bands at base and summit; **clear erosion surface at base**			▒				
		2b	29	5-7	brownish-grey	silty fine to medium sand with moderate fine gravel < 2 cm **clear erosion surface at base**			🟪				
		2a	23	15-20	grey-brown, grey at base	silty fine to medium sand with a few scattered small pebbles < 1 cm	gently dipping towards the west		🟪				
Hasli Formation sandy facies	**Part 1**	**1c**	5	5	olive-grey	fine gravel in a very sandy matrix; stones to 2 cm							
		1b		15	darkish olive-grey	fine to medium gravel in a very sandy matrix; clasts to 4 cm, matrix supported, clasts subrounded to rounded							
Höhere Deckenschotter Gravels		**1a**		>50	darkish olive-brown	sandy gravel up to 8 cm, clast supported, pebbles subangular to rounded; uppermost 8 cm partially cemented		Höhere Deckenschotter Gravels					

BOTTOM

Analysed 🟥
Layers that might be worth sampling 🟪
No sample possible ▒

Low frequencies of molluscs or sterile □
Moderate frequencies of molluscs ▤
Fairly abundant molluscs ▩
Abundant molluscs ■

Rare, small unidentifiable fragments of small mammals ≡
Small mammal remains include identifiable tooth frags 🟦

Table 4a : The Stratigraphy and Sampling of Irchel Amselboden 2021

Irchel Amselboden **Documentation and sampling 20.04.2021 - Daniel Kälin + Nigel Thew**

Stratigraphical Units TOP		Layer number	Thickness (cm)	Colour	Lithology	Additional remarks	Samples Amselboden'21	Sample processing	Richness molluscan material	Small mammal remains
Amselboden Schotter?		**10**	>135 (possibly 5 m more)	olive-brown (stained by Fe in places)	fine to medium gravel with some coarse to c.13 cm, better sorted, matrix supported, matrix of sand with some silt; pebbles subangular to rounded, predominant orientation at base is subhorizontal, some imbricated, some frost shattered clasts; moderate yellowish sandstone pebbles, especially in basal part	**possible slope deposit**				
		9	8	light olive-grey	laminated sandy-silt with some pebbles up to 4 cm **clear erosion surface at base**	**glaciogenic?**				
Amselboden Schotter		**8b**	100	olive-grey	fine to coarse gravel up to 13 cm, very poorly sorted, matrix supported (more matrix than Layer 6), matrix of silty-sand; pebbles angular to subangular + some sub-rounded, no clear orientation, many frost-shattered clasts; very frequent yellowish sandstone pebbles; patches stained black by Mn; near summit at the western side is up to 15 cm of brownish-grey sandy-silt with some clay + some pebbles up to 4 cm	**glaciogenic?** at western edge, 0.2-0.5 m from top of layer, a **large soft clast** >0.7 m across (cut by NW edge of trench), of brownish-grey sandy-silt with some clay and a few pebbles up to 4 cm; resembles a **diamicton**				
		8a	60	olive-brown to reddish-brown	as Layer 6; the gravel is strongly weathered; very frequent brown decomposed sandstone pebbles **clear erosion surface at base**	**possible slope deposit**				
		7	16-55 (mean thickness 30-40 cm)	grey to olive-grey	fine-medium finely bedded sand with some silt; medium-coarse sand at the top with some pebbles to 3 cm, subangular to sub-rounded, including frost-shattered; at the western side a lens of fine gravel, 13-30 cm thick, with clasts to 3 cm, matrix of sand with some silt **clear erosion surface at base**	top shows **erosional v-shaped rills** (small gullies) up to 25 cm deep base shows **erosional v-shaped rills** up to 32 cm deep so **probable slope deposit**	6	2.55 kg sieved: completely sterile; no biological material		
		6	25-60	olive-brown to reddish-brown	fine to medium gravel with some coarse up to c.10 cm; very poorly sorted; matrix supported, matrix of silty-sand; strongly weathered, pebbles subangular to subrounded, no clear clast orientation, some frost-shattered pebbles; very frequent brown decomposed sandstone pebbles **clear erosional surface at base**	**possible slope deposit**				
Hasli Formation	Part 2	**5**	36	olive-grey	finely banded silt with some fine sand / silt with clay + rare stones to 1 cm and very rare to 2.8 cm; 2 cemented sandy bands at 12-15 and 17-21 cm from summit; some calcareous nodules up to 1.5 cm; Fe-Mn mineralization (black) and some reddish (Fe staining) of more sandy bands at the top **clear erosion surface at base**	very compact, horizontally bedded; many fragments of **gastropods** in the basal part	1	5.55 kg sieved: fairly abundant molluscs, rather corroded and very fragmented; very frequent worm granules; rare ostracods; rare frags **small mammal** teeth	■	▥
		4b	25 (west) - 65 (east)	grey	silt with some clay and fine sand + some thin bands of clay-silt; frequent calcareous nodules up to 8 cm in upper 35 cm, a few in lower 30 cm, some sandy concretions up to 2.5 cm **clear erosion surface at base** that truncates the sandy layers	horizontally bedded; many fragments of **gastropods** throughout layer, some of them complete	2 (upper part)	6.8 kg sieved: abundant molluscs, well preserved but rather fragmented; frequent worm granules	■	
		4a					3 (lower part) + DK test sample	25.8 kg sieved: abundant molluscs, well preserved but fairly fragmented; fairly frequent worm granules; rare ostracods	■	
sandy-facies Hasli Formation	Part 1c	**3**	60-65	grey to olive-grey	6 cemented sand layers up to 12 cm thick, separated by olive-grey sandy silt (fine sand + some medium + little coarse), becoming reddish (Fe staining) at the summit + rare small stones to 0.4 cm; frequent sandy-calcareous concretions up to 4 cm + moderate sandy-calcareous nodules **clear erosion surface at base**	dipping 10-15° towards south-east	4	3.3 kg sieved: some molluscs, very fragmented and rather coroded; moderate worm granules; some *Chara* ; some ostracods		
	Part 1b	**2**	40	grey to olive-grey	3 cemented layers fine-medium sand up to 8 cm thick, separated by light olive-grey fine sand with some silt/silty fine sand with moderate medium sand + some small stones to 1.5 cm + few lenses of sand with fine gravel up to 2 cm + a few bands (up to 1.5 cm thick) of compact olive-grey laminated silt with clay or silt with some fine sand **clear erosion surface at base**	dipping 10-15° towards south-east	5	7.05 kg sieved: few molluscs, very fragmentedand rather coroded; some worm granules; rare *Chara* ; rare ostracods; rare frags **small mammal** teeth		▥
	Part 1a	**1b**	5(NW) -20 cm(SE)	reddish loive-brown	fine gravel to max. 3 cm in a very sandy matrix with some silt; matrix supported; includes several yellowish sandstone pebbles **clear erosion surface at base**	dipping 10-15° towards south-east	not sampled			
Höhere Deckenschotter Gravels		**1a**	> 100	olive-brown to reddish-brown	fine to medium gravel to 8 cm, clast supported, sandy matrix with some silt, pebbles subangular to rounded, horizontal or imbricated is the most common orientation; below c.60 cm have larger clasts up to 10 cm					

BOTTOM **Total 665 cm** altitude: difference from reference point (top of sand lens of layer 7) to top of gravel (layer 1) = 2.23 m

□	Low frequencies of molluscs or sterile
▤	Moderate frequencies of molluscs
▨	Fairly abundant molluscs
■	Abundant molluscs
▥	Rare, unidentifiable fragments of small mammals
🟦	Small mammal remains, including identifiable tooth fragments

Table 4b : The Stratigraphy of Wilemerirchel 2022 and sampling 2022-2023

Wilemerirchel 2022

24/08/2022 Layers 1-12 documented and sampled by Daniel Kälin + Nigel Thew (Nagra)
Additional samples taken by D. Kälin in 2021 (Test sample) + 2023 (Supplement)

TOP		Layer no 2022	Thickness (cm)	Colour	Lithology	Additional remarks	Samples 2022-2023
glaciogenic		Above is c.1.0 m of glaciogenic sediment (olive-grey/olive-brown silty-sand with 50% [base] to 10/20% stones)					
Forenirchel-Schotter		Above this are c.6-7 m of partially to heavily cemented fluvioglacial Forenirchel-Schotter (fine to coarse sandy gravel)					
		1	>100	olive-brown/olive-grey	partially cemented, horizontally-bedded fine to coarse sandy gravel with subangular to rounded clasts up to 10 cm; clasts with predominantly horizontal or imbricated orientation; brownish where Fe staining		
		2	20	olive-brown	medium to coarse sand, with some stones to 4 cm	pinches out towards NW	
		3	20	olive-grey	sandy, fine to coarse gravel with subangular to subrounded clasts to 6 cm; no clear clast orientation		
		4	2	olive-grey	fine gravel (to 2 cm) in a sandy-silt matrix	silt from Hasli Formation?	
Hasli Formation	**Part 3**	**5**	45	yellow-olive-grey	interbanded clayey-silt/silt with some fine sand + few thin sandier bands that are heavily iron stained; 2 bands of white calcareous nodules to 2 cm in the middle		
		6	25	darkish grey/grey in upper part grey/olive-grey at base	clayey-silt with some fine sand + a blackish band with Mn/ over silty-sand + few stones to 0.5 cm/ over silt becoming sandy-silt at base **sharp erosion surface at base**	HF layers above dip towards SE	
	Part 2	**7**	14-22	grey	silt with a little clay and some fine sand + few stones to 0.6 cm; some sandy calcareous nodules to 1.1 cm, some sandy-Fe concretions to 1.4 cm; **molluscs** seen	HF layers below are horizontal or dip towards NW	Test 2021 (top 7) 1 + supplement (2023) Test 2022 (base 7)
		8	11-12	grey	silty-sand (mostly fine, some medium), siltier in upper part, rare small stones to 1 cm; with two black Mn-rich bands 1-2 cm thick; upper band 2 cm from top, lower band 3 cm from base; cemented sand lens lies between the two Mn bands + small cemented sand lens at base; some sandy concretions to 1 cm		
		9	21-23	olive-grey/grey	* top 2 cm: interbanded olive-grey sandy silt and yellowish (iron stained) silty-sand * middle 13-14 cm: olive-grey sandy-silt with three levels of cemented sand lenses * 2 cm: grey silt with some clay and fine sand * basal 6-7 cm: interbanded olive-grey sandy silt and yellowish (iron stained) silty-sand, with two small lenses of cemented sand; **molluscs** seen		2 (not the cemented sand lenses)
		10	10	grey	silt with some clay and some sand (mostly fine, some medium, little coarse) + rare small stones to 0.4 cm; some sandy concretions to 5 cm		
		11	20-23	olive-grey/grey + bands stained reddish-brown (Fe)	top 6-7 cm: grey sandy-silt with thin blackish sandier bands rich in Mn middle 6-7 cm: interbanded olive-grey silty-sand/grey sandy-silt; thin Mn band at top, 6 mm Mn band at base basal 8-9 cm: olive-grey silty-sand with several bands of reddish-brown (Fe) fine-medium sand with rare stones to 2 cm; **molluscs** seen	sands are mostly fine	3 upper 10 cm
	Part 1	**12**	>5	olive-grey + bands stained orangy red (Fe)	>5 cm of strongly cemented finely bedded fine to medium sand with some thin silty bands		

BOTTOM

Total thickness of HF
>151-165 cm

Table 5 : Molluscan Faunas from the Irchel Sites, ZH, sampled 1955-2017

Analysis : Nigel Thew June 2018 - February 2019

Site		Irchel Ebni							Irchel Hasli			Irchel Hasli					Forenirchel Freienstein	Hochwacht NE (= 2019 Hochwacht East)
Sampled by		Nagra 2017 2687 010/1267 575; 575 m asl					Nagra 2019		Bräm 1955 (Note 3)			Bolliger/Kälin 1994/1995 (Note 4)			Nagra 2017 2688950/ 1265575		Graf 1990/91 (Note 4)	Graf 1990/91 (Note 4)
Sample location / number		5. 0.50-0.65 m	4. 0.34-0.50 m	3. 0.30-0.34 m	2. 0.15-0.30 m	1. 0-0.15 m	0.55-0.35		5m (equivalent to the lower faunal level of 1994/95)	5o (equivalent to the upper faunal level of 1994/95)	Total for all material (5m, 5o + shells from sieve residue) Note 4	lower level (eastern profile) 1994	upper level (western profile) 1994/95	summit upper level (western profile) 1994/95	summit upper level (western profile)			
Sediment description		grey marly-silt with some sand + little fine gravel; very frequent calcareous rootlet concretions	grey marly-silt with some sand + fine gravel; partially decalcified in places, with significant iron staining; frequent calcareous rootlet concretions				grey marly-silt with some sand + little fine gravel + calc. nodules to 4 cm + iron encrusted wood frags		grey silt (fairly intense iron staining) with some sand + a little fine gravel; some calcareous nodules, frequent very small Fe-Mn concretions			grey silt (intense iron staining) with some sand; frequent calcareous nodules; iron concretions	grey silt (iron staining) with some sand; some calcareous nodules	grey-brown silt (intense iron staining) with some sand + little fine gravel; some small calcareous nodules	grey-brown silt (intense iron staining) with some sand + little fine gravel; frequent calcareous nodules		light yellowish-grey silt with some sand	lightish grey silt with some sand
Residue available for sorting by NT		x	x	x	x	x	x				x	x		x	(x)			
Sample size (kg)		12.8	7.0	3.3	16.2	22.0	2.0								c.2.0			
Malacozone		IEb-1a			IEb-1b	IEb-1c	IEb-1b		IHaB-1			IHaA-1	IHaA-2	Sterile	IHaA-3		IFo-1	IHw-1
Ecological Groups	Species																	
1	🟦 *Aegopinella ressmanni*								3	1	494	9	6		1		1	
	🟥 *Archaegopis (Retinella) acutus*										2							
	Ena montana								4	2	76	1			3			1
	🟩 *Isognomostoma isognomostomos*														1			
	🟩 *Macrogastra ventricosa*										1							
	🟧 *Monachoides vicinus*														1			
	🟨 *Perforatella bidentata*										9	2	12		1			
	🟥 *Retinella (Lyrodiscus) elephantium*										2							
	🟩 *Trochulus edentulus* (eastern form)										8							
	% group 1	0.0	0.0		0.0	0.0	0.0				11.1	1.7	2.3		16.7		2.0	0.4
3	🟩 *Aegopinella pura*									2	139	9	1					
	🟥 *Azeca goodalli*										369	3	6					
	Clausilia dubia								8	4	154	12	1		1			1
	🟥 *Clausilia stranzendorfensis*								6	3	161	1					3	
	🟩 *Cochlodina laminata*										2							
	🟩 *Helicigona lapicida*																	1
	🟥 *Macrogastra sessenheimensis*								7	4	94	1					1	1
	Merdigera obscura										5	2						
	⬜ *Trochulus filicinus*									3	297				1		7	
	🟥 *Trochulus leucozonus*								2		107	8						
	🟨 *Urticicola umbrosus*								1		157	2	6		6			
	🟩 *Vitrinobrachium breve*								10	15	262	25	201		3		2	
	% group 3	0.0	0.0		0.0	0.0	0.0				32.7	8.7	27.7		26.2		26.5	1.1
4	🟩 *Aegopinella nitens*								6	2	337	32	14		2			
	Clausilia bidentata								5	3	62	28	1		1			1
	⬜ *Clausilia rugosa antiquitatis*									1	11	5						
	🟥 *Cochlostoma salomoni*										6	9	24				14	
	🟩 *Discus rotundatus*										1							
	Discus ruderatus									1	124	2	41				1	
	🟩 *Limax maximus/cinereoniger*										2							
	🟧 *Neostyriaca corynodes ornatula*								1		9							
	🟩 *Oxychilus cellarius*										2	1	2					
	Trochulus clandestinus/striolatus										2							
	Trochulus villosus											1						
	Vitrea subrimata														1			
	% group 4	0.0	0.0		0.0	0.0	0.0				10.4	10.7	10.6		9.5		30.6	0.4
6	*Arianta arbustorum*										5	4			1			3
	🟩 *Carychium tridentatum*								11	22	169	1	31				3	
	Cochlicopa lubrica								1	5	235	53	19		1		6	49
	🟩 *Fruticicola fruticum*								2	1	55	1	1		2			4
	Punctum pygmaeum										2		2					9
	Trochulus sericeus								1		69	63	4		4			2
	Vertigo substriata								2		20							
	Vitrea crystallina										21	1	1					13
	% group 6	0.0	0.0		0.0	0.0	0.0				10.8	16.9	7.5		19.0		18.4	30.0
7	*Cepaea hortensis*								3		104	25	9		5			
	Euconulus fulvus									1	79		9					1
	Limax/Deroceras sp.	7	1		83	75	4		174	97	384	382	94		5		9	36
	Nesovitrea hammonis								2	5	129	7	19		1			14
	Vitrea contracta										2							
	% group 7	100.0	100.0		100.0	89.3	80.0				13.1	57.0	16.9		26.2		18.4	19.1
8	*Abida secale*								1		23							
	Cochlicopa lubricella										5	1	1					2
	% group 8	0.0	0.0		0.0	0.0	0.0				0.5	0.1	0.1		0.0		0.0	0.7
9	*Pupilla muscorum*									2	57	2	6					45
	Vallonia costata								4	3	35		32					81
	Vallonia pulchella								23	36	238		8				1	2
	% group 9	0.0	0.0		0.0	0.0	0.0				6.2	0.3	5.9		0.0		2.0	47.9
10	*Granaria frumentum*								2		44							
	🟧 *Helicopsis striata*										1							
	% group 10	0.0	0.0		0.0	0.0	0.0				0.8	0.0	0.0		0.0		0.0	0.0
11	*Carychium minimum*								3		9		3					
	Cochlicopa nitens										14							
	Succinea putris								1		39		22					
	Vertigo antivertigo								6		17	1			1			
	🟩 *Vertigo moulinsiana*									8	12	1	12					
	Zonitoides nitidus										134	3	1					
	% group 11	0.0	0.0		0.0	0.0	0.0				4.2	0.7	4.9		2.4		0.0	0.0
12	*Euconulus alderi*										15	5	29					
	Galba truncatula					4	1		11	24	244		35					
	Oxyloma elegans					5				5	148	13	93					1
	Succinella oblonga									6	113	8	27				1	
	Vertigo angustior											1	3					
	Vertigo geyeri								9	15	27	1						
	% group 12	0.0	0.0		0.0	10.7	20.0	Totals			10.2	3.9	24.1		0.0	Totals	2.0	0.4
Total Terrestrial Molluscs		**7**	**1**	**sterile**	**83**	**84**	**5**	**180**			**5344**	**726**	**776**	**Sterile**	**42**	**1544**	**49**	**267**
Number of Terrestrial Species		**1**	**1**	**sterile**	**1**	**3**	**2**	**3**			**59**	**38**	**35**	**Sterile**	**20**	**49**	**12**	**19**
Slug plates (*Limax/Deroceras* sp.) as a proportion of total terrestrial molluscs (%)		**100.0**	**100.0**	**sterile**	**100.0**	**89.3**	**80.0**				**7.2**	**52.6**	**12.1**		**11.9**		**18.4**	**13.5**
13	*Anisus leucostoma*									1	1	16	24		1			
	Pisidium obtusale								4		4		4					
	% group 13										4.5	69.6	33.7		100.0			
14	*Armiger crista*									3	3							
	Pisidium casertanum								35		41	4	28					
	Pisidium personatum										3		6					
	Radix labiata								2		18	3	12					
	Stagnicola palustris/corvus										20							
	% group 14										76.6	30.4	55.4		0.0			
15a	*Pisidium milium*												3					
	Pisidium subtruncatum								19		19		5					
	Radix balthica										2		1					
	% group 15a										18.9	0.0	10.8		0.0			
Total Aquatic Molluscs		**0**	**0**	**sterile**	**0**	**0**	**0**	**0**			**111**	**23**	**83**	**0**	**1**	**107**	**0**	**0**
Number of Aquatic Species		**0**	**0**	**sterile**	**0**	**0**	**0**	**0**			**9**	**3**	**7**		**1**	**8**	**0**	**0**
Aquatic Molluscs as a proportion of Total Molluscs (%)		**0.0**	**0.0**	**-**	**0.0**	**0.0**	**0.0**				**2.0**	**3.1**	**9.7**		**2.3**		**0.0**	**0.0**
Total Molluscs		**7**	**1**	**sterile**	**83**	**84**	**5**	**180**			**5455**	**749**	**859**	**Sterile**	**43**	**1651**	**49**	**267**
Degree of surface dissolution of the shells Evidence of alteration		brownish moderate /severe	almost complete	complete	almost complete	f. severe /severe Note 1	almost complete Note 2		moderate /f. severe /severe			(moderate) /f.severe /severe	some/ moderate /(f. severe)	complete	fairly severe /severe		f. severe /severe	(moderate) /f. severe /severe
Redeposited shells from upper part of the OSM (brown/pale brownish-grey; some recrystalisation)											x	x			xx			
Redposited shells from lower part of the OSM (black, dark grey, occ. white; notable recrystalisation)						x									x			
7	earthworm granules	xxx	xx	x	xxx	xxx	xx				xxxx	xxxx	xx		xx		xxx	xx
	white calcareous balls (mollusc eggs?)											5						
	bird eggshell fragments											1						
	tooth/bone fragments - small vertebrates			x		x					x	xx	xxx	xx	xx			
	bone fragments - large vertebrates										xx				x			
13-15	seeds										1 *Ranunculus* T. *Batrachium*							
	charcoal fragments	xx	x	x	x	x	x				xx	xxx	xx	x	x			
	Cenoccocum						x											
13-15	*Chara* oospores					x												
13-15	ostracod valves					xx					2							

For a description of the ecological groups see Table 2a

Note 1: internal casts of FeO_2

Note 2: internal casts of secondary calcite

Note 3: the Bräm, Graf and Bolliger/Kälin shell material is all borrowed from the PIMUZ

▩ First appearance or reappearance of a marker species/ecologically interesting taxon

Note 4: unfortunately the sieve residues from the two levels became mixed together, so the faunal assemblage can only be treated for the profile as a whole

KEY

🟩	Species typical of interglacial warm periods
🟦	Interglacial Marker Species last present in Swiss molluscan faunas during the Eemian
🟨	Biostratigraphical Marker Species that disappeared from Swiss molluscan faunas after the Middle Pleistocene
⬜	Biostratigraphical Marker Species that disappeared from Swiss molluscan faunas during the Middle Pleistocene, possibly after MIS 11
🟧	Biostratigraphical Marker Species that disappeared from Swiss molluscan faunas after the end of the Early Pleistocene
🟥	Biostratigraphical Marker Species that probably disappeared from Swiss molluscan faunas after the older Early Pleistocene
🟪	Species from Hasli Bräm not found in the Hasli samples from 1994/95, 2016 and 2018/2019

Total Terrestrial Molluscs from the Irchel sites	**7384**
Total Aquatic Molluscs from the Irchel sites	**218**
Total Molluscs from the Irchel sites	**7602**
Total Number of Terrestrial Species	**65**
Total Number of Aquatic Species	**10**

Table 6a : The Molluscan Faunas from Irchel Hasli, Irchel Steig and Irchel Hütz, ZH, 2018-2020

Analysis : Nigel Thew 2018-2020

Site		Irchel Hasli 2018/2019, ZH																		
Stratigraphic unit		Part 1a				Part 1b		Part 1c		Part 2a							Part 2b			
Layer number		37		36	35	34b	34a	33	32	31		30	28	27		26	25	24	23	
Sample column / number		33	DK37upper (= 32)	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15 + DK23upper
Sediment description		For sediment descriptions see Table 1																		
Sample size (kg)		1.70	7.60	2.15	2.20	2.30	2.45	1.85	1.50	2.35	1.65	2.15	1.90	2.75	2.05	2.10	1.55	1.80	3.35	9.20
Malacozone		IHaC-1a	IHaC-1b	IHaC-1c	IHaC-1d	IHaC-1e	IHaC-1f	IHaC-2a	IHaC-2b		IHaC-3a	IHaC-3b		IHaC-3c		IHaC-3d	IHaC-4a	IHaC-4b	IHaC-4c	
Ecological Groups	Species																			
1	*Aegopinella ressmanni*			3	5	45	1				3			11	8	3	28	189	97	4
	Archaegopis (Retinella) acutus																			
	Clausilia cruciata																			
	Cochlodina orthostoma																			
	Discus perspectivus																			
	Ena montana	4	5	5	3	3										1	4	152	44	2
	Isognomostoma isognomostomos																			
	Macrogastra attenuata																			
	Macrogastra ventricosa																	2	1	
	Monachoides vicinus																	1	1	
	Perforatella bidentata				5													1	3	
	Retinella (Lyrodiscus) elephantium																			
	Spermodea lamellata																			
	Trochulus edentulus (eastern form)																	66	5	1
	Trochulus unidentatus																			
	% group 1	0.6	0.5	0.3	1.1	6.7	1.0	0.0			10.0	0.0	0.0	25.0	15.4	9.1	9.1	17.7	17.8	17.5
3	*Acanthinula aculeata*																			
	Acicula lineata																			
	Acicula parcelineata																			
	Aegopinella pura			1	1	10											2	13	35	
	Azeca goodalli					4								3	12	3	33	174	28	1
	Causa holosericea																			
	Clausilia dubia	79	236	513	119	24						2					3	67	16	
	Clausilia stranzendorfensis	21	185	183	101	15									1	3	15	106	9	
	Cochlodina laminata																			
	Helicigona lapicida																			
	Helicodonta obvoluta																			
	Macrogastra sessenheimensis	4	21	34	17	13						2					3	132	59	3
	Macrogastra plicatula																			
	Merdigera obscura																	6	5	
	Monachoides incarnatus																			
	Oxychilus glaber																			
	Ruthenica filograna																	3	3	
	Trochulus filicinus	24	37	148	71	102	1													
	Trochulus leucozonus																	139	61	12
	Urticicola umbrosus			5	1												8	91	25	
	Vitrinobrachium breve	27	18	67	98	105	2				9			5	5	2	11	65	62	1
	% group 3	23.5	48.0	34.0	33.4	38.1	2.9	0.0			30.0	50.0	0.0	18.2	34.6	18.2	21.2	34.4	35.7	42.5
4	*Aegopinella nitens*		1	3	3	10	3				9				5	1	5	82	45	1
	Clausilia bidentata	143	191	855	91	43						2			1	5	17	212	64	3
	Clausilia rugosa antiquitatis	5	7	17	3	2						2			1	1	10	4	34	3
	Clausilia rugosa parvula																			
	Cochlostoma salomoni	9	4	11	6	2										2	31	399	49	2
	Discus rotundatus																			
	Discus ruderatus	1	1	5	1												1	1	1	
	Helix pomatia																			
	Neostyriaca corynodes ornatula		2	33	2															
	Oxychilus cellarius			1														4	1	
	Oxychilus clarus																			
	Poiretia dilatata dilatata																			
	Trochulus clandestinus/striolatus																			
	Trochulus villosus			1															1	
	Vitrea subrimata																			
	% group 4	24.0	19.9	33.1	8.7	8.0	2.9	0.0			30.0	50.0	0.0	0.0	13.5	20.5	18.1	30.3	23.0	22.5
6	*Arianta arbustorum*	1	4	2												1	1	3	1	
	Carychium tridentatum	7	11	6	15	15											1	15	2	
	Ciliella ciliata																			
	Cochlicopa lubrica	114	76	261	91	46	2				1		1	1	9	4	60	8	7	
	Columella columella																			
	Columella edentula																			
	Fruticicola fruticum	2	2	2	1	2	1									1	7	3	1	
	Punctum pygmaeum	3	1	2	6	1												3		
	Trochulus sericeus	13	13	59	7	6	2				1			6	1	6	45	193	56	2
	Vertigo substriata																	1	1	
	Vitrea crystallina	2	1	3	1	1												8	1	
	% group 6	21.5	10.4	12.0	9.9	9.9	4.8	0.0			6.7	0.0	100.0	15.9	19.2	27.3	32.3	10.1	8.1	5.0
7	*Cepaea hortensis*	6	2	19	2	6	1				1			4	1	6	19	21	19	
	Euconulus fulvus	10	2	27	32	22	4										7	13	1	
	Limax/Deroceras sp.	6	28	13	13	10	37	2								2	4	9	16	5
	Nesovitrea hammonis	32	21	56	51	13	2							5			2	18	14	
	Vitrea contracta																	2		
	% group 7	8.2	5.1	4.1	8.0	7.1	42.3	100.0			3.3	0.0	0.0	20.5	1.9	18.2	9.1	2.7	5.9	12.5
8	*Abida secale*	1	4	16	6	1											1	8	7	
	Cochlicopa lubricella	22	6	55	18	5											4	1	1	
	% group 8	3.5	1.0	2.5	2.0	0.8	0.0	0.0			0.0	0.0	0.0	0.0	0.0	0.0	1.4	0.4	0.9	0.0
9	*Pupilla muscorum*	9	25	79	116	15											1		1	
	Vallonia costata	4	4	25	14	1											3		1	
	Vallonia pulchella	27	46	54	88	19											5			
	Vertigo pygmaea																			
	% group 9	6.1	7.2	5.6	17.9	4.9	0.0	0.0			0.0	0.0	0.0	0.0	0.0	0.0	2.5	0.0	0.2	0.0
10	*Granaria frumentum*		2	7	5	3											1	12	32	
	Helicopsis striata																			
	Pupilla sterri		1	3	3															
	% group 10	0.0	0.3	0.4	0.7	0.4	0.0	0.0			0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.5	3.8	0.0
11	*Carychium minimum*																			
	Cochlicopa nitens																		1	
	Succinea putris				21	103	13											1	8	
	Vertigo antivertigo		2	2	23	13	3											5	2	
	Vertigo moulinsiana																			
	Zonitoides nitidus	5	6	40	6	13	7				1			2	4	2	14	68	11	
	% group 11	0.8	0.8	1.5	4.1	18.0	22.1	0.0			3.3	0.0	0.0	4.5	7.7	4.5	4.0	3.2	2.6	0.0
12	*Euconulus alderi*			3	6	1								2						
	Galba truncatula	1	7	1	38	5								3			1	1	1	
	Oxyloma elegans	2	2	24	13	12	15				5			2	4	1	6	11	14	
	Succinella oblonga	72	51	135	97	20	10											3	2	
	Vertigo angustior																			
	Vertigo geyeri	3	11	22	21	5														
	% group 12	11.8	6.9	6.6	14.3	6.0	24.0	0.0			16.7	0.0	0.0	15.9	7.7	2.3	2.0	0.6	2.0	0.0
Total Terrestrial Molluscs		**659**	**1036**	**2801**	**1221**	**716**	**104**	**2**	**sterile**	**sterile**	**30**	**8**	**1**	**44**	**52**	**44**	**353**	**2316**	**849**	**40**
Number of Terrestrial Species		**31**	**36**	**42**	**41**	**37**	**16**	**1**	**sterile**	**sterile**	**8**	**4**	**1**	**11**	**12**	**17**	**32**	**44**	**46**	**13**
Slug plates (*Limax/Deroceras* sp.) as a proportion of total terrestrial molluscs (%)		**0.9**	**2.7**	**0.5**	**1.1**	**1.4**	**35.6**	**100.0**	**-**	**-**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**4.5**	**1.1**	**0.4**	**1.9**	**12.5**
13	*Anisus leucostoma*																			
	Aplexa hypnorum			1	2	27	1												14	
	Pisidium obtusale			1	10	2														
	% group 13	0.0	0.0	22.2	57.1	65.9	12.5											0.0	66.7	
14	*Armiger crista*																			
	Gyraulus laevis																			
	Pisidium casertanum		1	4	4	10	3											4	5	
	Pisidium personatum																			
	Planorbis planorbis																			
	Radix labiata	2	1	3	5	5	4											1	2	
	Stagnicola palustris/corvus																			
	% group 14	100.0	100.0	77.8	42.9	34.1	87.5											100.0	33.3	
15a	*Bathyomphalus contortus*																			
	Bithynia tentaculata shells																			
	Bithynia tentaculata opercula																			
	Lymnaea stagnalis																			
	Pisidium milium																			
	Pisidium nitidum																			
	Pisidium subtruncatum																			
	Radix balthica																			
	Segmentina nitida																			
	% group 15a	0.0	0.0	0.0	0.0	0.0	0.0											0.0	0.0	
15b	*Anisus vortex*																			
	Gyraulus albus																			
	Pisidium amnicum																			
	Unio sp. (*crassus* ?)																			
	Valvata piscinalis																			
	% group 15b	0.0	0.0	0.0	0.0	0.0	0.0											0.0	0.0	
15c	*Bythiospeum rhenanum* cf. *turneri* (Note 1)																			
	Moitessieriid/Hydrobiid sp.																			
	% group 15c	0.0	0.0	0.0	0.0	0.0	0.0											0.0	0.0	
Total Aquatic Molluscs		**2**	**2**	**9**	**21**	**44**	**8**	**0**	**sterile**	**sterile**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**5**	**21**	**0**
Number of Aquatic Species		**1**	**2**	**4**	**4**	**4**	**3**	**0**	**sterile**	**sterile**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**2**	**3**	**0**
Aquatic Molluscs as a proportion of Total Molluscs (%)		**0.3**	**0.2**	**0.3**	**1.7**	**5.8**	**7.1**	**0.0**	**-**	**-**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.2**	**2.4**	**0.0**
Total Molluscs		**661**	**1038**	**2810**	**1242**	**760**	**112**	**2**	**sterile**	**sterile**	**30**	**8**	**1**	**44**	**52**	**44**	**353**	**2321**	**870**	**40**
Total Molluscs per kilo of sediment		**389**	**137**	**1307**	**565**	**330**	**46**	**1.1**	**sterile**	**sterile**	**18**	**4**	**0.5**	**16**	**25**	**21**	**228**	**1289**	**260**	**4**
Degree of surface dissolution of the shells Evidence of alteration		(f. severe) /severe	f. severe /severe	(moderate) /f. severe /severe	moderate /f. severe /severe	(moderate) /f. severe /severe	severe	almost complete	complete	complete	severe	severe	severe	severe	severe	severe	severe	moderate /f. severe	(moderate) /f. severe /severe	severe
Redeposited shells from upper part of the OSM (pale brown/brownish-grey; some recrystalisation)					x					x			x	x	x	x		x	x	
Redposited shells from lower part of the OSM (black, dark grey, occ. white; notable recrystalisation)																				
7	earthworm granules	xxxxx	xxxxx	xxxxx	xxx	xxx	x	(x)	(x)	(x)	xxx	(x)	x	xx	x	xx	xx	xxxx	xxxx	xx
	white/pale yellow balls (mollusc eggs?)		1				1					19	3	3	1					
	bird eggshell fragments																			
	tooth/bone fragments - small mammals															x			x	xx
	bone fragments - larger mammals																		x	
	Fe-encrusted wood fragments			x	x	x	x	x	x	x	x	x	x	x	x					
	charcoal fragments						x	x	x	x		x	x				x			
	mineralised plant thorns? (<1.5 mm)					8														
	seeds/plant remains															*Picea* needles				
	Cenococcum																x		x	x
13-15	*Chara* oospores										1	2		2						
13-15	ostracod valves	1	2	8	35	**343**	**54**	9		2	3	1	2	**11**	10	**17**				
	Fe-Mn concretions			xxx	xxx	x								xx	xx	x		x	xx	xxx
	rootlet concretions																			
	calcareous nodules (s = sandy-calcareous)					x			xx	xx	x	xx	xx	xxx	xxx	xx	x			
	platy sandy concretions/frags cemented sand layer	xx	x	x				xx	x	x	x	x	x			xx				

Irchel Hasli 2018/2019, ZH: 38 samples; sample size total 128.35; ostracod valves total 526.

Irchel Steig West 2018 (+ 2019), ZH — Column 1 (eastern side): Part 1, Part 2, Part 3a, Part 3b, Part 4a; Column 2 (western side): Part 4b?, Part 4b?

Part 4b?
The samples were taken in blocks of silty sediment from Part 3 redeposited within the sands/gravels of Part 4b, in a small channel c.11 m wide by >3 m deep. The channel infill suggests marked down-cutting, then rapid deposition. There seem to be at least three more erosional episodes, followed by rapid deposition with angular blocks of collapsed bank material.

Layer number	2.1	4	5	6.1	6.3	7	8.1	10	10	12.1	12.3	12.3	12.3	13.2	14.2	14.2	14.4	16	
Sample column / number	C1 7	C1 6	C1 5	C1 4	C1 3	C1 2	C1 1	C2 11	C2 10	C2 7	C2 9	C2 8	C2 6	C2 5	C2 2	C2 3	C2 0	2019 C2 5	18 samples
Sample size (kg)	2.70	3.25	3.20	3.40	2.35	1.90	1.80	4.80	4.75	4.90	3.65	2.80	2.15	2.50	3.25	1.95	2.10	2.90	54.35
Malacozone	ISt-1	ISt-2	ISt-3	ISt-4a	ISt-4b	ISt-6a		Ist-4*	Ist-4*	Ist-4*	Ist-4*	Ist-4*	Ist-4*	Ist-4*	Ist-4*	Ist-4*	ISt-5*	?	

For sediment descriptions see Table 2a

The faunas from Samples 11, 10, 7, 9, 8 and 3 closely resemble those from Column 1 Samples 4 and 3 in their abundance, good preservation and species composition, with the marker species *Azeca goodali* and *Granaria frumentum* being always absent. The faunas from Samples 6, 5 and 2 are poorer and more corroded due to post-depositional weathering, but clearly belong within the same malacozone due to the species composition.

Irchel Steig East 2020, ZH

Stratigraphic unit	Part 1			Part 2	Part 3a	Part 3b			Part 4a				Part 4b					
Layer number	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5		2018, 2019, 2020
Sample column / number	C3 16	C3 15	C3 14	C3 13	C3 12	C3 11	C3 10	C3 9	C3 8	C3 7	C3 6	C3 5	C3 4	C3 3	C3 2	C3 1	16 samples	34 samples
Sample size (kg)	3.35	3.00	2.90	3.75	2.30	5.95	2.65	4.60	2.55	3.35	2.80	3.65	3.35	1.85	1.45	3.70	51.20	105.55
Malacozone	ISt-1a	ISt-1b	ISt-1c	Ist-2	ISt-3	ISt-4	ISt-5a	ISt-5b	ISt-6a			ISt-6b	ISt-6c					

For sediment descriptions see Table 2b

Irchel Hütz 2019, ZH

	Column 1 East		Column 2 West		
Stratigraphic unit	silty layer above Upper DS, **below** cemented sandstone	sandy layer (~670 m asl) **above** cemented sandstone	silty layer above Upper DS, **below** cemented sandy gravel	**Modern shells** (combined from 1-1 + 2-1)	
Sample column / number	1-2	1-1	2-1		3 samples
Sediment description	pale olive-yellow silt + little fine sand + freq. calc. nodules to 3 cm + some small sandy concretions to 1 cm	olive-yellow sand with silt + little fine gravel + rare stones to 3.5 cm + silty lenses; some sandy concretions to 5 cm + calc. nodules to 1.5 cm	light olive-brown fairly sandy silt + moderately frequent fine gravel + some stones to 5 cm		
Sample size (kg)	1.60	2.20	2.20		6.0

For a description of the Ecological Groups see Figure 2

KEY

- 🟩 Species typical of interglacial warm periods but absent from Irchel older Early Pleistocene deposits
- 🟩 Species typical of interglacial warm periods
- 🟪 Pioneer species typical of colder periods
- 🟦 Interglacial Marker Species last present in Swiss molluscan faunas during the Eemian
- 🟨 Biostratigraphical Marker Species that disappeared from Swiss molluscan faunas after the Middle Pleistocene
- ⬜ Biostratigraphical Marker Species that disappeared from Swiss molluscan faunas during the Middle Pleistocene, possibly after MIS 11
- 🟧 Biostratigraphical Marker Species that disappeared from Swiss molluscan faunas after the end of the Early Pleistocene
- 🟥 Biostratigraphical Marker Species that probably disappeared from Swiss molluscan faunas after the older Early Pleistocene
- 🟧 Extinct aquatic microprosobranch, still unidentified, that may have disappeared from Swiss molluscan faunas during/after the older Early Pleistocene

🟩 First appearance or reappearance of a marker species/ecologically interesting taxon

10 Includes articulated ostracod valves (articulated valves counted as 2)

⬜ includes 3 burnt frags of *Pupilla muscorum*

Note 1 This resembles *Bythiospeum rhenanum turneri,* because of its 6 slightly convex whorls, slender elongated cylindric-conical form, deep sutures, slit-like umbilicus and ovate mouth that is somewhat angled at the top. It is somewhat larger (almost 3 mm high x 1.2 mm wide), however, so may represent a new, but possibly extinct subspecies. Of note is that *B. rhenanum turneri* has only been found living in groundwater of the Töss Valley (between Kyburg and Gamser), that runs to the west of the Irchel Plateau just 12 km to the SE.

Key for molluscan frequencies

(x)	up to 5 individuals
x	6 up to 30 individuals
xx	30 up to 100 individuals
xxx	100 up to 200 individuals
xxxx	over 200 individuals

Note 2: Rare modern shells + rare granules + *Cenococcum*

Note 3: Moderate modern shells + some granules + *Cenococcum*

Table 6b: The Molluscan Faunas from Irchel Amselboden Irchel Hochwacht and Wilemerirchel, ZH, 2019-2022

Analysis : Nigel Thew 2019-2022

Site		Irchel Amselboden 2021, ZH							Irchel Hochwacht 2019-21, ZH																								Wilemerirchel 2021-22, ZH Nagra - 2687 867/1266 753						Irchel Hütz 2019, ZH
									East															West							Hasli Formation	Upper Channel	complete site sequence							
Stratigraphic unit		Part 1b	Part 1c	Part 2			Amselboden -Schotter		Part 1a	Part 1b	Part 1c	Part 2a	Part 2b					Part 3		Part 4a	Part 4b			Part 2b	Part 3	Part 4a	Upper Channel							Part 2						Modern shells (from sediment samples)
Layer number		2	3	4a	4b	5	7		28	27-26	24	22	20-19	18	17	16		15	13	12	11	10		5 + 6	7	10	19sc Note 7	20						11	9	7	base 7	top 7 (pr 2022)		
Sample column / number		5	4	3 + DK test	2	1	6	6 samples	15	14	13	12	11	10	9	DK16b = 8	7	6	5	4	3	2	1	L5+6	L7	L10	21/2-3	L20	21/2-2	21/2-1	18 samples	4 samples	22 samples	3	2	1	Test 2022	Test 2021		
Sediment description		For sedimentary details see SM Figure 1C							For sedimentary details see Figure 7 + SM Figure 1B															For sedimentary details see SM Figure 1A										Hasli Formation silts + sands						
Sample size (kg)		7.05	3.30	17.6 + 8.2 = 25.8	6.80	5.55	2.55	51.05	3.15	2.65	4.20	3.45	3.45	3.50	3.65	21.60	4.45	2.45	3.15	1.75	1.90	2.05	1.60	3.05	4.65	2.55	1.25	2.95	5.10	5.20	73.25	14.50	87.75	c.10.0	c.5.0	c.87.5	0.5	10.2		
Smallest sieve size (mm)		0.3	0.3	0.5	0.3	0.3	0.3		0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.5	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3				0.5	0.5	0.5	0.3	0.5		
Malacozone		IA-1a	IA-1b	IA-2	IA-3a	IA-3b			IHoc-1a	IHoc-1b	IHoc-2a	IHoc-2b	IHoc-3a	IHoc-3b	IHoc-3c	IHoc-3d	IHoc-3e	IHoc-4a	IHoc-4b	IHoc-5	IHoc-6a	IHoc-6b	IHoc-6c	Ihoc-3a/3b	Ihoc-4a/4b	IHoc-5	Ihoc-7	Ihoc-8a/b	Ihoc-8a	Ihoc-8b				WI-2a	WI-2c	WI-2d	WI-2d	WI-2f		
Ecological Groups	Species																																							
1	*Aegopinella ressmanni*	2	3	xxxx	xxx	xx				1	19	4	46	254	176	262	169	89	3	1				xxx	xx		xx	238	xxx	xxxx				xxx	xxx	xxx	31	8		
	Aegopis sp. (Note 8)																											6	(x)	x										
	Archaegopis (Retinella) acutus			(x)	(x)	xxx					7		20	101	81	199	15	6	1					x	x		(x)	22	x	x				xxx	x	x	9			
	Clausilia cruciata																																							x
	Clausilia pumila																											3	(x)	x										
	Cochlodina orthostoma																							(x)1																
	Discus perspectivus			(x)							4		53	40	72	134	8	1	1					x	(x)			1	(x)	(x)						(x)				
	Ena montana	1		xxx	xx	xx					13		14	16	26	133	34	4	1					xx	x		xx	182	xxx	xxx				(x)	(x)	xx	7	1		
	Isognomostoma isognomostomos					(x)				1	8	1	8	7	21	71	25	7						x	x			20	x	x				(x)	(x)	x	3			x
	Macrogastra attenuata																																							x
	Macrogastra ventricosa			(x)											1	2												13	(x)	(x)				(x)			1			x
	Monachoides vicinus	1									2		4	27	13	63	4	1						x	(x)		(x)	21	(x)	x				(x)	x	xx				
	Perforatella bidentata										4		6	4	1	4	1	8						(x)	x			4	x	x				(x)	(x)	(x)	3			
	Retinella (Lyrodiscus) elephantium			(x)	(x)	(x)					31	1	103	688	244	671	121	19	6					xx	x		xx	263	xxx	xxxx				(x)	(x)	(x)				
	Serrulella sp. (Note 9)										1		2	1										(x)1											x	x	8			
	Soosia diodonta																																			(x)				
	Spermodea lamellata		1											1		1	1	1																						
	Trochulus edentulus (eastern form)								1	3	31	1	41	126	156	332	64	9	5	1				xx	x		xx	222	xxx	xxx				xx	(x)	x	8	3		
	Trochulus unidentatus																																							x
	Triptychia new sp. (Note 10)																																	(x)	xx	xx	35			
	% group 1	11.1	10.3						6.7	25.0	35.8	26.9	33.2	38.5	45.7	45.7	32.6	13.7	2.1	2.4		0.0				0.0		38.3									53.3	27.9		
3	*Acanthinula aculeata*													8	5	4	2										(x)									(x)	1			x
	Acicula lineata																																							x
	Acicula parcelineata												2	6	2	9											(x)	3		(x)										
	Aegopinella pura	3	3	xx	xx	x					9	1	18	86	20	36	25	32	3					x	x		xx	59	x	xx				(x)	(x)	(x)	3			x
	Azeca goodalli			x	x	x				1	17	2	31	89	105	481	45	36	20	4				xx	x	5	xxx	96	xx	xx				(x)	(x)	x	2			
	Causa holosericea																											2	(x)	(x)										
	Clausilia dubia			(x)	(x)	x					13		9	8	2	29	4	2	1					x(25)	xx(99)		x	74	x	xx				x	(x)	(x)	2	1		
	Clausilia stranzendorfensis			(x)	(x)	xx					7		10	7	17	72	2	5	1					x(10)	xx(81)		x	114	x	xx	Note 12			(x)	(x)	x	4			
	Cochlodina laminata																													(x)						(x)				x
	Euomphalia strigella																													x										
	Helicigona lapicida										3		2	8	3	11	1	3						x	(x)		x	14	x	xx				x	(x)	x				x
	Helicodonta obvoluta																																							x
	Macrogastra sessenheimensis			x	x	xxx					4		4	4	19	59	11	3	1					x(10)	x(7)		x	47	xx	xx				(x)	(x)	(x)	1	2		
	Macrogastra plicatula																																							x
	Merdigera obscura			(x)	(x)	(x)					3		4	10	1	3								(x)	(x)		(x)	9	x	x										x
	Monachoides incarnatus																																							x
	Oxychilus glaber																																							x
	Ruthenica filograna														7	5	2																							
	Trochulus filicinus	10	5	xxxxx	xxxxx	xxxx					9		20	21	27	8	11	1	2					xx	x		x	42	x	x				x	x	(x)	3	1		
	Trochulus leucozonus			xxx	xxx	xxx				1	9		5	10	10	148	3	8						x	x		(x)	31	(x)	(x)				xx	(x)	xxx	6			
	Urticicola umbrosus	1		xx	xx	xx					5		17	31	25	29	46	71	49	1				xx	x		x	32	xx	xx				x	(x)	(x)	1			
	Vitrinobrachium breve	1	4	xxx	xxx	xx					9	2	69	176	72	101	36	28	44	7				xx	x	1	x	108	x	x				xx	x	x	7			
	% group 3	41.7	30.8						0.0	10.0	26.3	19.2	21.3	14.1	18.2	24.3	13.9	17.9	15.2	14.3		0.0				10.9		24.3									15.2	9.3		
4	*Aegopinella nitens*			xx	xx	x				1	12	4	33	209	78	322	58	25	3	1				xx	x		x	68	xx	xx				x	(x)	x	3			x
	Clausilia bidentata			(x)	(x)	(x)					12		9	2	4	19	6	6	2					x(28)	x(10)		x	60	x	x				(x)	(x)	(x)	4			
	Clausilia rugosa antiquitatis	1		(x)	(x)	xx					1		3	2	11	4	2	1							(x)1			8	(x)	x				(x)	(x)	(x)				
	Clausilia rugosa parvula																																							x
	Cochlostoma salomoni	1	4	xxxx	xxxx	xxxx					4			1	1	1	3							x	(x)		(x)	72	(x)	xx				(x)	(x)	(x)				
	Discus rotundatus										2				29	29	2	1						x	(x)			13	(x)	x							2			x
	Discus ruderatus			(x)		(x)									2	4	1	1						(x)	(x)			2	(x)	x					(x)					
	Helix pomatia																																							x
	Limax maximus/cinereoniger														1																									
	Milax/Tandonia sp.																												(x)							1				
	Neostyriaca corynodes ornatula		1		(x)	(x)									1	10	2		1								(x)	5	(x)	(x)				(x)	(x)	(x)				
	Neostyriaca dehmi (Note 11)			(x)												1																								
	Oxychilus cellarius			x									13	10	16	15	2	15	1					x	x		(x)	5	(x)	(x)						(x)				x
	Oxychilus clarus			x	x	x							2	31	53	52	4	2						x	(x)		x	9	(x)	x										
	Oxychilus steiningeri																											3		x										
	Poiretia dilatata dilatata				(x)						6		4	11	7	98	8	1						x	x			15	x	x				(x)	x	x	1			
	Trochulus clandestinus/striolatus																													(x)						(x)				
	Trochulus villosus																											1												x
	Vitrea subrimata			(x)		(x)					4	1	8	309	121	139	9	3	1					x	(x)		xx	62	x	xx				(x)	(x)	(x)				x
	% group 4	5.6	12.8						0.0	5.0	12.2	19.2	8.0	17.5	18.7	16.9	7.2	5.2	1.0	1.2		0.0				0.0		12.4									5.1	0.0		
6	*Arianta arbustorum*	1		x	x	x					1		2	14	10	9	2	3	49	4				xx	xx*		x	19	x	x				(x)	(x)	(x)	3	1		x
	Carychium tridentatum	1	1	xxxxx	xxxxx	xxx						1	19	99	37	36	48	4	2					x	x		xx	22	(x)	x						(x)	1			x
	Ciliella ciliata															1								(x)	(x)		(x)	9	(x)	x				(x)	x	(x)	1			
	Cochlicopa lubrica	2	2	xxxx	xxxx	xxx					5		85	296	38	66	217	217	279	21				xxx	xxx	11	xx	93	x	x				(x)	(x)	(x)	7	4		x
	Columella columella																		6						x															
	Columella edentula												3	26	1	3	2																							
	Fruticicola fruticum			xx	xx	xx				1	3		2	8	5	13	7	8	16	2				x	x		x	13	x	x				(x)	(x)	(x)	1	2		x
	Punctum pygmaeum			xxxx	xxx	x								14	7	6	1	11	5					(x)	xx		(x)	1	(x)	(x)										x
	Trochulus sericeus			x	x	x				1	13	2	45	62	12	23	23	72	30	1				xxx	xx	1	x	88	x	x				xx	xx	x	19			x
	Vertigo substriata			(x)	(x)																																			
	Vitrea crystallina			x	x	xx					3		11	40	27	25	27	9	2	1				x	x	1	x	21	x	xx						(x)				x
	% group 6	11.1	7.7						0.0	10.0	7.5	11.5	18.7	17.0	7.9	4.4	24.1	30.6	48.7	34.5		0.0				23.6		10.2									16.2	16.3		
7	*Cepaea hortensis*	1	4	xx	xx	xx			11	9	35	3	39	61	51	219	132	47	41	14				xx	xx	4	xx	174	xx	xx				xx	xx	xx	13	14		x
	Cepaea nemoralis																											2		(x)						(x)				
	Euconulus fulvus	1		xx	xx	x					2		35	113	19	14	6	3	21					x	xx	4	(x)	13	(x)	(x)										x
	Limax/Deroceras sp.	8	9	x	x	x			3	1	5	1	3	2	5	8	1	1	1	1		1		(x)	x	1	x	8	x	x				10	1	37	1	5		x
	Nesovitrea hammonis			xx	xx	x					9	2	24	7	5	17	11	54	27	1				x	xx	1	(x)	17	(x)	(x)					(x)	(x)				x
	Vitrea contracta			(x)										3	1	2		1						(x)				3	(x)	(x)						(x)				
	% group 7	27.8	33.3						93.3	50.0	15.2	23.1	11.3	5.7	4.7	6.3	11.1	10.0	11.3	19.0		50.0				18.2		8.3									7.1	44.2		
8	*Abida secale*		1	x	x	(x)					2		6	1			2		1					x			(x)	22	x	x						(x)	3			x
	Cochlicopa lubricella			x	(x)	(x)					2		10	29	1	5	7	27	3					x	x		(x)	12	(x)	(x)										x
	% group 8	0.0	2.6						0.0	0.0	1.2	0.0	1.8	0.9	0.1	0.1	0.7	2.6	0.5	0.0		0.0				0.0		1.3									1.5	0.0		
9	*Pupilla muscorum*			(x)	(x)						1		12	2	8	18	4	133	102	1		1		x	xxx	3		8	(x)	x						(x)				
	Vallonia costata			(x)		(x)										1		1						x	xxx			1	(x)	x							1			x
	Vallonia pulchella			(x)																								2	(x)	x										
	Vertigo pygmaea																								(x)															
	% group 9	0.0	0.0						0.0	0.0	0.3	0.0	1.3	0.1	0.5	0.5	0.3	12.7	12.8	1.2		50.0				5.5		0.4									0.5	0.0		
10	*Granaria frumentum*			x	(x)																				(x)			25	(x)	x										
	Helicopsis striata															1		1						(x)	(x)			1		(x)						(x)				
	Pupilla sterri																											3	(x)											
	% group 10	0.0	0.0						0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.02	0.0	0.1	0.0	0.0		0.0				0.0		1.1									0.0	0.0		
11	*Carychium minimum*																																							
	Cochlicopa nitens																																							
	Succinea putris			(x)	(x)	(x)							18	26	12	16	39	39	37	11				(x)	(x)			53	(x)	x				(x)		(x)	1	1		
	Vertigo antivertigo			(x)		(x)							1	28	16	5			10						(x)			1	(x)	(x)										
	Vertigo moulinsiana																												(x)											
	Zonitoides nitidus			(x)		x					4		8	119	13	5	5	16	2					x	x		(x)	13	(x)	x										
	% group 11	0.0	0.0						0.0	0.0	1.2	0.0	3.0	5.3	2.4	0.6	3.2	5.2	6.1	13.1		0.0				0.0		2.6									0.5	2.3		
12	*Euconulus alderi*			(x)										5	2																									
	Galba truncatula			xx	x						1		5	10	14	20	71	4	5	4				x	(x)	23		10	(x)	x							1			
	Oxyloma elegans	1	1	x	(x)	(x)							5	7	10	15	21	12	3	4				x	(x)			12	x	x						(x)				
	Succinella oblonga			x	x	x							1	1	1	7	2	6	7	4				x	(x)		(x)	6	(x)	(x)										
	Vertigo angustior					(x)								2	4																									
	Vertigo geyeri				(x)	x							1	4	1	1			3						(x)															
	% group 12	2.8	2.6					Totals	0.0	0.0	0.3	0.0	1.3	0.9	1.8	1.0	6.9	2.1	2.3	14.3		0.0				41.8		1.1			Totals						0.5	0.0	Totals	
Total Terrestrial Molluscs		**36**	**39**	**abundant**	**abundant**	**abundant**	**sterile**		**15**	**20**	**335**	**26**	**895**	**3283**	**1730**	**4097**	**1355**	**1058**	**798**	**84**	**sterile**	**2**	**sterile**	**c.1000**	**c.790**	**55**	**c.1000**	**2601**	**c.2000**	**c.4000**	**c.15540**	**c.9600**	**c.25140**	**c.400**	**c.250**	**c.2500**	**197**	**43**	**c.3390**	
Number of Terrestrial Species		**16**	**13**	**51**	**42**	**44**	**sterile**	**58**	**3**	**10**	**41**	**14**	**50**	**57**	**60**	**62**	**53**	**50**	**40**	**19**	**sterile**	**2**	**sterile**	**54**	**56**	**11**	**42**	**66**	**63**	**67**	**71**	**72**	**81**	**35**	**36**	**50**	**35**	**12**	**56**	**36**
Slug plates (*Limax/Deroceras/Milax/Tandonia* sp.) as a proportion of total terrestrial molluscs (%)		**22.2**	**23.1**				**-**		**20.0**	**5.0**	**1.5**	**3.8**	**0.3**	**0.1**	**0.3**	**0.2**	**0.1**	**0.1**	**0.1**	**1.2**	**-**	**50.0**	**-**	**c.0.1**	**c.0.1**	**1.8**	**c.0.1**	**0.3**						**c.2.5**	**c.0.4**	**c.1.5**	**0.5**	**11.6**		
13	*Anisus leucostoma*			x	(x)	(x)							3	4	5	9	66	4	6					2	1			2		7										
	Aplexa hypnorum										2			3	2	5	5	1	1						1			4		1										
	Pisidium obtusale					(x)								1	1	1								3																
	% group 13	0.0	0.0								11.8	0.0	11.1	7.8	5.1	12.4	56.3	38.5	58.3	0.0				11.1	15.4			9.0	0.0	15.1				0.0	0.0	0.0	0.0	0.0		
14	*Armiger crista*																																							
	Gyraulus laevis										1		1			2														2										
	Pisidium casertanum		1	x	(x)	(x)					4		8	38	43	31	36	6	2					16	3			15	3	16				2		8	1			
	Pisidium personatum										1		3	44	71	46	6							2				2												
	Planorbis planorbis														1	1								1				1		1						1				
	Radix labiata			x	(x)	(x)					2		3	2	13	6	10	2	2	1				7	4			16	2	4					1	2	1	2		
	Stagnicola palustris/corvus			(x)									1		2	2	2							7	3			4												
	% group 14	0.0	100.0								47.1	0.0	59.3	82.4	83.3	72.7	42.9	61.5	33.3	50.0				73.3	76.9			56.7	100.0	43.4				100.0	100.0	84.6	100.0	66.7		
15a	*Bathyomphalus contortus*												1																											
	Bithynia tentaculata shells													1																2										
	Bithynia tentaculata opercula	4									6	1																		1						2		1		
	Lymnaea stagnalis																							3	1															
	Pisidium milium			(x)									1											1				1		1										
	Pisidium nitidum																																							
	Pisidium subtruncatum			(x)																								6		5										
	Radix balthica																											3		3										
	Segmentina nitida												1															2												
	Valvata cristata																													1										
	% group 15a	100.0	0.0								35.3	100.0	11.1	1.0	0.0	0.0	0.0	0.0	0.0	0.0				8.9	7.7			17.9	0.0	24.5				0.0	0.0	15.4	0.0	33.3		
15b	*Anisus vortex*															1								1																
	Gyraulus albus																																							
	Pisidium amnicum																							1				1												
	Pisidium clessini			(x)																																				
	Unio sp. *(crassus?)*																																							
	Valvata piscinalis			(x)											5	1																								
	% group 15b	0.0	0.0								0.0	0.0	0.0	0.0	3.2	1.7	0.0	0.0	0.0	0.0				4.4	0.0			1.5	0.0	0.0				0.0	0.0	0.0	0.0	0.0		
15c	*Bythiospeum rhenanum* cf. *turneri*			(x)	(x)						1		4	6	13	16				1				1			1	9		8										
	Hauffenia/Islamia sp.																													1										
	Moitessieriid/Hydrobiid sp.												2	3			1		1								18	1												
	% group 15c	0.0	0.0					Totals			5.9	0.0	22.2	8.8	8.3	13.2	0.8	0.0	8.3	50.0				2.2	0.0			14.9	0.0	17.0	Totals			0.0	0.0	0.0	0.0	0.0	Totals	
Total Aquatic Molluscs		**4**	**1**	**c.50**	**c.30**	**c.20**	**sterile**	**c.105**	**0**	**0**	**17**	**1**	**27**	**102**	**156**	**121**	**126**	**13**	**12**	**2**	**sterile**	**0**	**sterile**	**45**	**13**	**0**	**19**	**67**	**5**	**53**	**635**	**144**	**779**	**2**	**1**	**13**	**2**	**3**	**21**	
Number of Aquatic Species		**1**	**1**	**9**	**4**	**4**	**sterile**	**11**	**0**	**0**	**7**	**1**	**11**	**9**	**10**	**12**	**7**	**4**	**5**	**2**	**sterile**	**0**	**sterile**	**12**	**6**	**0**	**2**	**14**	**2**	**13**	**19**	**18**	**23**	**1**	**1**	**4**	**2**	**2**	**4**	
Aquatic Molluscs as a proportion of Total Molluscs (%)		**10.0**	**2.5**				**-**		**0.0**	**0.0**	**4.8**	**3.7**	**2.9**	**3.0**	**8.3**	**2.9**	**8.5**	**1.2**	**1.5**	**2.3**	**-**	**0.0**	**-**	**c.4.4**	**c.1.4**	**0.0**	**c.1.9**	**2.5**						**c.0.5**	**c.0.4**	**c.0.5**	**1.0**	**6.5**		
Total Molluscs		**40**	**40**	**c.3000**	**c.1500**	**c.1000**	**sterile**	**c.5600**	**15**	**20**	**352**	**27**	**922**	**3385**	**1886**	**4218**	**1481**	**1071**	**810**	**86**	**sterile**	**2**	**sterile**	**c.1045**	**c.800**	**55**	**c.1020**	**2668**	**c.2000**	**c.4050**	**c.16175**	**c.9745**	**c.25920**	**c.400**	**c.250**	**c.2510**	**199**	**46**	**c.3410**	
Total Molluscs per kilo of sediment		**6**	**12**				**sterile**		**5**	**8**	**84**	**8**	**267**	**967**	**517**	**195** (Note 6)	**333**	**437**	**257**	**49**	**sterile**	**1**	**sterile**	**c.330**	**c.170**	**22**	**c.800**	**904**	**c.390**	**c.770**				**40**	**50**	**29**	**398**	**5**		
Degree of surface dissolution of the shells Evidence of alteration		moderate /f. severe /severe	moderate /f. severe /severe	some/ moderate	some/ moderate	(moderate) /f. severe /(severe)			severe	severe	(moderate) /f. severe /severe	f. severe /severe	moderate /f. severe /severe	moderate /f. severe /(severe) (Note 2)	moderate /f. severe (Notes 2, 3)	moderate /f. severe (Note 3	moderate /f. severe /severe (Notes 2, 3)	(moderate) /f. severe /severe (Note 3)	moderate /f. severe /severe (Note 3)	severe (Note 3)	almost complete	almost complete (Note 4)	almost complete	moderate /f. severe	moderate /f. severe (Note 3)	severe (Note 5)	moderate /f. severe	(moderate) /f. severe /severe	(moderate) /f. severe /severe	moderate /f. severe /(severe)			Note 13	(moderate) /f. severe /(severe)	moderate /f. severe /(severe)	(moderate) /f. severe /(severe)	(moderate) /f. severe /(severe)	(f.severe) /severe		none /some
Redeposited shells from upper part of the OSM (pale brown/brownish-grey; some recrystalisation)		x			x	x			xx	xx	x	x	xx	x	x	x	x	x	xx	x				xxx	xx	x	x	xxx	x	xx				x	x	x	x	x		
Redposited shells from lower part of the OSM (black, dark grey, occ. white; notable recrystalisation)		xx				x			x	xx	x		x				x			x				x	x	x		x		x				x		x	x			
7	earthworm granules	x	xx	xxx	xxxx	xxxxx			x	(x)	xx	x	xx	xxx	xxx	xxx	x	xxx	xx	xx	x	xx	x	x	xx	xx	xxx	xx	xx	xx				x	x	xxx	xxx	xx		x
	white/pale yellow balls (mollusc eggs?)	3	5											1																										
	bird eggshell fragments																											1												
	tooth/bone fragments - small mammals	4				1					7		8 (Note 1)				2	1		1					5	5		4		6						xx		1 bone		
	bone fragments - larger mammals	1							1	1												1						2						1						
13-15	fish tooth																																							
	Fe encrusted wood fragments									x	x	x	x	x	x	x	x	x	x	x	x			x	x	x										x				
	charcoal fragments	x	x	x	x	xx			x	xx	xx		x		x	x	x	x	x					x	xx	x	x	x	x	x				x		x	x			
	Cenococcum	xx	x		x	x						x	x					xx	x		xx	x	x				x	x	x	x							x			
13-15	*Chara* oospores	4	12			1																																		
13-15	ostracod valves	**4**	37	**2**		13		**56**					**3**	27	28	**5**				**4**				**2**		4				1	**74**									
	Fe-Mn concretions					x					xx				xxx	x	xxxx	xx	x			x	xx	x	x	x								xx	x	xx	xx	xxx		
	rootlet concretions																										x													
	calcareous nodules (s = sandy-calcareous)		xs	x	xxx	xxx					xxs	xxxs	xxxs	xxx	x	x	x	xs	xxx	xx				xs	xs	xx	x		x	x					xs	xxs	xxs	xx		
	platy sandy concretions/frags cemented sand layer	xxx	xxx		x				xxx	xxx	xx	xx	x	x	x						x	xxx	xx				x	xx	xx	xx				x	xxx	x	x	x		

For a description of the Ecological Groups see Table 2a

🟩 First appearance or reappearance of a marker species/ecologically interesting taxon

10 Includes articulated ostracod valves (articulated valves counted as 2)

KEY

🟩	Species typical of interglacial warm periods but absent from Irchel older Early Pleistocene deposits
🟩	Species typical of interglacial warm periods
🟪	Pioneer species typical of colder periods
🟦	Interglacial Marker Species last present in Swiss molluscan faunas during the Eemian
🟨	Biostratigraphical Marker Species that disappeared from Swiss molluscan faunas after the Middle Pleistocene
⬜	Biostratigraphical Marker Species that disappeared from Swiss molluscan faunas during the Middle Pleistocene, possibly after MIS 11
🟧	Biostratigraphical Marker Species that disappeared from Swiss molluscan faunas after the end of the Early Pleistocene
🟥	Biostratigraphical Marker Species that probably disappeared from Swiss molluscan faunas after the older Early Pleistocene
🟨	Extinct aquatic microprosobranch, still unidentified, that may have disappeared from Swiss molluscan faunas during/after the older Early Pleistocene

🟧	Species found in the Hasli Formation at Hochwacht but not at Hasli, Steig or Amselboden
🟥	Species found in the Hasli Formation at Hochwacht and Amselboden but not at Hasli or Steig
🟦	Species not found in the Hasli Formation at Hasli, but found at Steig and Amselboden
🟪	Species also found in Bräm material from Hasli, but not in other Hasli or Steig samples from the Hasli Formation
🟨	Species found in the Hasli Formation at Wilemerirchel but at no other site
⬜	Species present in upper channel deposits at Hochwacht that are absent from the Hasli Formation at this site
🟩	Species present in upper channel deposits at Hochwacht that are absent from the Hasli Formation at all sites
🟫	larger Arvicolid tooth frags that may be idenifiable

Note 1 the 8 tooth frags seem to come from 2 larger pieces

Note 2 some shells encrusted with black Mn concretions + a few with Fe

Note 3 includes shells filled with clear precipitated calcite

Note 4 external cast of FeO_2

Note 5 internal casts of FeO_2 or white precipitated calcite

Key for estimated molluscan frequencies

(x)	up to 5 individuals
x	6 up to 30 individuals
xx	30 up to 100 individuals
xxx	100 up to 200 individuals
xxxx	200 up to 300 individuals
xxxxx	over 300 individuals

Note 6 as the smallest sieve size used for this sample was 0.5 mm, unlike the others where it was 0.3 mm, the sample total was significantly lower while the smallest species are under-represented

Note 7 this sample represents a soft clast of silty sediment from near the summit of the Layer 19 gravels

Note 8 not *Aegopis klemmi* or *A. verticillus,* because although the shell fragments have fairly sharp closely spaced ribs, they lack spiral microsculpture + the keel is less well defined on the juveniles. There are blunt less well-defined ribs on the underside of the shells for the juvenile fragments

Note 9 whorl frags from a species c.3.2 mm diameter, with closely spaced, pronounced but notably blunt ribs that bend leftwards at the suture; also pieces with two spiral columellar lamellae (notably smaller than *Triptychia* sp.)

Note 10 remains include frags from 11 large apices, 8 decollate apices, body whorl frags with fairly closely spaced rather blunt ribs on the first whorls that bend leftwards at the suture, fairly pronounced rather regular growth lines on middle whorls and rather well-defined, but fairly irregular growth lines on the final whorls, + frags with a columellar lamella and subcolumellar lamella that inside the mouth become two spiral lamellae that continue upwards for several whorls, typical of *Triptychia* spp.; est. diameter c.7.5-8.5 mm; whorls are only slightly curved, sutures rather shallow, external mouth edge slightly thickened and probably little deflected outward, but with no teeth

Note 11 in sample Amselboden 3 a specimen of *Neostyriaca* is *N. dehmi*, a new species defined by Nordsieck (2007, p.174-5). It is smaller (D = 1.8 mm) than *N. corynodes ornatula* (D = 2.4 mm) and more densely ribbed

Note 12 specimens of *Clausilia stranzendorfensis* in Col 2 L7 are exceptionally complete

Note 13 around 10-20% of the shells in all samples are encrusted with Fe and sometimes Mn

Table 7a : The Stratigraphy and Sampling of Albishorn-Bürglen 2 Profile 1 E 2019

Albishorn-Bürglen 2
Profile 1 E 15-7-2019

Coordinates	**CH1903**	**Elevation (m a.s.l)**
Top of profile	2683375.8 /1234521.9	855
Base of profile	2683377.3 / 1234528.9	848

Layer number	Thickness (cm)	Cumulative thickness (cm)	Colour	Lithology	Shells observed while sampling (+, ++, +++)	Interpretation	Additional remarks	Samples for Malacology	Short sample name	Previous samples	Sample processing 2020	Richness of molluscan material	Small mammal remains
1	>105	525->630	olive-brown to yellow-brown	f-c **Gravel**, with beds of open work f-m gravel and beds of sandy gravel (at 45-50, 60-65, 90-105 cm); clasts: mostly flat-lying with few vertically aligned, towards the top more chaotic; basal contact fairly gradual		**Albisboden-Schotter** interglacial, frapidly accumulating, fluvial sediments							
2	45	480-525	grey-brown	f-c **Gravel**, sandy; clasts: up to 20 cm, commonly imbricated or flat-lying. Basal contact: sharp with strong colour change									
3	20	460-480	yellow-grey	f-m **Gravel** with silty-sand; clasts: up to ~20 cm, often horizontally aligned; basal contact sharp (colour change)									
				at base (left side of outcrop) up to ~10 cm thick lens of clean f-c **Sand** with some silt, some fine gravel and a few stones to 4 cm; rare sandy concretions to 0.5 cm				Albishorn-15.7.2019-Profile1-E-1	P1-E-1		2.25 kg sieved: rare molluscs, mostly fragmented and corroded; rare granules; rare **small mammal** tooth frags		▥
4	80-85	380-460	grey	m-c **Gravel**, very sandy; basal 20 cm rich in boulders (up to 30-40 cm espcially in the lower part) and more chaotic appearance (clast fabric appears disorganized with several vertically-oriented clasts); basal contact sharp, strong increase in depositional energy (possibly erosive)									
5	3-35	360-380	olive-grey to grey with yellowish iron staining, banded	Bands of **Silt** with some clay and fine sand, sandy-silt, silty-sand and fine sand + some fine gravel + a few clasts (sub-rounded to angular) to 5 cm; max. thickness reached where it infills a small channel, laterally thinning into a thin 3 cm thick layer; internal bedding inclined towards channel, indicating a progressive infilling of the channel; carbonate concretions up to ~1 cm; basal contact sharp, follows channel morphology	+		This layer can be correlated with gully outcrop Profile 1-W, where "Albishorn-15.7.2019-Profile-1-W-5 " was taken; section could not be cleaned between the two profiles (too much surface debris)	Albishorn-15.7.2019-Profile1-E-2: upper ~10 cm Albishorn-15.7.2019-Profile1-E-3; middle ~10 cm Albishorn-15.7.2019-Profile1-E-4; lower ~10 cm (Albishorn-15.7.2019-Profile1-W-5)	P1-E-2 P1-E-3 P1-E-4 (P1-W-5)	ALB-17-P1	P1E-2: 4.65 kg sieved; some molluscs, broken and corroded; some granules; very rare ostracods; rare **small mammal** tooth frags		▥
											P1E-3: 3.45 kg sieved; moderate molluscs, broken and corroded; some granules; rare **small mammal** tooth frags	▤	▥
											P1E-4: 4.15 kg sieved; some molluscs, broken and corroded; some granules; very rare ostracods		
6	0-50	335-360	yellow-olive	f-m **Gravel**, silty-sandy matrix, clasts up to 15 cm, no preferential clast orientation observed, with carbonate concretions, at base: 5-8 cm clayey **Silt** unit (similar to thicker channel fill above) but unclear whether lens or soft clast; basal contact forms channel margin (incised into lower unit)									
7	10-60	295-335	yellow-olive	f-m **Gravel**, sandy; clasts: up to 15 cm, no preferential orientation observed; lower 25 cm with soft clasts or lenses of silt and clayey silt									
8	55	240-295	grey	f-c **Gravel**, sandy-silty, matrix-rich to matrix-supported; clasts: up to ~30 cm, size decreasing upwards, imbrication and flat-lying clasts commonly observed; iron oxidation stains on clast surfaces									
9	20	220-240	yellow-olive to olive	f-c **Gravel**, sandy, silty, matrix-supported and locally open-work with cross-bedding?; no preferential clast orientation observed, up to 15 cm, with soft clasts (clayey silt), up to 8 cm long									
10	20	200-220	grey	f-c **Gravel**, sandy, clasts up to 20 cm									
11	25	175-200	yellow-olive	f-m **Gravel**, silty, sandy, clast-supported, compact, clasts up to ~12 cm with soft clast (silty, clayey fine sand)									
12	0-20	165-175	yellow-grey	interbedded bands of fine **Sand** with some medium, silty-sand**,** some bands of fine to coarse sand with a little fine gravel + few clasts (sub-rounded to angular) to 5 cm, + some bands of sandy-silt, and rare silty bands; rare sandy concretions to 1 cm; cross-bedded, lens geometry?				Albishorn-15.7.2019-Profile1-E-6	P1-E-6		4.05 kg sieved: rare molluscs, mostly fragmented and corroded; rare granules; rare **small mammal** tooth frags		▥
13	10-20	150-165	brown-grey	m-c **Gravel**, sandy, silty; matrix-rich; clasts: up to ~12 cm, no preferential orientation rather chaotic emplacement; compact locally cemented; basal contact forms channel shape									
14	30	120-150	brown-grey	f-m **Gravel**, sandy, loose									
15	40	80-120	brown-grey	f-c **Gravel**, sandy, silty, matrix-rich; clasts: up to ~20 cm, commonly imbricated									
16	55-60	20-80	brown-grey	f-c **Gravel**, sandy, silty, matrix-rich, cemented in places, clasts up to ~20 cm, with imbrications and areas of more chaotically emplaced clasts			difficult to clean due to partial cementation						
17	15-25	0-20	brown-grey	f-m **Gravel**, very sandy, with few cobbles; clasts: up to ~12 cm, broken clasts frequent; basal contact sharp, undulating, erosional = bedrock surface, rounded/scoured with angular break-outs (evidence of bedrock plucking)			difficult to clean due to groundwater seepage						
18	>80		blue-grey, light grey, yellow, mottled	**Siltstone-Sandstone,** marly, very compact		**Upper Freshwater Molasse**							

Total profile thickness	**c.710 cm**

Further observations: Clast rounding relatively similar in all gravelly layers, estimated as SA-SR
Gravels rich in light-colored granites (Aaregranit)
Windgällen-Porphyries found throughout profile

□	Low frequencies of molluscs or sterile
▤	Moderate frequencies of molluscs
🟩	Fairly abundant molluscs
■	Abundant molluscs
▥	Rare, small unidentifiable fragments of small mammals
🟦	Small mammal remains include identifiable tooth frags

Table 7b : The Stratigraphy and Sampling of Albishorn-Bürglen 2 Profile 1 W 2019

Albishorn-Bürglen 2
Profile 1 W 15-7-2019

Layer number	Thickness (cm)	Colour	Lithology	Shells observed while sampling (+, ++, +++)	Additional remarks	Samples for Malacology	Short sample name
1	+15	grey to olive-yellow	interbedded sandy **Gravel** and silty **Fine sand**; **diamictic**; inclined basal contact (channel fill)				
2	15-20	olive-grey to olive-yellow	**Fine sand**, silty, top more clayey; has internal cross-bedding + horizontal bedding	+	This layer corresponds to the one sampled by M. Büchi in 2017 (ALB-17-P1); it correlates with Layer 5 in 15-7-2019-Profile-1-E	Albishorn-15.7.2019-Profile1-W-5	P1-W-5
3	25	grey with oxidation stains	f-m **Gravel**, sandy, silty; matrix-rich to matrix-supported near top; basal contact sharp, erosional, forms channel margin		Corresponds to Layer 6 in 15-7-2019-Profile-1-E		
4	+10	olive-grey	f-m **Gravel**, sandy, silty		Corresponds to the base of Layer 7 in 15-7-2019-Profile-1-E		

Table 7c : The Stratigraphy and Sampling of Albishorn-Bürglen 2 Profile 2 2019

Albishorn-Bürglen 2
Profile 2 15-7-2019

Coordinates	**CH1903**	**Elevation (m asl)**
Top of profile	2683325.8 / 1234569.1	864
Base of profile	2683324.9 /1234575.9	856

Layer number	**Thickness (cm)**	**Cumulative thickness (cm)**	**Colour**	**Lithology**	**Shells observed while sampling (+, ++, +++)**	**Interpretation**	**Additional remarks**	**Samples for Malacology**	**Short sample name**	**Test samples**	**Sample processing 2020**	**Richness of molluscan material**	**Small mammal remains**
1	>200		Grey-brown	**Boulders** up to >80 cm in f-c **gravels** in a sandy matrix with some silt		glaciogenic	Corresponds to the **Boulder Layer** in profiles documented by Thomas Gubler (Reference??)						
2	75	0-75	Grey-brown	f-m **Gravel**, sandy, silty; clast-supported but matrix-rich; massive, no preferential clast orientation/chaotically emplaced; clasts up to ~10 cm		**Albisboden-Schotter** interglacial, frapidly accumulating, fluvial sediments							
3	60-65	75-140	Grey-brown	f-c **Gravel**, very sandy (coarser than above); clast-supported but matrix-rich; with imbrication + horizontally aligned clasts; very platy clasts, several rounded; clasts up to ~10 cm									
4	0-12	140-145	beige-olive and grey	**Silt** (olive-grey) with clay and some fine sand + bands of grey fine sand with silt + a little m-c sand + little fine gravel to 1 cm; lens shape (~1 m lateral extent visible but ends abruptly); intense iron staining (oxidation) of sand on the top surface and in small pocket within lens; some iron-rich concretions to 1 cm	+		In the field this was initially thought to be an *in-situ* layer, due to horizontal internal bedding and lateral extent, but the abrupt truncation at the eastern margin when excavating for sampling rather suggests a **large soft clast**. If so, there has been minimal lateral transport.	Albishorn-15-7-2019-Profile2-1	P2-1		P2-1: 4.8 kg sieved; moderate molluscs, rather broken and fairly corroded; fairly frequent granules; rare **small mammal** tooth frags	▤	▥
5	40-50	145-190	Grey-brown	f-c **Gravel**, sandy, fairly silty; very matrix-rich, with clasts up to 14 cm; several **soft clasts** from 10 up to 40 cm embedded within gravel	++		**Soft clasts** with shell fragments; Sample 3 rare black Fe-Mn concretions	Left **soft-clast**: Albishorn-15-7-2019-Profile2-2 Right **soft-clast:** Albishorn-15-7-2019-Profile2-3	P2-2 P2-3		P2-2: 4.55 kg sieved; fairly abundant molluscs, rather broken and somewhat corroded; fairly frequent granules; rare **small mammal** tooth frags	▩	▥
				Sample 2: an olive-grey silt with moderate fine sand, some medium to coarse + little fine gravel to 1.5 cm **Sample 3**: an olive-grey silt with some fine sand, little medium to coarse + little fine gravel to 1.2 cm; upper part is slightly reddened by Fe						Test sample P2-3	Test P2-3: 0.75 kg sieved; abundant molluscs, rather broken and somewhat corroded; fairly frequent granules; rare **small mammal** tooth frags P2-3: 7.05 kg sieved; as above, including fairly rare **small mammal** tooth frags	▩	▥
6	65	190-255	Grey-brown	f-c **Gravel**, very sandy, silty; poorly sorted; clasts up to ~15 cm + one 30 cm boulder, many platy clasts, clasts horizontally aligned but no clear imbrication observed									
7	30	255-285	grey	f-c **Gravel**, sandy to relatively clean; clasts up to ~15 cm, no preferential alignment observed, seemingly chaotic emplacement; sharp basal contact with black stained (Fe-Mn oxidation) sand									
8	30-40	285-320	dark olive-beige slightly reddish	at summit thin layer up to 5 cm thick of compact **Silt** with some clay and fine sand + some dispersed fine gravel + some clasts to 6 cm; subrounded to subangular; 1 clast has cemented sand still adhering	+		Few sandy Mn and Fe-Mn concretions <0.5 mm; some iron staining	Albishorn-15-7-2019-Profile2-4	P2-4		P2-4: 3.55 kg sieved; fairly abundant molluscs, rather broken and corroded; fairly frequent granules	🟩	
			dark olive-grey/olive-beige/olive-brown mottled	sandy-**Silt**, somewhat clayey, **diamictic**, solid-cohesive, with some fine gravel and clasts to 12 cm, subrounded to angular, no preferential alignment, occurring either in thin beds of f-m gravel ("Geröllschnüre") or dispersed throughout the fines				Albishorn-15-7-2019-Profile2-5 Albishorn-15-7-2019-Profile2-6	P2-5 P2-6		P2-5: 3.3 kg sieved; fairly abundant molluscs, rather broken and fairly corroded; fairly frequent granules	🟩	
											P2-6: 3.75 kg sieved; fairly abundant molluscs, rather broken and corroded; fairly frequent granules; rare **small mammal** tooth frags	🟩	▥
9	40	320-360	beige-brown	f-c **Gravel**, sandy; clasts up to 12 cm, no preferential clast orientation with many vertically aligned clasts indicating chaotic emplacement									
10	5-10	360-370	grey	**Sand** with f-m gravel (up to 8 cm)									
11	170	370-540	beige-olive and grey	f-c **Gravel**, sandy, silty; clast-supported, ~30 cm below top is 1 small soft clast; clasts up to 15 cm, imbrication rare, flat-lying alignment common, several disintegrated granites and Windgällen porphyries observed									
12	50	540-590	grey or beige-olive	f-c **Sand**, silty or clean, horizontally-bedded + possible cross-bedding in places; top with some small silty lenses + some fine gravel + a few small stones to 4 cm, sub-rounded to angular + a few **soft-clasts** within upper 10 cm (marked in photo with yellow line)				Albishorn-15-7-2019-Profile2-7 Albishorn-15-7-2019-Profile2-8	P2-7 P2-8		P2-7: 5.65 kg sieved: rare molluscs, fragmented and corroded; rare granules; rare **small mammal** tooth frags		▥
13	>70	590->660	grey	f-c **Gravel**, sandy, silty; clasts up to 15 cm, massive									

Total profile thickness **c.860 cm**

Further general comments: Location of Profile 2 is a ravine between Thomas Gubler's Profile 1 and Profile 2
The gravels and sands in Profile 1 form the base of the **Albisboden-Schotter,** while the gravels and sands in Profile 2 form the summit.
There seem to be a few metres that remain undocumented and unsampled between the two profiles

☐	Low frequencies of molluscs or sterile
▤	Moderate frequencies of molluscs
🟩	Fairly abundant molluscs
▩	Abundant molluscs
▥	Rare, small unidentifiable fragments of small mammals
🟦	Small mammal remains include identifiable tooth frags

Table 7d : The Stratigraphy and Sampling of Albishorn-Bürglen 1 2016

Albishorn-Bürglen 1
Profile 20.4.2016 + 13/14.09.2016

Coordinates: 2683 439-40 / 1234 425
Top of profile: 872 m asl

Layer number	Thickness (cm)	Cumulative thickness (cm)	Colour	Lithology	Interpretation	Samples	Sample processing 2017
1	>40		yellow-olive	Fine to coarse sandy gravel to 10 cm, clast-supported; represents the base of the **Albiswald-Schotter**	glaciogenic		
2	8-10	0-10	beige grey	sandy-silt with some stones to 2 cm + some very thin bands of brownish organic silt; top 3 cm stained reddish (Fe)	warm period fluvial overbank sediments		
3	40	10-50	blackish-brown and darkish grey-brown	bands (up to 5 cm thick) and lenses of silty lignite, alternating with bands of sandy-silt + thin bands of tufaceous silt		Test DK 1a, 1b, 1c DK 2 MB 1 (13.10.2017)	DK 1 blackened plant remains incl. seeds, charcoal, some shell frags., small bone frags., 1 Characeae + small fish otoliths DK 2 blackened plant remains incl. seeds, charcoal, some shell frags., 1 frag. rodent incisor
4	10	50-60	grey	silty-sand with fine gravel + few stones to 4 cm			
5	30	60-90	brownish-grey, grey and blackish-brown	sandy-silt with bands of silty-lignite + thin bands of tufaceous silt; + 2 bands with fine gravel to 2 cm; less organic below 75 cm		DK 3	blackened plant remains incl. seeds, charcoal, few shell fragments
6	20	90-110	grey	diffusely laminated sandy-silt, with some fine gravel in places to 2 cm			
7	25-30	110-135/140	bluish-grey	interbanded sandy-silt and silty-sand, with some fine gravel to 2 cm			
8	>120		grey/brownish-grey	massive diamicton with clasts up to 40 cm, with much material from the underlying molasse; represents the summit of the **Bürglen-Till**	glaciogenic		

Total profile thickness **c.300 cm**

Table 8 : The Molluscan Faunas from Albishorn-Bürglen 2 and 1, ZH 2016-2019

Analysis : Nigel Thew 2017-2020

Site		**Albishorn-Bürglen 2 (ZH) 2017 Profile 1** (2683 380/1234 525; 852 m asl) = Graf 2019 Pr. 1	**Albishorn-Bürglen 2 (ZH) 2019 Profile 1** (2683 377/1234 526; 852 m asl) = Graf 2019 Profile 1					**Albishorn-Bürglen 2 (ZH) 2019 Profile 2** (2683 326/1234 573; 848-864 m asl)								**Albishorn-Bürglen 1 (ZH) 2016 - Profile 1** (2683 439-440/1234 425; 871-2 m asl) same location as Graf 2019 Profile 2						**Albishorn-Bürglen 1 (ZH) 2016 - Profile 2** (2683 415/1234 450; c.872-3 m asl)			**Boppelsen -Cholholz Ost (ZH) 2017** (2673 664 /1258 893; 693 m asl)
Context		***Albisboden-Schotter*** **(fluvial gravels)** **beneath *Bürglen Till* (lower glacial unit)**														**alluvial overbank deposits** **above *Bürglen Till* (lower glacial unit)**									**Layer 1.10**
		silty layer with stones	sandy layer	silty layer with stones	silty layer with stones	silty layer with stones	sandy layer	sandy layer	silty layer with stones	silty layer with stones	silty layer with stones	soft clast of silt	soft clast of silt	soft clast of silt											
Sample location / number		**Profile 1 ALB'17 P1** (=ALB'19 1-4 to 1-2)	**Profile 1E 1-6**	**Profile 1E 1-4**	**Profile 1E 1-3**	**Profile 1E 1-2**	**Profile 1E 1-1**	**Profile 2 2-7**	**Profile 2 2-6**	**Profile 2 2-5**	**Profile 2 2-4**	**Profile 2 Test 2-3**	**Profile 2 2-2**	**Profile 2 2-1**	**13 samples**	**Albishorn DK1alt** 0.50-0.10 (taken **1993**)	**Albishorn DK3** 0.90-0.60 m	**Albishorn DK2** 0.50-0.20 m	**Albishorn DK1a + 1b** 0.50-0.10 m	**Albishorn Test 1** 0.20-0.10 m	**Albishorn MB-PE2** 0.90-0.10 (taken **2017**)	**Bürglen 6** 0.50-0.30 m	**Bürglen 1** 0.50-0.30 m		**Bop-Chal Ost 2**
Sediment description		olive-grey silty-sand with bands of grey silt, sandy-silt and grey-brown fairly organic silt + some fine gravel + few stones to 2 cm	yellow-grey sand with some silt, some fine gravel + few stones to 5 cm	olive-grey silt with moderate fine sand, some medium-coarse + some fine gravel + few stones to 4 cm	grey silt with moderate fine sand, some medium-coarse + some fine gravel + few stones to 5 cm	olive-grey silt with moderate fine sand, some medium-coarse + some fine gravel + few stones to 2 cm	yellow-grey fine to coarse sand with some silt, some fine gravel + few stones to 4 cm	olive-grey sand with some silt + some fine gravel + few stones to 4 cm	dark olive-brown-grey silt with clay + moderate fine sand, some medium-coarse + some fine gravel + stones to 5 cm	darkish olive-grey silt with clay + moderate fine sand, some medium-coarse + some fine gravel + stones to 3.5 cm	darkish olive-grey silt with clay + some fine sand, little medium-coarse + some fine gravel + some stones to 3.5 cm	soft clast of olive-grey silt with some fine sand + little fine gravel to 1.2 cm	soft clast of olive-grey sandy-silt (mostly fine sand) + little fine gravel to 1.5 cm	soft clast of olive-grey silt with some fine sand, a little medium to coarse + little fine gravel to 1 cm		dark blackish-brown very organic sandy (f) silt with bands of light brownish-grey sandy-silt and tufaceous silt	brownish-grey sandy-silt and thin bands of tufaceous silt + dark blackish-brown very organic clay-silt with clay + some sand + fine gravel	dark blackish-brown very organic sandy (f) clay-silt with bands of greyish-brown sandy-silt and tufaceous silt + some m/c sand + little fine gravel	dark blackish-brown very organic sandy (f) clay-silt with bands of greyish-brown sandy-silt and tufaceous silt + some m/c sand + little fine gravel	dark blackish-brown very organic sandy (f) clay-silt with bands of greyish-brown sandy-silt and tufaceous silt + some m/c sand + little fine gravel	brownish-grey to dark blackish-brown organic sandy-silt to clay-silt with a little fine gravel	grey/brownish-grey silty fine sand with some clay + some fine gravel, reddened by iron staining in places, with dark brownish plant remains; decalcified			light grey-beige fairly silty-sand with some fine gravel + calc. nodules to c.0.3 cm
Residue available for sorting by NT		x	x	x	x	x	x	x	x	x	x	x	x	x			x	x	x	x	x	x	x		x
Smallest sieve size (mm)		0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3		0.5	0.5	0.5	0.5	0.3	0.3	0.5	0.5		0.5
Sample size (kg)		2.30	4.05	4.15	3.45	4.65	2.25	5.65	3.75	3.30	3.55	0.80	4.55	4.80	**54.30**	c.50.0	9.4	9.6	29.8	0.45	7.3	12.4	5.5		4.6
												7.05 (Note 6)													
Malacozone		**Alb2-2**	**Alb2-1**	**Alb2-2a**	**Alb2-2b**	**Alb2-2c**	**Alb2-3**	**Alb2-4**	**Alb2-5a**	**Alb2-5b**	**Alb2-5c**	**Alb2-6a**	**Alb2-6b**	**Alb2-7**		**Alb1-2**	**Alb1-1**	**Alb1-2a**	**Alb-2b**	**Alb-2**					
Ecological Groups	**Species**																								
1	🟦 *Aegopinella ressmanni*	7		11	26	10			123	92	69	141	273	69			1	1							
	🟥 *Archaegopis (Retinella?) acutus*								7	1		3	14												
	⬜ *Clausilia pumila*															1			1						
	▨ *Cochlodina fimbriata*																	1	1						
	Ena montana	1			8	3	1	1	29	18	9	4	10	47			1	1	1	1					
	🟩 *Isognomostoma isognomostomos*					1			4	1		2	11						2						
	▨ *Macrogastra attenuata*																1								
	🟩 *Macrogastra ventricosa*							1				2	9												
	🟧 *Monachoides vicinus*				2				3		1	2	9					9	1	1					
	🟨 *Perforatella bidentata*								8	1															
	🟥 *Retinella (Lyrodiscus) elephantium*								2	1			2												
	🟩 *Trochulus edentulus* (eastern form)											53	214						1						
	% group 1	9.4	0.0	9.9	11.5	7.6	4.0	13.3	23.9	12.3	11.7	31.1	30.0	26.7		14.3	50.0	23.5	23.3	50.0	0.0				
3	🟥 *Acicula parcelineata*											2													
	🟩 *Aegopinella pura*	2		1	2	3			13	3	2	2	23				1	1							
	Clausilia dubia		1	1	3				7			4	8												
	🟥 *Clausilia stranzendorfensis*				3	1			2		1	10	18												
	🟩 *Cochlodina laminata*				1							1													
	🟩 *Helicigona lapicida*					1																			
	🟧 *Macrogastra densestriata*				1					1			4												
	▨ *Macrogastra plicatula*																		1						
	🟥 *Macrogastra sessenheimensis*				4				8	1		1	3												
	Merdigera obscura								8	2	1		2												
	▨ *Monachoides incarnatus*																1	7							
	Orcula dolium								3			2	21				1		1						
	⬜ *Trochulus filicinus*	4	1	5	10	7			9	149	39	24	48	33											
	🟥 *Trochulus leucozonus*								3	4			3	52											
	🟨 *Urticicola umbrosus*	1							1	10	1	66	141	15											
	🟩 *Vitrinobrachium breve*	16	1	1	4	4	2		114	33	43	56	222	7											
	% group 3	27.1	27.3	7.2	8.9	8.6	8.0	0.0	22.8	22.0	12.9	25.2	27.3	24.7		0.0	50.0	15.7	6.7	0.0	0.0				
4	🟩 *Aegopinella nitens*				3	1			4	7	3	6	9	1							1				
	Clausilia bidentata								5			2	4	1											
	⬜ *Clausilia rugosa antiquitatis*											1													
	🟥 *Cochlostoma salomoni*	3		1	21	2		2	27	8		6	23	6											
	🟩 *Discus rotundatus*											1	2						2						
	Discus ruderatus	1			2				41	3	109	6	62												
	🟩 *Limax maximus/cinereoniger*								1																
	🟧 *Neostyriaca corynodes ornatula*		1									1				1									
	🟩 *Oxychilus cellarius*	1							2	1		1	2	1				1							
	🟥 *Poiretia dilatata dilatata*											1	9												
	Trochulus clandestinus/striolatus																	3							
	Trochulus villosus																		1	1					
	Vitrea subrimata												1						3						
	% group 4	5.9	9.1	0.9	8.3	1.6	0.0	13.3	10.9	2.1	16.6	3.8	6.2	2.1		14.3	0.0	7.8	20.0	25.0	50.0				
Indet	unidentified species (Note 7)																	1		1					
6	*Arianta arbustorum*	10	4	19	24	6	5	6	22	11	2	1	9	3				7	5						
	🟩 *Carychium tridentatum*				1						1	1													
	Cochlicopa lubrica	10		41	79	105		1	141	262	242	151	414	55				2							
	Columella edentula												1												
	🟩 *Fruticicola fruticum*	4							4	1	4	4	3	7				4	1						
	Punctum pygmaeum								2	1		3													
	Trochulus sericeus	14	1	13	56	7	1		25	91	35	32	82	84							1				
	Vitrea crystallina	2		2	8	2			10	6	1	14	23	10				1	4						
	% group 6	47.1	45.5	67.6	53.7	64.9	24.0	46.7	27.7	40.3	42.2	30.9	29.5	36.6		0.0	0.0	27.5	33.3	0.0	50.0				
7	*Cepaea hortensis*	4		2	10	4	15	3	26	19	14	7	31	17				7	2						
	Euconululus fulvus			2	6	3			15	25	2	2	2	1		1									
	Limax/Deroceras sp.	2	2	2	1	1	1	1	7	1	2	1	1	5											
	Nesovitrea hammonis	1		10	26	18			10	36	8	6	12	15											
	Vitrea contracta								1			1													
	% group 7	8.2	18.2	14.4	13.7	14.1	64.0	26.7	8.0	8.8	3.9	2.6	2.5	8.8		14.3	0.0	13.7	6.7	0.0	0.0				
8	*Abida secale*								5	1		4	2	2		1									
	Cochlicopa lubricella	1			3	4			6	6	7	12	15	3											
	% group 8	1.2	0.0	0.0	1.0	2.2	0.0	0.0	1.5	0.8	1.0	2.4	0.9	1.2		14.3	0.0	0.0	0.0	0.0	0.0				
9	*Pupilla muscorum*					1			15	85	12	9	44												
	Vallonia costata				1				8	18	1	8	9												
	Vallonia pulchella											1													
	% group 9	0.0	0.0	0.0	0.3	0.5	0.0	0.0	3.1	11.1	1.9	2.7	2.9	0.0		0.0	0.0	0.0	0.0	0.0	0.0				
11	*Carychium minimum*																		1						
	Succinea putris															1		2							
	Zonitoides nitidus				2							1	1					1	1						
	% group 11	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.1	0.0		14.3	0.0	5.9	6.7	0.0	0.0				
12	*Euconulus alderi*									2															
	Galba truncatula				1	1			3	5	4	2	2												
	Oxyloma elegans	1			5				13	16	55		2			1		2	1						
	Succinella oblonga									2	7	5	4			1									
	Vertigo geyeri											1													
	% group 12	1.2	0.0	0.0	1.9	0.5	0.0	0.0	2.2	2.7	9.8	1.2	0.4	0.0	**Totals**	28.6	0.0	3.9	3.3	0.0	0.0			**Totals**	
	Total Terrestrial Molluscs	**85**	**11**	**111**	**313**	**185**	**25**	**15**	**737**	**924**	**675**	**666**	**1804**	**434**	**5985**	**7**	**6**	**51**	**30**	**4**	**2**	**Sterile**	**Sterile**	**100**	**Sterile**
	Number of Terrestrial Species	**19**	**7**	**14**	**28**	**21**	**6**	**6**	**40**	**35**	**27**	**47**	**45**	**21**	**58**	**7**	**6**	**17**	**18**	**4**	**2**	**Sterile**	**Sterile**	**33**	**Sterile**
Slug plates (*Limax/Deroceras* sp.) as a proportion o total terrestrial molluscs (%)		**2.4**	**18.2**	**1.8**	**0.3**	**0.5**	**4.0**	**6.7**	**0.9**	**0.1**	**0.3**	**0.2**	**0.1**	**1.2**		**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**				
13	*Anisus leucostoma*				4				1									2							
	% group 13	0.0	0.0	0.0	40.0	0.0	0.0	0.0	11.1	0.0	0.0	0.0	0.0				0.0	2.0	0.0						
14	*Armiger crista*																		1						
	Gyraulus laevis																1	16	2						
	Pisidium casertanum								1	1	1	1	2												
	Planorbis planorbis																	16	1						
	Radix labiata								3	3	4	2	3					8							
	Stagnicola palustris/corvus								2																
	% group 14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	66.7	100.0	71.4	42.9	33.3				12.5	39.2	13.3						
15a	*Bithynia tentaculata* shells	2									1		3			1		12	3						
	Bithynia tentaculata opercula		3	1	1	2	1		2		1	1					7	3	16						
	Lymnaea stagnalis																	2	2						
	🟩 *Planorbarius corneus*											1	1					22	2						
	🟩 *Planorbis carinatus*	3		3	4	1						1	1					12	2						
	Radix balthica																	9	1						
	% group 15a	100.0	100.0	100.0	50.0	100.0	100.0	0.0	22.2	0.0	28.6	42.9	33.3				87.5	58.8	86.7						
15b	*Valvata piscinalis*				1			1																	
	% group 15b	0.0	0.0	0.0	10.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0	0.0				0.0	0.0	0.0						
15c	*Bythiospeum rhenanum* cf. *turneri*											1	4												
	Moitessieriid/Hydrobiid sp.												1												
	% group 15c	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	14.3	33.3				0.0	0.0	0.0						
	Total Aquatic Molluscs	**5**	**3**	**4**	**10**	**3**	**1**	**1**	**9**	**4**	**7**	**7**	**15**	**0**	**69**	**1**	**8**	**102**	**30**	**0**	**0**	**Sterile**	**Sterile**	**141**	**Sterile**
	Number of Aquatic Species	**2**	**1**	**2**	**4**	**2**	**1**	**2**	**5**	**2**	**3**	**6**	**7**	**0**	**10**	**1**	**2**	**9**	**8**	**0**	**0**	**Sterile**	**Sterile**	**10**	**Sterile**
	Aquatic Molluscs as a proportion of Total Molluscs (%)	**5.6**	**21.4**	**3.5**	**3.1**	**1.6**	**3.8**	**6.3**	**1.2**	**0.4**	**1.0**	**1.0**	**0.8**	**0.0**		**12.5**	**57.1**	**66.7**	**50.0**	**0.0**	**0.0**				
	Total Molluscs	**90**	**14**	**115**	**323**	**188**	**26**	**16**	**746**	**928**	**682**	**673**	**1819**	**434**	**6054**	**8**	**14**	**153**	**60**	**4**	**2**	**Sterile**	**Sterile**	**241**	**Sterile**
	Total Molluscs per kilo of sediment	**39**	**3**	**28**	**94**	**40**	**12**	**3**	**199**	**281**	**192**	**841**	**400**	**90**		**0.2**	**1**	**16**	**2**	**9**	**0.3**				
	Degree of surface dissolution of the shells **Evidence of alteration**	severe	(f. severe) /severe	severe	severe	severe	severe	severe	(f. severe) /severe	f. severe /severe	(f. severe) /severe	moderate /f. severe (severe)	(moderate) /f. severe /(severe)	(moderate) /f. severe /(severe)		some/ moderate	some/ moderate /f. severe	some/ moderate	some/ moderate	moderate	some/ moderate	complete	complete		complete
	Redeposited shells from upper part of the OSM (brown/pale brownish-grey; some recrystalisation)	xx	xxx	xxx	xxx	xxx	xxx	x	xxx	xx	xx	xx	xxx	x	Note 2	x	xxx	xx	xxx			x	x		x
	Redposited shells from lower part of the OSM (black, dark grey, occ. white; notable recrystalisation)	x	x	x	x	x	x	x	x		x	x	x			x	x	x	x						x
	Pomatias cf *elegans* opercula (Note 1)		1	2	1 + 1 shell frag	1	5																		
7	earthworm granules	(x)	(x)	x	x	x	(x)	(x)	xxx	xxx	xx	xx	xxx	xxx	Note 5	(x)	(x)	(x)	(x)	x	(x)				
	white/pale yellow balls (mollusc eggs?)			2	6	7				1															
	(iron encrusted) wood fragments															x	x	x	x	x	x	xx	xx		
	charcoal fragments	x	x	x	x	x	x	x	xx	x	x	x	xxx	x		xxx	xxxx	xxx	xxxx	xxxx	xxxx	xx	x		x
	seeds/plant remains												Note 3			xx	xx	xx	xx	x		xx	x		
	Cenococcum											x									x				
	insect fragments																				x				
	bird eggshell fragments																		1						
	bone fragments - larger mammals	x	x	x	x	x	x										x	x	x						
	bone fragments - small vertebrates		4		4	1	2	2	6			21 (Note 4)	2	7		1		1			1				
15	fish teeth and bones																2		4		x scales				
15	fish otolith																		5						
13-15	Trichoptera tubes																	2	1						
13-15	*Chara* oospore																		1						
13-15	ostracod valves			2		2									**4**										

For a description of the Ecological Groups see Figure 2

KEY

🟩	Species typical of interglacial warm periods
▨	Species typical of interglacial warm periods but absent from Irchel and Albishorn-Bürglen 2 older Early Pleistocene deposits
🟦	Interglacial Marker Species last present in Swiss molluscan faunas during the Eemian
🟨	Biostratigraphical Marker Species that disappears from Swiss molluscan faunas after the Middle Pleistocene
⬜	Biostratigraphical Marker Species that disappears from Swiss molluscan faunas before the end of the Middle Pleistocene, possibly after MIS 9
🟧	Biostratigraphical Marker Species that disappears from Swiss molluscan faunas after the end of the Early Pleistocene
🟥	Biostratigraphical Marker Species that disappears from Swiss molluscan faunas after the older Early Pleistocene

Note 1: These appear to be redeposited from the upper part of the OSM

Note 3: 1 mineralised frag of *Equisetum* sp.

Note 4: 1 frag from test sample, 20 frags from larger sample

Note 6: Larger sample processed and sorted but only scanned

Note 2: includes aquatic taxa such as *Bithynia* sp., *Lymnaea* sp., *Radix* spp., *Gyraulus* sp., *Planorbarius* sp., *Planorbis sp.* + some shells from terrestrial species such as Clausiliidae, *Discus* sp., *Monachoides* sp.

Note 5: the listing of the non-molluscan remains is based on NT's observations of material in the sieve residues when resorting the samples + Daniel Kälin's original sorting notes

Note 7: the small fragment from DK2 (0.8 mm across) comes from the underside of the 2nd or 3rd? whorl (from a shell with a diameter of at least 2 mm) of a flat, possible Zonitid species with a shiny shell and a moderately wide umbilicus. The umbilical fragmemt is rather shallow (0.25 mm deep), so the species must be of low height. The fragment has regularly spaced incised grooves similar to those seen on the upper side of *Nesovitrea* . The second small fragment from the TEST sample (1.3 mm across, from a shell with a diameter of at least 2.5 mm) is also from the underside of the 3rd? whorl; the umbilicus and whorl shape are similar to *Nesovitrea* , and the fragment also has regularly spaced incised grooves.

Table 9 : The Stratigraphy and Sampling of Hungerbol, Schienen, D 2017-2020

Hungerbol, Schienen (D)
2708.092 / 1282.505

Located at the western end of a landslip scar, north of the forest road

Documented and sampled by Daniel Kälin + Nigel Thew 06/08/2019;
additional documentation and sampling by DK - October-November 2020

TOP

Biostratigraphic unit		**Layer number 2019**	**Thickness (m)**	**Cumulative thickness 2019 from base of lower gravels (m)**	**Description**	**Sediment/ Interpretation**	**Eastern profile documented by DK in 2020; sampled 2019 by GC-B 1-4 m further E**				**Correlation with sequence documented in 20.10.2016 + 05.07.2017**		**Cumulative thickness 2017 from base of lower gravels (m)**	**2017-18 Palaeo-magnetic samples**	**2016 Pollen samples**	**2016 DK samples for small mammal remains and molluscs**	**2019 Samples**	**Sample processing 2020**	**Richness of molluscan material**	**Small mammal remains**
							Layer number	**Thickness 2020 profile**	**Thickness 2019 profile** 1.7 m to E	**Description**	**Layer number 2016-17**	**Thickness**								
topsoil		1	0.30	15.80 to 16.10	grey-black humic rich topsoil with moderate stones	topsoil	0	0.30	0.30	grey-black humic rich topsoil with moderate stones	-									
slope deposit		2	0.60-0.80	15.10 to 15.80	fine to coarse, matrix supported, very sandy gravel, with clasts to 40 cm; clasts with follow slope angle, sometimes steeply inclined **major erosion surface at base** that truncates underlying layers, especially to the right, where this layer becomes up to ~2 m thick	slope deposit	1	0.60	1.40	olive-grey, olive-brown at summit, silty-sandy fine-coarse gravel with clasts to 30 cm; dipping sharply by 30-45°; includes bedding with +/- sandy layers with +/- sized clasts, most beds are poorly sorted but also have thin well sorted beds (concentrated slope flow), matrix supported, majority of clasts follow slope angle, but some are imbricated; strongly weathered with roots at summit **major erosion surface at base** descends to 1-2 m above the molasse	-									
glaciogenic diamicton?		3	0.20-0.60	14.70 to 15.10	probable diamicton: olive-grey-brown mix of silt and sand, with some clay plus moderate to fairly frequent clasts **irregular erosion surface at base**	glaciogenic diamicton	hiatus	hiatus	hiatus	hiatus	-									
fluvioglacial gravel	**Bannholz-Schotter**	4	up to 5.50 10-12 m to the E of the cleaned profile	9.20 to 14.70	bedded grey fine-coarse sandy gravel, sometimes very coarse with boulders to 1.2 m, especially at base and near the summit; includes sand lenses and layers of fine gravel with inclined-bedding and internal erosion surfaces; mostly clast supported with a sandy matrix, but matrix supported with a sandy matrix + some silt in places; clasts with horizontal to vertical orientation, but with a clear tendency for horizontal or imbricated in places; **major erosion surface at base**, causing the earlier deposits at the eastern side of the exposure to be truncated	fluvioglacial	2	>0.80 much thicker to west	hiatus	light grey sandy gravel, with clasts to 30 cm at base; mostly clast supported; mostly fine gravel with inclined bedding (30°) in basal 0.40 m; clasts angular to rounded	1a note the full thickness of the upper gravels was only visible in the middle of the exposure	>1.60	9.55 to >11.15							
							3	1.60	1.60	grey sandy gravel, with boulders to 90 cm at base, otherwise to 20 cm; clast supported; clasts mostly well rounded; strong tendency for near horizontal orientation + imbrication in the upper 0.50 m; **major erosion surface at base**											
cold climate slope deposits		5	0.10	9.10 to 9.20	yellow-olive-grey horizontally-bedded silty-sand	slope deposit	hiatus	hiatus	hiatus	hiatus	1b	not specified	9.45 to 9.55				*not sampled*			
		6	1.90	7.20 to 9.10	crudely bedded grey-beige fine to coarse gravel, poorly sorted, mostly matrix supported, sometimes very coarse with boulders to 60 cm; includes sand lenses, some soft clasts of silty sand in basal 0.50 m; matrix varies from sand to silty-sand in places; clasts with horizontal to vertical orientation, but with a clear tendency for an inclined orientation, resembling imbrication = a classic indicator of solifluction/gelifluction; **major erosion surface at base**, causing the underlying sequence to become progressively truncated at the eastern side of the exposure	slope deposit signs of gelifluction	4	0.40	hiatus	grey-beige sandy gravel, mostly matrix supported, with clasts to 60 cm; inclined orientation resembling imbrication; **major erosion surface at base**	1c	3.40	sand lens at 8.15 sample 16-01 taken in a layer of beige silty fine to medium sand up to 0.2 thick, 0.87 above base of gravel 6.05 to 9.45				*not sampled*			
		7	0.10	7.10 to 7.20	olive-grey horizontally-bedded sand + some silt; with reddish bands	slope deposit	hiatus	hiatus	hiatus	hiatus				16-01			*not sampled*			
		8	0.90	6.20 to 7.10	darkish grey-brown fine to medium silty-sand with fairly abundant matrix supported fine gravel + some medium-coarse to 15 cm; poorly sorted, in places very compact and cemented, more sandy at base (~0.1 m); thin layer of light olive-grey interbanded sand / silty sand at 0.45-0.50 m from top of layer, + two bands of olive-grey sand with some fine gravel at 0.70-0.75 m and 0.80-0.85 m from layer summit; clasts oriented from horizontal to almost vertical **major erosion surface at base**	slope deposit	hiatus	hiatus	hiatus	hiatus							*not sampled*			
Hungerbol 1		9	0.50	5.70 to 6.20	olive-yellow fine sand (+ moderate medium and some coarse) with some silt + rare small stones to 0.7 cm; three cemented sand lenses: at 0.05 and 0.20 from summit that are 0.06-0.08 m thick, and at the base of the layer, which is up to 0.15 m thick and is stained black by Mn; includes soft clasts of reddish olive-grey sandy-silt with clay to 3 cm; moderate sandy-calcareous concretions to 6 cm; fairly frequent blackish Mn concretions to 4 cm, especially at base **irregular erosion surface at base**	near channel overbank and floodplain deposits	5a	0.04-0.12 (truncated)	hiatus	olive-beige (reddish in places) silty fine sand + a few small stones to 1 cm; **erosion surface at base** with stones to 4 cm	2	0.75	5.30 to 6.05	26-01, 26-02			HB 1	1: 6.25 kg sieved; no molluscs; some granules		
							5b	0.18	0-0.08 (truncated)	olive-beige (reddish in places) silty fine sand with some clay + a few small stones to 1 cm; **erosion surface at base** with stones to 3 cm										
							5c	0.01-0.02		band of whitish partially cemented sand	3	0.15	5.15 to 5.30							
		10	0.20	5.50 to 5.70	olive-grey interbanded fine sand and silty fine sand (+ moderate medium and some coarse) + rare stones to 0.5 cm; sandy bands are stained reddish by Fe (especially at 0.05-0.10 from summit) and have a lot of mica (especially at the base); some sandy-calcareous concretions to 0.8 cm; some calcareous nodules to 0.5 cm; some Fe-Mn concretions to 2.5 cm; black spots caused by Mn **irregular erosional contacts at base** and at 0.15 from summit		6	hiatus	0-0.20	up to 0.07 m of olive-grey fine to medium sandy gravel + a few coarse to 13 cm; followed by up to 0.14 m of olive-beige silty-sand with a few small stones to 1 cm **erosion surface at base**	4	0.75	4.40 to 5.15	25-01 508: 15-01 495: 15-02	4.80-4.90 (=5.20-5.30)		HB 2	2: 4.55 kg sieved; no molluscs; no granules; rare **small mammal** remains		▤
		11	0.60	4.90 to 5.50	grey and olive-grey banded silt with some sand (mostly fine, moderate medium, some coarse) + some fine gravel and some small stones to 2 cm; thin red iron stained sandier bands; 0.05 m from summit have nodular concretions; some sandy-calcareous concretions to 1.8 cm; some calcareous nodules to 1.1 cm; upper 0.20 m is banded and has less fine sand (11a)		7	0.70	0.45-0.60	olive-grey-beige silt with some clay + reddish bands of silty fine sand (> than Layer 8a) + rare stones to 1 cm; laminations (mm to cm); three grey-black bands at 0.53, 0.59 and 0.62 cm from base				483: 15-03, 15-04 469: 15-05, 15-06	**4.60-4.65 (=5.00-5.05)**	HB17 1o lower 0.30m	HB 3 (upper 0.25m)	3: 4.30 kg sieved; no molluscs; no granules		
							8a	1.10		olive-beige/grey sandy-silt with some clay + some reddish bands of silty fine sand; more clay-rich at 0.23-0.30 m from base; **mollusc shells**				456-478: 24-01		HB17 1u upper 0.30m	HB 4 (lower 0.30m)	4: 4.55 kg sieved; no molluscs; no granules; some larger **small mammal** tooth fragments		🟦
		12	0.15	4.75 to 4.90	olive-grey (mottled reddish by Fe staining) interbanded silty-sand (mostly fine, moderate medium, some coarse) and sandy-silt + some fine gravel + scattered pebbles up to 4 cm, especially at base; some thin sandy iron stained bands; clasts angular to sub-rounded; some sandy-calcareous concretions to 1.2 cm; the surface of the underlying gravels is iregular with signs of erosion by rilling		8b	0.15		olive-beige silty fine sand with some fine gravel, clasts to 2 cm				449: 15-07, 15-08			HB 5	5: 3.70 kg sieved; no molluscs; no granules		
		13	0.75-0.80	4.00 to 4.75	olive-brown/reddish-brown/black, fine to coarse bedded sandy gravel, clasts to 16 cm; imbricated in places, upper 0.30 m more silty and compact; heavily stained with Fe + Mn and cemented in places; sandy bands at 0.30 m and 0.50 m from summit; lower band approx. 0.05 m thick; a clear tendency for clasts >3 cm to be either horizontal or imbricated; this layer is of variable thickness (from 0.50 m up to 0.90 m) **major erosion surface at base**	fluvial channel deposits	9	>0.30		olive-brown to black fine to coarse gravel, strongly cemented, stained black by Mn at the top	5	0.60	3.80 to 4.40				*not sampled*			
Hungerbol 2	**Part 3.3**	14	0.40-0.50	3.55 to 4.00	olive-grey sandy-silt (mostly fs, some ms) + some small stones (angular to sub-rounded) to 1.3 cm; with sandier Fe stained bands; fairly frequent sandy-calcareous concretions to 2 cm	near channel overbank and floodplain deposits	not exposed; covered with overburden				6	0.25	3.55 to 3.80	375: 15-09 363.5: 15-11 363: 15-10			HB 6	6: 4.80 kg sieved; fairly abundant molluscs; very fragmented but fairly well preserved; moderate granules; rare **small mammal** remains	🟩	▤
	Part 3.2	15	0.05-0.15	3.45 to 3.55	light olive-brown sandy fine gravel + some medium to 3 cm; well sorted; **erosional contact at base**	channel deposit?					7	0.15	3.40 to 3.55				*not sampled*			
	Part 3.1	16	0.10	3.35 to 3.45	olive-grey sandy-silt (fs, little ms) with a band of marly clay-silt at base + some small stones to 1.2 cm; includes thin bands of compact clay-silt; moderate Fe concretions to 2.5 cm	near channel overbank and floodplain deposits					9 + 8	0.30	3.10 to 3.40	335: 15-12			HB 7	7: 4.05 kg sieved; fairly abundant molluscs; very fragmented and rather corroded; some granules	🟩	
		17	0.12	3.23 to 3.35	grey sandy-silt (fs, little ms) + some small stones to 1 cm; includes bands of compact clay-silt, plus Fe stained sandier bands; some Fe concretions to 1 cm **an erosion surface at base** is marked by a horizon of fine gravel + occasional lenses of fine gravel up to 0.04 m thick									325: 15-13, 15-14 310: 15-15	2.70-2.80 (=3.10-3.20)					
	Part 2	18	0.55	2.68 to 3.23	olive-grey/grey mottled reddish (by Fe staining, especially in upper part) silt with moderate sand (mostly fine, moderate medium, little coarse) + rare small stones to 0.6 cm; includes bands of clay-silt + some sandy bands; rare sandy-calcareous concretions to 0.7 cm, some Fe concretions to 0.8 cm						10 **molluscs** up to 1 cm across were seen in this layer	1.90	1.20 to 3.10	290: 15-16, 15-17 272: 15-18, 15-19 252: 15-20, 15-21			HB 8 (upper 0.25m)	8: 5.45 kg sieved; no molluscs; some granules; severeal larger **small mammal** tooth fragments		🟦
																	HB 9 (lower 0.30m)	9: 4.80 kg sieved; rare molluscs; some granules; several larger **small mammal** tooth fragments		🟦
		19	0.30	2.38 to 2.68	bluish-grey silt with moderate sand (mostly fs, some ms, little cs) + rare small stones to 1 cm; some sandy-calcareous concretions to 1.5 cm + rare calcaeous nodules to 0.5 cm; basal 0.05 m sandier and stained reddish by Fe; **molluscs seen**									233: 15-22, 15-23	**2.10-2.20 (= 2.30-2.50)**		HB 10	10: 5.40 kg sieved; moderate molluscs, rather fragmented and moderately coroded; some granules	▤	
		20	0.37	2.01 to 2.38	grey mottled reddish (Fe staining, especially in basal part) sandy-silt (mostly fs, moderate ms, little cs in basal part) + rare small stones to 0.9 cm in basal part; some small silty lenses in upper part; some sandy-Fe-calcareous concretions to 2 cm + sandy-calcareous concretions to 1.5 cm; **molluscs seen** in upper part									214: 15-24, 15-25 194: 15-26, 15-27		HB17 2o	HB 11 (upper 0.17m)	11: 5.30 kg sieved; moderate molluscs, rather fragmented and significantly coroded; moderate granules; rare **small mammal** remains	▤	▤
																	HB 12 (lower 0.20m)	12: 4.55 kg sieved; some molluscs, rather fragmented and coroded; some granules; rare **small mammal** remains		▤
	Part 1	21	0.10	1.91 to 2.01	grey silty fine sand (with moderate ms + a little cs) + very rare small stones to 0.5 cm; moderate sandy-calcareous concretions to 1.5 cm + rare calcaeous nodules to 0.5 cm; reddish mottling by iron staining										1.60-1.70 (= 1.80-1.90)		HB 13	13: 2.80 kg sieved; no molluscs, rare granules; rare **small mammal** remains		▤
		22	0.20	1.71 to 1.91	grey silty fine to medium (more fine) sand, with a little coarse and very rare small stones to 0.5 cm; some reddish mottling by iron staining + includes sandier bands stained by Fe; some small sandy-calcareous concretions to 1 cm; iron staining									174: 15-28, 15-29			HB 14	14: 4.60 kg sieved; no molluscs; rare granules		
		23	0.35	1.36 to 1.71	grey silty fine to medium sand with some coarse + a little fine gravel + rare stones to 2 cm in basal part; some whitish sandy-calcareous nodules at base; some small thin silty lenses; moderate small sandy-calcareous concretions up to 1 cm; **molluscs seen in 2016/17**									152: 15-30		HB17 2u	HB 15 (upper 0.20m)	15: 4.70 kg sieved; rare molluscs; some granules		
																	HB 16 (lower 0.15m)	16: 5.10 kg sieved; some molluscs, very fragmented and rather coroded, some granules		
		24	0.15	1.21 to 1.36	yellow-olive fine to coarse sand with some silt + some fine gravel to 1 cm + rare larger stones to 4 cm; fairly frequent very crumbly **whitish sandy-calcareous concretions** to 8 cm, linked with partial cementation in places	seasonal channel-flow deposit					11	0.10	1.10 to 1.20				HB 17	17: 4.90 kg sieved; fairly rare molluscs, very fragmented and coroded; some granules		
	Hungerbol-Schotter	25	0.02-0.04	1.18 to 1.21	olive-grey fine to medium sandy gravel to 3 cm, in a matrix of medium to coarse sand; sub-angular to sub-rounded clasts	fluvial channel deposits					-	-	1.10				*not sampled*			
		26	0.23	0.95 to 1.18	interbanded olive-grey fine to medium sand, orangey (Fe stained) medium to coarse sand and grey sand with some silt; two bands of fine gravel with clasts to 5 cm, at 0.13 m and 0.17 m from summit; band of cemented sand 0.05 m from summit						12	0.20	0.90 to 1.10	105: 24-02, 24-03 100: 15-31 95: 24-04, 24-05			*not sampled* (this layer should be sampled)			
		27	0.23	0.72 to 0.95	olive-grey/yellow brown (Fe staining) fine to coarse gravel to 12 cm, in a matrix of medium to coarse sand, matrix supported; angular to sub-rounded clasts; most clasts >5 cm are imbricated						13	0.90	0.00 to 0.90				*not sampled*			
		28	0.15	0.57 to 0.72	olive-grey fine to medium gravel + some coarse to 10 cm, in a matrix of fine to coarse sand, more matrix supported than Layer 27; angular to sub-rounded clasts; majority of clasts >5 cm are imbricated												*not sampled*			
		29	0.17	0.40 to 0.57	yellow-brown (Fe staining)/olive-grey fine to coarse sandy gravel to 11 cm, in a matrix of medium to coarse sand; clast supported; angular to sub-rounded clasts; most clasts >5 cm are imbricated												*not sampled*			
		30	0.40	0.00 to 0.40	olive-grey/black (stained by Mn) fine to coarse sandy gravel with clasts to 18 cm, plus soft clasts; in a matrix of medium to coarse sand; clast supported; angular to sub-rounded; clasts >5 cm are all imbricated; mostly fine gravel in top 0.05 m; includes small sand lenses near top and bottom												*not sampled*			
USM		31	0.35	0.00 to -0.35	light grey laminated mudstone with frequent white carbonate nodules; extremely compact; appears to be a facies of the **Upper Freshwater Molasse**	molasse					14	0.30	0.00 to -0.30		**-0.25 to -0.15** Note 1					
		32	>4.00	-0.35 to >-4.35	mica-rich sandstone, extremely compact: **Upper Freshwater Molasse**	molasse					15	>3.50	-0.30 to >-3.80							

BOTTOM

Note 1 Pollen of *Fagus* , *Hippophae* , *Picea* and *Pinus* are present;
in bold = analysed pollen sample

☐ Low frequencies of molluscs or sterile
▤ Moderate frequencies of molluscs
🟩 Fairly abundant molluscs
■ Abundant molluscs

▤ Rare, small unidentifiable fragments of small mammals
🟦 Small mammal remains present, including identifiable tooth fragments

Table 10 : The Molluscan Faunas from Hungerbol, Schienen, D 2017-2020

Analysis : Nigel Thew 2017-2020

Site		Hungerbol (D; 2708,100/1282,505; c.585 m asl) 2019																				Hungerbol (D) 2016					Iberig, AG 2018
Biostratigraphical unit		Hungerbol 2														Hungerbol 1						Hungerbol 2		Hungerbol 1			
Layer groupings		Part 1					Part 2					Part 3.1	Part 3.2	Part 3.3		Upper silts						Part 1	Part 2	Upper silts			
Layer (2019)		24	23		22	21	20		19	18		17+16	15	14	13	12	11b	11a	10	9	17 samples	2		1		4 large samples	
Sample location / number		17	16	15	14	13	12	11	10 + DK 2020	9	8	7	fluvial gravels not sampled	6	fluvial gravels not sampled	5	4	3	2	1		2u (=2019 Layers 23+22)	2o (= 2019 Layer 20)	1u (=2019 Layer 11b)	1o (=2019 Layer 11a)		
Sediment description		For sediment descriptions see Table 9																				up to 1.9 m of grey silty fine sand with a little fine gravel; significant iron staining in places		up to 1.8 m of yellow-olive-grey silty-sand with a little fine gravel; significant iron staining in places			lens of silty-sand within a thick gravel sequence
Residue available for sorting by NT		x	x	x	x	x	x	x	x	x	x	x	-	x	-	x	x	x	x	x		x		x	Note 5		x
Sample size (kg)		4.90	5.10	4.70	4.60	2.80	4.55	5.30	11.50	4.80	5.45	4.05	-	4.80	-	3.70	4.55	4.30	4.55	6.25	85.90 kg	43.0	20.9	23.5	16.9	104.3 kg	1.0
Malacozone		HB-1a	HB-1b	HB-1c	HB-1d		HB-2a	HB-2b	HB-3a	HB-3b		HB-4a	-	HB-4b	-	HB-5?						HB-1b/1c	HB-2a/b	HB-5			
Ecological Groups	Species																										
1	🟦 *Aegopinella ressmanni*		1					10	4			74		83								1					
	⬜ *Aegopis* cf. *klemmi*																					1					
	🟩 *Clausilia cruciata*							101	41	1		15		86								36	2				
	⬜ *Clausilia pumila*		1					106	227	6		66		165								46	4	47	1		
	🟩 *Cochlodina fimbriata*								7																		
	Ena montana	1	1					3	10			23		17								39	1	119	11		
	🟩 *Isognomostoma isognomostomos*													1								1					
	🟩 *Macrogastra attenuata*								2					4								51	1				
	🟧 *Monachoides vicinus*	1	1						2			3		9								4					
	⬜ *Perforatella bidentata*	1	1					3	78	2		88		154								84	3	112	1		
	🟩 *Trochulus edentulus*																					5					
	% group 1	7.9	6.0				0.0	31.6	28.3	26.5		24.5		40.0								*8.7*	*6.9*	*2.7*	*4.4*		
2	*Vertigo alpestris*								1																		
	% group 2	0.0	0.0				0.0	0.0	0.1	0.0		0.0		0.0													
3	🟩 *Aegopinella pura*								2			16		42								2					
	Clausilia dubia		2				2	3	43	2		24		17								277	6	126	4		
	🟩 *Cochlodina laminata*																					4					
	🟧 *Macrogastra densestriata*																					33					
	🟩 *Macrogastra plicatula*								5																		
	Merdigera obscura		3					1	4			15		1								6					
	🟩 *Platyla polita*											10		2													
	⬜ *Trochulus filicinus*	1	3				3	35	105	2		84		51								425	7				
	🟩 *Vitrinobrachium breve*							2	2			25		18								3					
	% group 3	2.6	9.5				17.9	5.8	12.3	11.8		15.9		10.1								*24.3*	*8.2*	*1.2*	*1.3*		
4	🟩 *Aegopinella nitens*							3	1			25		34								1					
	Clausilia bidentata		1					11	38			24		19								141	2	47	3		
	⬜ *Clausilia rugosa antiquitatis*							4	10			1										39		7			
	Clausilia rugosa parvula								2					3								4					
	🟩 *Discus rotundatus*																						1				
	Discus ruderatus																					17					
	🟩 *Limax maximus/cinereoniger*																						1				
	🟧 *Neostyriaca corynodes ornatula*		2					36	46	3		8		53								325	29	1505	56		
	🟩 *Oxychilus cellarius*											2		4								4					
	Trochulus clandestinus/striolatus		1									3		4													
	% group 4	0.0	4.8				0.0	7.7	7.4	8.8		5.7		9.0								*17.2*	*20.8*	*15.1*	*19.8*		
6	*Arianta arbustorum*	4	8				5	126	173	11		23		32								64	21	561	26		
	Cochlicopa lubrica		3					11	16			18		61								43	1	577	18		
	🟪 *Columella columella*																							10			
	Fruticicola fruticum		2				2	9	23			39		7								273	7				
	Punctum pygmaeum											3		4								2		1			
	Trochulus sericeus	1	24				13	135	119	4	1	185		161								443	26	3355	89		
	Vitrea crystallina		1					55	107	1		139		112								203	9	1177	25		
	Vitrina pellucida											1										1					
	% group 6	13.2	45.2				71.4	47.7	33.4	47.1		37.2		29.1								*33.3*	*40.3*	*55.1*	*53.0*		
7	*Cepaea hortensis*	28	20	1			3	19	19	1		9		20								51	19				
	Euconululus fulvus		1						3					18								7		51	2		
	Limax/Deroceras sp.	1	1						1			1										1		1			
	Nesovitrea hammonis		1					3	4			3		3								17	1	1			
	Trochulus hispidus											1		2								12		26	1		
	Vitrea contracta								5																		
	% group 7	76.3	27.4				10.7	3.1	2.4	2.9		1.3		3.3								*2.8*	*12.6*	*0.8*	*1.0*		
8	*Abida secale*		1					1	2			20		16								164	2	1			
	Cochlicopa lubricella							5	3			8		7								35	1	71	1		
	% group 8	0.0	1.2				0.0	0.9	0.4	0.0		2.6		1.8								*6.4*	*1.9*	*0.7*	*0.3*		
9	*Pupilla muscorum*		2					17	27			10		41								94	10	1057	21		
	Vallonia costata		2					1	7			7		12								87	1				
	Vallonia pulchella								1			12		2								6	1				
	Vertigo pygmaea													1								2					
	% group 9	0.0	4.8				0.0	2.6	2.7	0.0		2.6		4.3								*6.1*	*7.5*	*10.3*	*7.0*		
10	*Granaria frumentum*								1																		
	🟧 *Helicopsis striata*								1													1					
	Pupilla triplicata		1						1					1								26	1				
	% group 10	0.0	1.2				0.0	0.0	0.2	0.0		0.0		0.1								0.9	*0.6*	*0.0*	*0.0*		
11	*Carychium minimum*											5		2													
	Succinea putris								9			5		6								5					
	Zonitoides nitidus								3			2		7									1				
	% group 11	0.0	0.0				0.0	0.0	0.9	0.0		1.1		1.2								*0.2*	*0.6*	*0.0*	*0.0*		
12	*Euconulus alderi*													2													
	Galba truncatula								77			81		2													
	Oxyloma elegans							3	61	1		12		7								5	1				
	Succinella oblonga var. *elongata*							2	21			6		3								1		1452	39	Totals	
	% group 12	0.0	0.0				0.0	0.7	12.1	2.9		9.0		1.1								*0.2*	*0.6*	*14.1*	*13.1*		
Total Terrestrial Molluscs		38	84	1	sterile	sterile	28	705	1313	34	1	1096	-	1296	-	sterile	sterile	sterile	sterile	sterile		3092	159	10304	298	18449	sterile
Number of Terrestrial Species (and subspecies)		8	24	1	sterile	sterile	6	26	43	10	1	40	-	44	-	sterile	sterile	sterile	sterile	sterile		47	25	21	15	61	sterile
13	*Aplexa hypnorum*		1																								
	Pisidium obtusale								4																		
	% group 13	0.0	5.3	0.0					2.4			0.0		0.0								*0.0*	*0.0*	*0.0*			
14	*Pisidium casertanum*								97																		
	Planorbis planorbis								1																		
	Radix labiata		1						33			2		2								1					
	Stagnicola palustris/corvus								15																		
	% group 14	0.0	5.3	0.0					88.5			40.0		40.0								*0.4*	*0.0*	*0.0*			
15a	*Bithynia tentaculata* shells								3													2					
	Bithynia tentaculata opercula	39	4						1			3		2								201	74	2			
	Lymnaea stagnalis		1																			4	1				
	Pisidium nitidum								1																		
	🟩 *Planorbarius corneus*		1																			4	1				
	Planorbis carinatus								2					1								1					
	Radix balthica								3													4					
	🟩 *Segmentina nitida*								1																		
	% group 15a	92.9	31.6	0.0					6.7			60.0		60.0								*76.1*	*85.4*	*50.0*			
15b	*Pisidium amnicum*	3																				1					
	🟧 *Theodoxus danubialis*		2																			5					
	Unio crassus		9	2					4													61	13				
	Unio sp.																							2			
	% group 15b	7.1	57.9	100.0					2.4			0.0		0.0								*23.6*	*14.6*	*50.0*			
Total Aquatic Molluscs		42	19	2	sterile	sterile	0	0	165	0	0	5	-	5	-	sterile	sterile	sterile	sterile	sterile		284	89	4	0	615	sterile
Number of Aquatic Species		2	7	1	sterile	sterile	0	0	11	0	0	2	-	3	-	sterile	sterile	sterile	sterile	sterile		9	4	2	0	16	sterile
Aquatic Molluscs as a proportion of Total Molluscs (%)		52.5	18.4	66.7	-	-	0.0	0.0	11.2	0.0	0.0	0.5	-	0.4	-	-	-	-	-	-		8.4	35.9	0.04	0.0		-
Total Molluscs		80	103	3	sterile	sterile	28	705	1478	34	1	1101	-	1301	-	sterile	sterile	sterile	sterile	sterile		3376	248	10308	298	19064	sterile
Total Molluscs per kilo of sediment		16	20	1	sterile	sterile	6	133	129	7	0.2	272	-	271	-	sterile	sterile	sterile	sterile	sterile		79	12	439	18		sterile
Degree of surface dissolution of the shells		fairly severe /severe sand grain impressions	(moderate) /f. severe /severe some sand grain impressions	almost complete sand grain impressions	almost complete	almost complete	f. severe /severe few sand grain impressions	f. severe /severe few sand grain impressions (Note 3)	moderate /f. severe /severe	f. severe /severe	almost complete	(moderate) /f. severe /severe	-	moderate /f. severe /(severe)	-	complete	complete	complete	complete	almost complete		some/ moderate /f. severe some sand grain impressions	fairly severe /severe few sand grain impressions	some/ moderate /(f. severe)	moderate /f. severe		
Redeposited shells from upper part of OSM (Note 4) (brown/pale brown/pale greyish-white; some recrystalisation)		xxx	xxx	x				x	x			xx		xx								xxx	x	x	x		
Redposited shells from lower part of OSM (black, dark grey, occ. white; notable recrystalisation)		xxx	x		x							x		x								xx	x	x	x		
7	earthworm granules	x	x	x	(x)	(x)	x	xxx	xx	x	x	x		xxx						x		xx	xx	xxx	xxx		
	iron encrusted wood fragments						x	x		x	x											x	xx	xx	xx		
	iron encrusted plant remains						xx *Picea* needles	x *Picea* needles																			
	charcoal fragments				x	x	x	x	x	x	x			x			x	x				x	x	x	x		
	bone fragments - larger mammals		x	x	x		x	x	x		x											x	x	x			
	redeposited bone fragments - larger mammals		x	x																							
	bone fragments - small vertebrates		x	x	x	**x**	**x**	**x**		**xx**	**xx**			**x**			**xx**		**x**			**x**	**x**	**x**	**x**		
	redeposited bone fragments - small vertebrates	x	x	x																		x					
15	bone fragments - fish		x	x	x		x	x	x													x					
13-15	*Chara* oospores																					x					
13-15	ostracod valves											**3**															

For a description of the Ecological Groups see Figure 2

Note 1 **x** indicates presence of Arvicolid tooth frags contemporary with the sediment
Note 2 **2** denotes that there are articulated ostracod valves (articulated valves counted as 2)
Note 3 Includes internals casts of FeO_2

Note 4: Includes 30% fragments from terrestrial species such as *Arianta* sp., *Cepaea* sp., Clausiliid spp., *Discus* sp., *Ena* sp., *Isognomostoma* sp., *Monachoides* sp., *Trochulus* spp. + *Succinea* spp., as well as 70% fragments from aquatic taxa such as *Bithynia tentaculata* , *Lymnaea stagnalis* , *Radix ovata*, *Radix peregra* , *Gyraulus* sp., *Planorbarius* sp., *Planorbis* sp., *Segmentina nitida,* Unio *sp.* and an unidentified prosobranch gastropod.

Note 5: The residue from sample 1o is available but has not been sorted. The shell material is very abundant, probably giving a frequency similar to sample 1u. A quick inspection of the residue revealed no fragments from aquatic molluscs and no new terrestrial species.

KEY

🟩	Species typical of interglacial warm periods
🟪	Pioneer species typical of colder periods
🟦	Interglacial Marker Species last present in Swiss molluscan faunas during the Eemian
⬜	Biostratigraphical Marker Species that disappear from Swiss molluscan faunas before the end of the Middle Pleistocene, possibly after MIS 9
🟧	Biostratigraphical Marker Species that disappears from Swiss molluscan faunas after the end of the Early Pleistocene

Table 11 : The Molluscan Faunas from Ecoteaux, VD

Analysis : Nigel Thew 2018, 2023, 2024

Site (Note 1) (Note 2)		**Bassin d'Ecoteaux, VD**							
Sampling Location		**Location A** **0.6 km E of Ecoteaux, erosional cliff NW side of La Broye Valley** 2556 360/1155 050; 778 m asl		**Location B** **0.6 km SW of Ecoteaux, N bank of La Crosat stream** (c.1.5 m below surface, within a large landslip 1.5 x 0.55 km WSW of Ecoteaux) 2555 370/1154 680; 694 m asl				**Location C** **275 m NNW of Loc B, N of La Crottaz stream** 2555 274/1154 938; 702 m asl	
Sample (*first scanned by Burri)		***1** (Note 3)	**2**	***3**	**5**	***4**	**6**	**7**	
Sediment description		dark blue-grey/grey laminated silt with some sand + moderate organic debris	grey laminated marly-silt with some fine sand + thin bands of organic debris	dark grey laminated silt with some sand + moderate organic debris	dark grey laminated organic silt with some clay + some sand + few small stones to 0.5 cm + wood pieces	grey laminated fairly marly-silt with some sand + moderate organic debris	grey laminated marly-silt with some fine sand + thin bands of organic debris + Fe concretions	grey laminated interbanded silt, sandy-silt and silty-sand, + organic debris; some small sandy calc. concretions; few small stones to 0.3 mm	
Sample weight (kg)		0.7	2.3	2.2	0.7	0.1	2.1	1.7	
Smallest sieve size (mm)		0.5	0.3	0.5	0.3	0.5	0.3	0.3	
Residue available for sorting/resorting		x	x	x	x	x	x	x	
Dating evidence				^{14}C date on wood from near base of the lake sediments: >54,000 BP					
Malacozone		**Ecot A-1**	**Ecot A-2**	**Ecot B-1**	**Ecot B-2**	**Ecot B-3**	**Ecot B-4**		
Probable Age (pollen + AAR Dating + stratigraphy)		Cromerian MIS 15							
Ecological Groups	**Species**								
2	*Vertigo pusilla*						5		
	% group 2	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.2*		
3	🟩 *Acicula lineata*						1		
	🟦 *Acicula lineolata*						1		
	🟩 *Aegopinella pura*						1		
	Clausilia dubia						8		
	🟩 *Euomphalia strigella*	1					1		
	🟩 *Helicigona lapicida*						3		
	Merdigera obscura		6				1		
	Nesovitrea petronella						16		
	🟦 *Pagodulina pagodula*						1		
	% group 3	*1.0*	*0.6*	*0.0*	*0.0*	*0.0*	*1.6*		
4	🟩 *Discus rotundatus*						3		
	Discus ruderatus			2					
	🟩 *Oxychilus cellarius*		1				13		
	Trochulus cf. *clandestinus*						2		
	Vitrea subrimata		1				13		
	% group 4	*0.0*	*0.2*	*3.1*	*0.0*	*0.0*	*1.5*		
6	*Arianta arbustorum*		9				19		
	🟩 *Carychium tridentatum*						3		
	Cochlicopa lubrica				2		11		
	Columella edentula		3		1		3		
	🟩 *Fruticola fruticum*		1				8		
	Punctum pygmaeum		1						
	Trochulus sericeus	4	111	1			339		
	Vertigo substriata						1		
	% group 6	*4.0*	*13.2*	*1.6*	*16.7*	*0.0*	*18.5*		
7	*Cepaea hortensis*		22		2		31		
	Euconulus fulvus		9				25		
	Limax/Deroceras sp.		26				28		
	Nesovitrea hammonis		3				72		
	% group 7	*0.0*	*6.3*	*0.0*	*11.1*	*0.0*	*7.5*		
9	*Vallonia costata*						2		
	Vallonia declivis						11		
	Vallonia pulchella	2	2				64		
	% group 9	*2.0*	*0.2*	*0.0*	*0.0*	*0.0*	*3.7*		
11	*Carychium minimum*		71				148		
	Cochlicopa nitens						36		
	Succinea putris		141		1		421		
	Vertigo antivertigo		52				126		
	🟩 *Vertigo moulinsiana*						65		
	Zonitoides nitidus		68	1	1		247		
	% group 11	*0.0*	*35.1*	*1.6*	*11.1*	*0.0*	*50.4*		
12	*Euconulus alderi*		128				115		
	Galba truncatula	91	26	53	3	1	33		
	Oxyloma elegans	3	265	7	8	1	186		
	Succinella oblonga					1	8		
	Vertigo geyeri		1						**Totals**
	% group 12	*93.1*	*44.4*	*93.8*	*61.1*	*100.0*	*16.5*		
Total Terrestrial Molluscs		**101**	**947**	**64**	**18**	**3**	**2071**	**sterile**	**3204**
Number of Terrestrial Species		**5**	**21**	**5**	**7**	**3**	**38**	**sterile**	**41**
13	*Anisus leucostoma*		8				5		
	Aplexa hypnorum		75		4	1	138		
	Pisidium obtusale		1		3				
	% group 13	*0.0*	*4.1*	*0.0*	*0.3*	*1.8*	*4.1*		
14	*Armiger crista*				12				
	Gyraulus laevis		4	26	54	1	13		
	Pisidium casertanum	36	4	122	288	2	2		
	Planorbis planorbis		21		3		30		
	Radix labiata		17		21		29		
	Sphaerium corneum	209	176	182	187	15	329		
	Stagnicola palustris/corvus		411		7		457		
	% group 14	*93.2*	*31.0*	*48.1*	*27.0*	*32.1*	*24.7*		
15a	🟩 *Acroloxus lacustris*		57				301		
	Bathyomphalus contortus			3	1				
	Bithynia tentaculata shells	1	221	216	352	26	393		
	Bithynia tentaculata opercula	3	87	177	793	50	246		**1356**
	Hippeutis complanatus		135		7		211		
	Lymnaea stagnalis	1	11		33		9		
	Pisidium milium		146	1	5		237		
	Pisidium nitidum	1		6	31				
	Pisidium subtruncatum		112	17	93		49		
	🟩 *Planorbarius corneus*		101				173		
	Planorbis carinatus	5	93		26		274		
	Radix balthica	7	25	81	167	9	67		
	🟩 *Segmentina nitida*		124				482		
	Valvata cristata		297		3		275		
	% group 15a	*5.7*	*64.7*	*47.2*	*33.9*	*62.5*	*70.8*		
15b	🟩 *Anisus vorticulus*					1			
	⬜ *Pisidium clessini*				219				
	🟩 *Pisidium henslowanum*				73				
	Pisidium lilljeborgii				12				
	🟩 *Pisidium moitessierianum*				52				
	Valvata piscinalis (Note 4)	3	5	32	468	1	14		
	% group 15b	*1.1*	*0.2*	*4.7*	*38.8*	*3.6*	*0.4*		
Total Aquatic Molluscs (not including *B. tentaculata* opercula)		**263**	**2044**	**686**	**2121**	**56**	**3488**	**sterile**	**8658**
Number of Aquatic Species		**8**	**21**	**10**	**24**	**8**	**20**	**sterile**	**29**
***Bithynia tentaculata* shells / opercula**		**1.38**	**2.54**	**1.22**	**0.44**	**0.52**	**1.60**		
***Bithynia tentaculata* opercula / Total Aquatic Molluscs** (%)		**1.1**	**4.3**	**25.8**	**37.4**	**89.3**	**7.1**		
Aquatic Molluscs as a proportion of Total Molluscs (%)		**72.3**	**68.3**	**91.5**	**99.2**	**94.9**	**62.7**		
Total Molluscs		**364**	**2991**	**750**	**2139**	**59**	**5559**	**sterile**	**11862**
Total Molluscs per kilo of sediment		**520**	**1300**	**341**	**3056**	**590**	**2647**	**sterile**	
Degree of surface dissolution of the shells		moderate /f. severe	some/moderate /(f. severe)	moderate /f. severe	moderate/f. severe/ (severe) (Note 5)	moderate /f. severe	some/moderate /(f. severe)	complete	
7	earthworm granules		x (most very small)	x (most very small)	(x) (very small)		xx (most very small)		
tooth/bone fragments - small mammals					1		9		
bone fragments - larger mammals					4				
insect fragments			xxx Alnus, Betula, Picea, Carex, moss, unident		xx		xxx	x	
plant material		xx	xxxx *Alnus*, *Betula*, *Picea*, *Carex*, moss, unident	xx unident seeds	xxx ***Carex***, ***Potomogeton***, ***Ranunculus* T. *Batrachium***, *Zannichellia palustris*, *Abies*, *Picea*, *Rubus*, *Gypsophila*, moss, unident	xx	xxxx *Abies, Alnus*, *Betula*, *Picea*, *Sambucus*, *Taxus*, *Carex*, *Gypsophila*, moss, leaves, unident	xxxx *Abies*, *Picea*, *Taxus*, *Gypsolphila*, moss, unident	
wood fragments		x	xx	x	xxx Carex, Potomogeton, Picea, Rubus, moss, unident	xx	xxx	xxx	
charcoal					x		x		
yellow fragments of tree resin			x		x				
Cenococcum					x		(x)	xx	
15	fish teeth/bones/scale fragments				xxx Carex, Potomogeton, Picea, Rubus, moss, unident		x	(x)	
13-15	*Chara* oospores		1	16	132 (Note 6)	1	2		**151**
13-15	ostracod valves		48	6					**54**

For a description of the ecological groups see Figure 2

Note 2 the core at Ecoteaux was taken 1 km S of Ecoteaux at 2555 840/1154 130; 729 m asl
Note 3 includes Burri Sample 1 and the very small Sample 2 (4 *Pisidium casertanum*)
Note 4 a high spired form of *Valvata piscinalis*
Note 5 includes internal casts of FeO_2
Note 6 none of the *Chara* oospores have the calcareous casing preserved

KEY

🟩	Species typical of interglacial warm periods
🟦	Interglacial Marker Species last present in Swiss molluscan faunas during the Eemian
⬜	Biostratigraphical Marker Species that disappeared from Swiss molluscan faunas during the Middle Pleistocene, possibly after MIS 13

Note 1 All samples except Location C were taken by M. Weidmann in 08.1990; molluscs from 3 samples were scanned by F. Burri in late 1990 and mentioned in Pugin et al. 1993.
All material except Location C was borrowed from the Musée cantonal de Géologie, Lausanne
Loaction C was sampled by G. Deplazes in 17.10.2019

Table 12 : The Molluscan Faunas from Sous-Terre, GE

Sampled : A. Jayet 1967
Provisional analysis : A.Jayet 1967-8
Analysis : N. Thew 2019-2022

Site (Note 1)		**Sous-Terre, GE**								
Sample context		**Interglacial sandy-silts** from summit of the lignite to c.0.6 m below	**Blue-grey silts**			**8-10 m terrace of the Rhône**				**brown tufaceous sandy-silt**
Sediment description		**top** - 2 cm laminated sandy organic-silt (lignite) + abundant organic detritus + wood frags; - 10 cm diffusely laminated dark grey fairly organic silty-sand + organic detitus + wood frags; - diffusely banded alternating darkish grey silty-sand / bluish-grey sandy-silt + organic detritus + wood frags + little fine gravel + some larger stones to 5 cm	very compact laminated fairly dark greenish blue-grey silt (no clay, so loessic origin?) with a little fine sand + rare small stones to 0.5 cm + moderate organic detritus; some silvery to blackish pyritic concretons			**base of terrace**: grey marly silty fine-med sand with silty lenses + moderate fine-medium gravel (subrounded to subangular) to 3 cm	**upper part of terrace**: grey sandy (fine) marly-silt with some fine gravel (subrounded to subangular) to 1 cm			intrusive shells from the overlying brown tufaceous layer (Note 5)
Sample size (kg - dry weight)		c.19.0 (Note 4)	1.2			0.65	c.5.0 (Note 7)			
Residue available for resorting/sorting		x	x			x	x			
Malacozone		**ST-1**	**ST-2**			**ST-3a**	**ST-3b**			**ST-4**
Probable Age (molluscs, stratigraphy, AAR Dating)		MIS 11	MIS 10			earlier Preboreal	late Preboreal			Subatlantic
Ecological Groups	**Species**				**major hiatus**				**hiatus**	
1	⬜ *Aegopis klemmi*	743								
	🟦 *Aegopis verticillus*	25								
	🟩 *Clausilia cruciata*	184								
	⬜ *Clausilia pumila*	348								
	🟦 *Discus perspectivus*	401								
	Ena montana	265					2			
	🟩 *Macrogastra attenuata*	54								
	🟩 *Macrogastra ventricosa*	246					1			
	🟩 *Trochulus edentulus*									1
	% group 1	*34.4*	*0.0*			*0.0*	*0.7*			
3	🟩 *Acanthinula aculeata*									1
	🟩 *Aegopinella pura*	10								
	Cepaea sylvatica	23								
	Clausilia dubia	19								
	🟩 *Cochlodina laminata*	205					1			
	🟩 *Euomphalia strigella*	31					3			
	🟩 *Helicigona lapicida*	13								
	🟩 *Helicodonta obvoluta*	642								
	🟩 *Macrogastra plicatula*	42								
	Merdigera obscura	12					3			
	🟩 *Monachoides incarnatus*	375								
	🟩 *Platyla polita*	9								
	🟦 *Ruthenica filograna*	74								
	🟩 *Sphyradium doliolum*	138								
	⬜ *Zonitoides sepultus*	1								
	% group 3	*24.2*	*0.0*			*0.0*	*1.5*			
4	🟩 *Aegopinella nitens*	1015					2			
	Clausilia bidentata	47								
	Clausilia rugosa parvula	10					1			
	⬜ *Clausilia rugosa antiquitatis* (Note 2)	12								
	🟩 *Cochlostoma septemspirale* (Note 3)	1484								1
	🟩 *Discus rotundatus*	58					4			1
	Discus ruderatus	3				23	1			
	🟩 *Milax/Tandonia* sp.	9								
	🟩 *Oxychilus cellarius*	12								
	Trochulus montanus	2								
	Vitrea subrimata	15								
	% group 4	*40.5*	*0.0*			*43.4*	*1.8*			
6	*Arianta arbustorum*	42	2			4	1			
	🟩 *Carychium tridentatum*	16								
	Cochlicopa lubrica	15				1	4			
	Columella edentula	1								
	🟩 *Fruticicola fruticum*	201					6			
	Punctum pygmaeum	2								
	Trochulus sericeus	65				2	15			
	Vitrea crystallina	44								
	% group 6	*5.9*	*50.0*			*13.2*	*5.7*			
7	*Cepaea hortensis*	282				2	1			
	Euconululus fulvus	2								
	Limax/Deroceras sp.	11				2	5			
	Nesovitrea hammonis	4					1			
	% group 7	*4.5*	*0.0*			*7.5*	*1.5*			
8	*Cochlicopa lubricella*						1			
	% group 8	*0.0*	*0.0*			*0.0*	*0.2*			
9	🟩 *Candidula unifasciata*									1
	Pupilla muscorum var. *bigranata*	3				1				
	Vallonia costata	5	1							
	Vallonia pulchella					2	4			
	% group 9	*0.1*	*25.0*			*5.7*	*0.9*			
11	*Carychium minimum*	2								
	Succinea putris	16								
	Vertigo antivertigo						1			
	Zonitoides nitidus	5				10	6			
	% group 11	*0.3*	*0.0*			*18.9*	*1.5*			
12	*Euconulus alderi*					2				
	Galba truncatula	11					49			
	Oxyloma elegans	78	1			3	341			
	Succinella oblonga	21		**Totals**		1	3	**Totals**		
	% group 12	*1.7*	*25.0*			*11.3*	*86.2*			
Total Terrestrial Molluscs (excluding intrusive shells)		**6585**	**4**	**6589**		**53**	**456**	**509**		**5**
Number of Terrestrial Species (excluding intrusive shells)		**53**	**3**	**53**		**12**	**23**	**25**		**5**
13	*Anisus leucostoma*						(x)			
	Pisidium obtusale	1				12	x			
	% group 13	*0.6*				*3.9*				
14	*Armiger crista*						(x)			
	Gyraulus laevis					2	xx			
	Pisidium casertanum	49	1			11	xxx (Note 6)			
	Planorbis planorbis	5				4	xx			
	Radix labiata	82					(x)			
	Sphaerium corneum	3				11	(x)			
	Stagnicola palustris/corvus	2				2	xx			
	% group 14	*81.0*				*9.9*				
15a	*Bithynia tentaculata* shells	8				48	xxxx			
	Bithynia tentaculata opercula	1				64	xxxxx			
	Hippeutis complanatus					9	(x)			
	Lymnaea stagnalis	8				10	xxx			
	Pisidium milium					2	x			
	Pisidium nitidum	2				8	(x)			
	Pisidium subtruncatum	4				40	xx			
	🟩 *Planorbis carinatus*					46	xxx			
	Radix balthica	4				9	xx			
	Valvata cristata					8	xx			
	% group 15a	*15.5*				*80.3*				
15b	*Ancylus fluviatilis*	1				1				
	🟩 *Anodonta cygnea*	1								
	🟩 *Gyraulus albus*					1	x			
	Pisidium amnicum					2				
	Valvata piscinalis var. *piscinalis*	3				14	(x)			
	% group 15b	*2.9*				*5.9*				
Total Aquatic Molluscs		**174**	**1**	**175**		**304**	**>2500**			**0**
Number of Aquatic Species		**14**	**0**	**14**		**19**	**20**	**22**		**0**
Aquatic Molluscs as a proportion of Total Molluscs (%)		**2.6**	**20.0**			**85.2**	**aq >>> ter**			**0.0**
Total Molluscs		**6759**	**5**	**6764**		**357**	**c.3000**			**5**
Total molluscs per kilo of sediment		**396**	**4**			**546**				
Degree of surface dissolution of the shells		moderate /f. severe	moderate /f. severe			moderate /f. severe	moderate /(f.severe)			some
fragments of redeposited Tertiary molluscs		5								
7	earthworm granules	xxx	(x)			x	x			
larger mammal bone frags		x								
small mammal bone/teeth frags		xx				2	1			
bird egg-shel		1								
wood fragments		xxx	x							
needles		xx *Picea*, some *Taxus*, rare *Abies*	xxx *Picea*							
plant remains		xx 1 *Quercus* acorn, *Prunus*, *Rubus*, *Sambucus*, *Carex*, several unidentified species	x							
moss fragments		xx	xx							
charcoal fragments		x				x	xx			
13-15	fish bones					4				
13-15	*Chara*						4			
small (2 mm) fragments of pottery										1
small fragments (to 3 mm) of tile/brick										x

For a description of the ecological groups see Figure 2

Note 1 borrowed from the Muséum d'Histoire Naturelle, Genève
Note 2 width 2.2 mm, with closely spaced rather sharp ribs
Note 3 fine ribbed form for the interglacial deposits

Note 4 estimate arrived at by comparing the number of granules from the freshly sieved 4.72 kg (dry weight) with the granules from the previously sieved sediment

Note 5 intrusive shells from the overlying tufaceous layer that has frags of tile and brick. The shells are more transluscent and have brownish sediment adhering
Note 6 includes several individuals with still articulated valves

Note 7 Sieved by Jayet. Sample size estimated from the number of terrestrial molluscs

KEY

🟩	Species typical of interglacial warm periods
🟦	Interglacial Marker Species last present in Swiss molluscan faunas during the Eemian
⬜	Biostratigraphical Marker Species that disappear from Swiss molluscan faunas before the end of the Middle Pleistocene, possibly after MIS 11

Table 13 : The Molluscan Faunas from Montfleury, GE

Site (Note 1)		**Montfleury, GE** (2494.400/2119.265; 432.61 m asl)			
Level in 1946 Core Montfleury 1		**1** **72.50-72.0 m** **360.11-360.61 asl**	**2** **68.60-68.40 m** **364.01-364.21 m asl**	**3** **64.55-64.25 m** **368.06-368.36 m asl**	
Sediment description		grey sand with silt in places + some fine gravel + organic debris	grey diffusely laminated silt with some clay + a little fine gravel	lightish grey silt with moderate fine sand, a little coarse sand + rare small stones (<1 cm)	
Residue available for resorting		x	x	x	
Malacozone		**Mf-1**	**Mf-2**	**Mf-3**	
Probable Age (pollen, stratigraphy, AAR Dating)		MIS 11	MIS 11	MIS 10	
Ecological Groups	**Species**				
1	🟩 *Clausilia cruciata*	2			
	🟩 *Macrogastra attenuata*	4			
	🟩 *Macrogastra ventricosa*	3			
	⬜ *Perforatella bidentata*	20			
	% group 1	*5.2*	*0.0*	*0.0*	
3	🟩 *Cochlodina laminata*	6			
	🟩 *Euomphalia strigella*	73			
	🟩 *Macrogastra plicatula*	12			
	🟩 *Monachoides incarnatus*	27	1		
	% group 3	*21.1*	*0.1*	*0.0*	
4	*Clausilia rugosa parvula*			387	
	🟩 *Discus rotundatus*	1			
	% group 4	*0.2*	*0.0*	*13.9*	
6	*Arianta arbustorum*	16	10		
	Cochlicopa lubrica	2	6	309	
	🟪 *Columella columella*			🟪 12	
	🟩 *Fruticicola fruticum*	328			
	Trochulus sericeus	6	104	582	
	% group 6	*63.0*	*14.7*	*32.3*	
7	*Cepaea hortensis*		1		
	Euconululus fulvus			16	
	Limax/Deroceras sp.	1	9	81	
	Nesovitrea hammonis	2		52	
	Trochulus hispidus			128	
	% group 7	*0.5*	*1.2*	*9.9*	
8	*Cochlicopa lubricella*	1		4	
	% group 8	*0.2*	*0.0*	*0.1*	
9	*Pupilla muscorum*	2	13	572	
	Vallonia pulchella			162	
	% group 9	*0.4*	*1.6*	*26.3*	
11	*Cochlicopa nitens*			16	
	Succinea putris	5	26		
	% group 11	*0.9*	*3.2*	*0.6*	
12	*Euconulus alderi*			17	
	Galba truncatula		7	1	
	Oxyloma elegans	48	596	377	
	Succinella oblonga		42	77	**Totals**
	% group 12	*8.6*	*79.1*	*16.9*	
Total Terrestrial Molluscs		**559**	**815**	**2793**	**4167**
Number of Terrestrial Species		**19**	**11**	**16**	**29**
13	*Aplexa hypnorum*	7	3		
	Pisidium obtusale		52	1	
	% group 13	*1.0*	*18.2*	*12.5*	
14	*Armiger crista*		1		
	Gyraulus laevis	1	5		
	Pisidium casertanum		66		
	Planorbis planorbis	1			
	Sphaerium corneum	9			
	Stagnicola palustris/corvus		3		
	% group 14	*1.6*	*24.8*	*0.0*	
15a	*Bithynia tentaculata* shells		1		
	Lymnaea stagnalis	36	109	1	
	Pisidium subtruncatum	2	1		
	🟩 *Planorbis carinatus*	9	1		
	Radix balthica	116	49	5	
	% group 15a	*24.1*	*53.3*	*75.0*	
15b	*Pisidium amnicum*	416	2		
	🟩 *Pisidium tenuilineatum*	1			
	🟩 *Unio crassus*	6			
	Valvata piscinalis piscinalis	71	9	1	
	% group 15b	*73.2*	*3.6*	*12.5*	
Total Aquatic Molluscs		**675**	**302**	**8**	**985**
Number of Aquatic Species		**12**	**13**	**4**	**17**
Aquatic Molluscs as a proportion of Total Molluscs (%)		**54.7**	**27.0**	**0.3**	
Total Molluscs		**1234**	**1117**	**2801**	**5152**
Degree of surface dissolution of the shells		some/ moderate /f. severe	some/ moderate /f. severe	moderate /f. severe	
7	earthworm granules	xx	xxx	xxx	
insect remains			x		
bird eggshell fragments			3		
bone fragments - small vertebrates		x	x		
wood fragments		xx	x		
charcoal fragments				x	
plant remains		xx (1 *Quercus* acorn)	xx c *Carex*, r *Potomageton*, c *Ranunculus Batrachium*, *Picea* needles, c moss		
13-15	ostracod valves		8	2	

For a description of the ecological groups see Figure 2

KEY

🟩	Species typical of interglacial warm periods
🟪	Pioneer species typical of colder periods
⬜	Biostratigraphical Marker Species that disappear from Swiss molluscan faunas before the end of the Middle Pleistocene, possibly after MIS 11

Note 1 Montfleury Core 1, taken August 1946 by E. Joukowsky; detailed in Lanterno et al. 1981. All three levels were partially analysed by Favre, leaving numerous shells/fragments unidentified. All material has been reanalysed by N. Thew Shell material borrowed from the Muséum d'Histoire Naturelle, Genève

Table 14 : The Molluscan Faunas from Coupy, Bellegarde-sur-Valserine, Ain, FR

Sampled : A. Jayet Feb/March 1966
and L. Chaix 1970's
Analysis : N. Thew 2023

Site (Note 1)		**Coupy, Bellegarde-sur-Valserine, Ain, France**						
Location		**c.400 m ESE of Coupy, N side of the Bellegarde-Geneva road, c.390 m asl**			**terrace of the Rhône, edge of the Rhône, SE of Coupy, 315-320 m asl**			
Sample context		**Interglacial sands**	**modern contamination** (Note 2)		**Holocene silty-sands**		**modern contamination** (Note 2)	
Sediment description		yellowish-olive-grey somewhat silty fine-coarse sand + some fine gravel; partially cemented in places; subrounded to angular clasts; flint, Jura limestone, quartzite, few alpine rocks			olive-grey very sandy silt with some iron staining	olive-beige silty-sand ('sable supérieur')		
Sampled by		Jayet			Chaix			
Residue available for resorting/sorting		very little residue remaining			very little residue remaining			
Smallest sieve used		1 mm			0.5 mm			
Malacozone		**Coup-1**	**Coup-3a**		**Coup-2**		**Coup-3b**	
Probable Age (molluscs, stratigraphy)		MIS 11	modern		late Preboreal/early Boreal		modern	
Ecological Groups	**Species**							
1	*Ena montana*	2				2		
	🟩 *Isognomostoma isognomostomos*	4						
	🟩 *Macrogastra attenuata*	2			3	1		
	🟩 *Macrogastra ventricosa*	1			7			
	⬜ *Retinella (Lyrodiscus) elephantium*	5						
	🟩 *Trochulus edentulus*	1						
	% group 1	*6.8*	*0.0*		*4.4*	*2.7*		
3	🟩 *Aegopinella pura*	2						
	⬜ *Aegopis klemmi*	39						
	🟦 *Aegopis verticillus*	3						
	Cepaea sylvatica	5						
	Clausilia dubia				3	1		
	🟩 *Euomphalia strigella*	1						
	🟩 *Helicigona lapicida*	5						
	🟩 *Helicodonta obvoluta*	31						
	🟩 *Monachoides incarnatus*	15						
	% group 3	*45.7*	*0.0*		*1.3*	*0.9*		
4	🟩 *Aegopinella nitens*	10			2			
	Clausilia rugosa parvula				3			
	🟩 *Discus rotundatus*					1		
	Eucobresia diaphana				13	9		
	🟨 *Hygromia cinctella*		1					
	🟩 *Oxychilus cellarius*	1						
	Trochulus montanus	1						
	Trochulus villosus	2			46	17		
	% group 4	*6.3*	*6.3*		*28.3*	*23.9*		
6	*Arianta arbustorum*	42			23	11		
	Cochlicopa lubrica	1			41	8		
	🟩 *Fruticicola fruticum*	9			1			
	Trochulus sericeus	6			3	12		
	Vitrea crystallina				20	13		
	% group 6	*26.2*	*0.0*		*38.9*	*38.9*		
7	*Cepaea hortensis*	32	4		8	9		
	Limax/Deroceras sp.				12	2		
	% group 7	*14.5*	*25.0*		*8.8*	*9.7*		
8	*Abida secale*				3	2		
	Cochlicopa lubricella	1			5	5		
	🟩 *Pomatias elegans* shells		6					
	🟩 *Pomatias elegans* opercula		1					
	% group 8	*0.5*	*43.8*		*3.5*	*6.2*		
9	🟩 *Candidula unifasciata*		2					
	Pupilla muscorum		1		2	2		
	Vallonia costata				4	1		
	Vallonia pulchella				2			
	% group 9	*0.0*	*18.8*		*3.5*	*2.7*		
10	*Helicella itala*		1					
		0.0	*6.3*		*0.0*	*0.0*		
12	*Oxyloma elegans*				2			
	Succinella oblonga			**Totals**	23	17		**Totals**
	% group 12	*0.0*	*0.0*		*11.1*	*15.0*		
Total Terrestrial Molluscs		**221**	**16**	**237**	**226**	**113**	**0**	**339**
Number of Terrestrial Species		**24**	**6**	**29**	**21**	**17**	**0**	**23**
14	*Armiger crista*						1	
	Pisidium casertanum						1	
	Radix labiata						1	
	Stagnicola palustris/corvus				3			
	% group 14						*17.6*	
15a	*Lymnaea stagnalis*						7	
	Pisidium milium					1		
	Pisidium nitidum				1			
	Radix balthica						7	
	% group 15a						*41.2*	
Total Aquatic Molluscs		**0**	**0**	**0**	**4**	**1**	**17**	**22**
Number of Aquatic Species		**0**	**0**	**0**	**2**	**1**	**5**	**8**
Aquatic Molluscs as a proportion of Total Molluscs (%)		**0.0**	**0.0**		**1.7**	**0.9**	**0.0**	
Total Molluscs		**221**	**16**	**237**	**230**	**114**	**17**	**361**
Degree of surface dissolution of the shells		some/moderate/f.severe with sand grain impressions (Note 3)	none		moderate f. severe/severe	moderate f. severe/severe	none	
redeposited Tertiary marine bivalves (*Ostrea*), coral, ooids		xx			xx	xx		
7	earthworm granules	x (9)	?		x	x		
small mammal bone/teeth frags					1			
bird egg-shell		2						
charcoal fragments		x			x	x		
13-15	*Chara*						4	
13-15	ostracod valves				1			
polished and rounded sand grains		x			xx	xx		

For a description of the ecological groups see Figure 2

Note 1 borrowed from the Muséum d'Histoire Naturelle, Genève
Note 2 shown by the translucent condition of the shell fragments
Note 3 impressions of sand grains at the surface of the shells were caused by prolonged burial in a very sandy sediment

KEY

🟩	Species typical of interglacial warm periods
🟦	Interglacial Marker Species last present in Swiss molluscan faunas during the Eemian
⬜	Marker species that disappeared from Swiss molluscan faunas before the end of the Middle Pleistocene, possibly after MIS 11
🟨	Very recent (probably since c.1900) arrival in the area

Table 15 : The Molluscan Faunas from two boreholes in Geneva (SE of the Petit Lac)

Sampled: E. Joukowsky 1939-41
Analysis: J. Favre 1941
Reanalysis: Nigel Thew 1998
Petite Boissière referred to in Joukowsky 1941

Core location (Note 1)		**"Puits du Parc de La Grange,** Service des Eaux 1939, côte du terrain 404.26" est. 2502 180/1117 960	**"Sondage de la Petite Boissière,** Service des Eaux 1940, côte du terrain 411.30" est. 2502 020/1117 220	
Sample depth and altitude		depth 45.80-46.10 m altitude 358.16-46 m asl	depth 47.80-48.10 m altitude 363.20-50 m asl	
Sediment description		yellowish-grey silt of loessic origin with sand, some clay + bands with some fine gravel (<1.5 cm) [Note 2]	yellowish-grey silt of loessic origin with some sand + a little fine gravel (<1 cm)	
First analysed by		N. Thew	J. Favre	
Sample weight (kg)		0.5	15.0	
Residue available for sorting by NT		x		
Possible Age (stratigrapghy, molluscs)		early MIS 6? (or possibly MIS 8?)	mid MIS 6	
Ecological Groups	**Species**			
3	*Clausilia dubia*	1		
	% group 3	*4.0*	*0.0*	
4	*Clausilia rugosa parvula* (Note 3)	3	3	
	% group 4	*12.0*	*3.3*	
6	*Arianta arbustorum*		4	
	Columella columella	1	24	
	Trochulus sericeus	2	2	
	% group 6	*12.0*	*32.6*	
7	*Limax/Deroceras* sp.		17	
	% group 7	*0.0*	*18.5*	
8	*Abida secale*	1		
	% group 8	*4.0*	*0.0*	
9	*Pupilla muscorum*	7	5	
	Vallonia costata	1		
	% group 9	*32.0*	*5.4*	
12	*Oxyloma elegans*	2		
	Pupilla alpicola	1		
	Succinella oblonga	5	37	
	Vertigo genesii	1		**Totals**
	% group 12	*36.0*	*40.2*	
Total Terrestrial Molluscs		**25**	**92**	**117**
Number of Terrestrial Species		**11**	**7**	**13**
15a	*Bithynia tentaculata* shells	1		
	Radix balthica	1		
Total Aquatic Molluscs		**2**	**0**	**2**
Number of Aquatic Species		**2**	**0**	**2**
Aquatic Molluscs as a proportion of Total Molluscs (%)		**7.4**	**0.0**	
Total Molluscs		**27**	**92**	**119**
Total Molluscs per 1kg		**54**	**6**	
7	earthworm granules	x (5)	xxx (289)	
	charcoal	x		

For a description of the Ecological Groups see Figure 2

Note 1: shells material borrowed from the Muséum d'Histoire Naturelle, Genève
Note 2: this deposit consists of two layers: a sterile loessic silt, over a silt with some sand, clay and fine gravel + some shells
Note 3: the large form typical of colder period sediments

KEY

🟪	Pioneer species typical of colder periods
🟧	Pioneer species typical of both colder periods + the start of warmer periods

Borehole Stratigraphies (E. Joukowsky)

Parc de La Grange (404.26 m asl; Joukowsky manuscript)
1 Terre végétale 0.20
2 Sables fluents 4.90
3 Glaise (limon-argileux) jaune stratifié 1.10
4 Moraine würmienne 14.15
5 "Alluvion ancienne" - graviers et poudingues cimentés 25.45
6 Limon ocre à coquilles 0.20-0.30 coquilles à 45.90 de profondeur
7 Moraine "rissienne" - 358.16 m asl

La Petite Boissière (411.30 m asl; Joukowsky 1942)
1 Terre végétale 0.20
2 Sables et limons 0.70
3 Limon-argileux (glaise) massif 0.70
4 Moraine würmienne riche en blocs et cailloux striés 13.70
5 "Alluvion ancienne" couche supèrieure - graviers sableux très poreux 31.10
6a Limon ocre stérile 0.30
6b Gravier sableux 1.10
6c Limon ocracé à coquilles 0.30
7 "Alluvion ancienne" couche infèrieure - graviers sableux très poreux 20.10
8 Moraine "rissienne" - 343.20 m asl

Table 16 : The Molluscan Faunas from Petit Saconnex, GE

Sampled: Claude Ruchat 1994
Analysis: Nigel Thew 1999-2000
Published samples analysed: Adrien Jayet 1961
Published: Jayet et al. 1961

Site		**Petit Saconnex, GE**					
Date / Location		**1994** 2498 930/1119 760; 433 m asl			**1961** (Note 1) 2499 250/11220 050; 433 m asl		
Sample description		yellow-brown silt with clay, some sand (moderate iron staining) + little fine gravel (<1.5 cm)	light yellow-brown sandy-silt with some clay + little fine gravel (<1.8 cm)	dark olive-grey clay-silt with some sand (fairly intense iron staining) + some fine gravel (<1.6 cm)	olive-grey sandy clay-silt with some sand + occasional stones	grey-brown sandy clay-silt with some sand	
Layer		**5**			**5b**	**5a**	
Sample		**Sample 1**	**Sample 2**	**Sample 3**	Jayet et al 1962 Sample 6	Jayet et al 1962 Sample 5	
Sample size (kg)		1.0	0.8	1.0	?	?	
Residue available for sorting by NT		x	x	x			
Malacozone		**PS-1**	**PS-2a**	**PS-2b**	**PS-1**	**PS-2**	
Probable age (stratigrapghy, molluscs)		early MIS 6? (or possibly MIS 8?)					
Ecological Groups	**Species**						
3	*Clausilia dubia*	2					
	% group 3	*0.5*	*0.0*	*0.0*		*0.0*	
4	*Clausilia rugosa parvula* (Note 5)	45	61	96	x	75	
	Trochulus montanus (Note 6)	109	29	97	x? (Note 3)	x? (Note 3)	
	Trochulus villosus	17	8	4	x? (Note 3)		
	% group 4	*45.0*	*41.4*	*41.0*		*c.18.6*	
6	*Arianta arbustorum*	86	18	97	x	20 (Note 4)	
	Cochlicopa lubrica	6			6		
	Columella columella	2	2	3		91	
	Punctum pygmaeum	2				3	
	Trochulus sericeus	41	45	48	x? (Note 3)	x? (Note 3)	
	Vitrea crystallina	9	9	7			
	% group 6	*38.4*	*31.2*	*32.2*		*>28.3*	
7	*Limax/Deroceras* sp.	1	6	3		2	
	Trochulus hispidus	3	1	8	x? (Note 3)	x? (Note 3)	
	% group 7	*1.1*	*3.0*	*2.3*		*>0.5*	
8	*Abida secale*	5	1	2			
	% group 8	*1.3*	*0.4*	*0.4*		*0.0*	
9	*Pupilla muscorum*	15	9	49	x (Note 2)	22 (Note 2)	
	Vallonia costata	6	13	5		2	
	Vertigo pygmaea	1					
	% group 9	*5.8*	*9.3*	*11.2*		*c.6.0*	
10	*Pupilla sterri*	3	1	8	x? (Note 2)	x? (Note 2)	
	% group 10	*0.8*	*0.4*	*1.7*		*c.1.0?*	
12	*Galba truncatula*		1			2	
	Succinella oblonga	27	33	54	x	186	
	Vertigo genesii				1		**Totals**
	% group 12	*7.1*	*14.3*	*11.2*		*c.46.7*	
Total Terrestrial Molluscs		**380**	**237**	**481**	**>11**	**>403**	**>1512**
Total Molluscs per kg of sediment		**380**	**296**	**481**	**9?**	**12?**	
Number of Terrestrial Species		**18**	**15**	**14**	**9?**	**12?**	**20**
7	earthworm granules	xxxx 51 > 1 mm many hundreds > 0.5 mm	x 20 from all fractions > 0.5 mm	xxx 14 > 1 mm few hundred > 0.5 mm	xx	xxxx hundreds	
	insect fragments			x		x	
	charcoal fragments	x					
	plant debris					xx (Note 7)	
	wood fragments	x		xx		x	
	Cenococcum	x					

For a description of the Ecological Groups see Figure 2

Note 1: the 1961 shell material was lodged with the Muséum d'Histoire Naturelle, Genève, but could not be found and may have been lost

Note 2 possibly wrongly identified as *Pupilla alpicola;* these are more likely to be a mix of *P. muscorum* and *P. sterri*

Note 3 almost certainly missed and included with unidentified shell debris

Note 4 Jayet noted that these are very fragmented

Note 5 includes the larger form more typical of loessic/cold period sediments

Note 6 the variety represented here has pronounced spiral striations and fairly prominent growth lines

Note 7 leaf fragments + needles of *Pinus*, *Picea* + *Juniperus*

KEY

🟪	Pioneer species typical of colder periods
🟧	Pioneer species typical of both colder periods + the start of warmer periods

Table 17 : The Molluscan Faunas from the World Health Organisation (OMS), GE

Sampled: Louis Chaix 1979
Preanalysis: Louis Chaix 1979/80
Analysis: Nigel Thew 2021

Site (Note 1)		**World Health Organisation (OMS), Rte des Morillons, GE** Core taken 1979; 2499 230 /1120 850; c.448.10 m asl						
Sample description		grey sandy-silt with some small stones						
Sample depth (m)		9.30-8.80	8.80-8.30	8.30-7.80	7.80-7.30	7.30-6.80	6.80-6.30	
Malacozone		**WHO-1a**	**WHO-1b**	**WHO-2**	**WHO-3a**	**WHO-3b**	**WHO-4**	
Probable age (stratigraphic correlation, pollen, molluscs; note 4)		early MIS 6? (or possibly MIS 8?)						
Ecological Groups	**Species**							
3	*Clausilia dubia*		2					
	Orcula dolium	2	1					
	% group 3	*1.9*	*4.8*	*0.0*	*0.0*	*0.0*	*0.0*	
4	*Clausilia rugosa parvula* (Note 2)	5	6	5	53	26	11	
	Trochulus montanus (Note 3)	5	1	2	27	1	2	
	Trochulus villosus	11	8	3				
	% group 4	*19.6*	*24.2*	*7.3*	*12.3*	*3.4*	*4.9*	
6	*Arianta arbustorum*	44	21	45	257	486	139	
	Cochlicopa lubrica	1	1					
	Punctum pygmaeum	1						
	Trochulus sericeus	23	15	44	195	194	73	
	Vitrea crystallina	1		1	2	1		
	% group 6	*65.4*	*59.7*	*65.7*	*69.6*	*86.0*	*80.3*	
7	*Cepaea hortensis*	2	1	1				
	Euconulus fulvus						1	
	Limax/Deroceras sp.	2	2	2	42	36	7	
	Trochulus hispidus				2			
	% group 7	*3.7*	*4.8*	*2.2*	*6.7*	*4.5*	*3.0*	
8	*Abida secale*	2						
	% group 8	*1.9*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	
9	*Pupilla muscorum*	2	1	20	31	13	3	
	Vallonia costata			1	9	2		
	% group 9	*1.9*	*1.6*	*15.3*	*6.1*	*1.9*	*1.1*	
12	*Galba truncatula*	1						
	Succinella oblonga	5	3	13	34	33	28	**Totals**
	% group 12	*5.6*	*4.8*	*9.5*	*5.2*	*4.2*	*10.6*	
Total Terrestrial Molluscs		**107**	**62**	**137**	**652**	**792**	**264**	**2014**
Number of Terrestrial Species		**15**	**12**	**11**	**10**	**9**	**8**	**19**
grey shell fragments redeposited from the molasse			1					
7	earthworm granules	x	xx	x	xx	xx	x	
bone frags - small mammals		1						
wood fragments		x	x	x	xx	xx	xx	

For a description of the Ecological Groups see Figure 2

Note 1: shell material borrowed from the Muséum d'Histoire Naturelle, Genève
Note 2: the larger form typical of loessic/cold period sediments
Note 3: the variety represented here has a pronounced spiral striation and fairly prominent growth lines
Note 4: the pollen was studied by C. Reynaud (1982)

Table 18 : The Molluscan Faunas from Nuolen/Buechberg, SZ

Site (Note 1)		**Kiesgrube, Nuolen/Buechberg, Wangen, SZ**				
Location		**western gravel quarry** est.2710 100/1228 620; c.487 m asl.			**eastern gravel quarry** est.2710 340/1228 440; c.478 m asl.	
Level of warm period sediments		**middle level** (the upper and lower organic/marly levels were not sampled)				
Sample		**1**	**2**	**3**	**4** **'*Chara*-mergel'**	
Sediment description		fairly dark grey laminated silts with some sand + small stones (<1 cm); moderate organic remains; some organic bands + bands of sand with fine gravel	fairly dark grey laminated silts with some sand + small stones (<1 cm); some organic remains; moderate iron staining; rare sandy bands with a little fine gravel	rather dark greenish-grey laminated silts with some sand + small stones (<1 cm); moderate organic remains; thin organic bands; iron staining	dark grey laminated silts with some sand + fairly abundant organic remains	
Sample size (kg - dry weight)			0.4	0.1		
Residue available for sorting by NT			x	x		
Malacozone (Note 2)		**Nu-0**	**Nu-1**		**Nu-2**	
Probable age (pollen data Welten 1988, molluscs, AAR Dating)		later Middle Pleistocene - MIS 7				
Ecological Groups	**Species**					
1	*Aegopinella ressmanni* 🟦		34	1		
	Clausilia cruciata 🟩		3			
	Cochlodina fimbriata 🟩		4	1		
	Ena montana		59	8		
	Urticicola umbrosus 🟨		19		1	
	% group 1		*11.0*	*8.8*	*14.3*	
3	*Aegopinella pura* 🟩		9			
	Clausilia dubia		13	1		
	Cochlodina laminata 🟩		95	4		
	Monachoides incarnatus 🟩		99	11		
	Platyla polita 🟩		2			
	Semilimax semilimax 🟩		50	2		
	% group 3		*24.8*	*15.9*	*0.0*	
4	*Aegopinella nitens* 🟩		31	3		
	Discus rotundatus 🟩		118	16		
	Milax/Tandonia sp. 🟩		7			
	Neostyriaca corynodes		2			
	Oxychilus cellarius 🟩		5			
	Trochulus clandestinus/striolatus		4			
	% group 4		*15.4*	*16.8*	*0.0*	
6	*Arianta arbustorum*		228	32		
	Carychium tridentatum		5		1	
	Cochlicopa lubrica		22	1		
	Fruticicola fruticum		9	4		
	Trochulus sericeus		43	7		
	Vitrea crystallina		51	11		
	% group 6		*33.1*	*48.7*	*14.3*	
7	*Cepaea hortensis*		126	6		
	Limax/Deroceras sp.		7	2	2	
	Nesovitrea hammonis		2			
	% group 7		*12.5*	*7.1*	*28.6*	
8	*Cochlicopa lubricella*		2			
	% group 8		*0.2*	*0.0*	*0.0*	
9	*Vallonia costata*		2			
	% group 9		*0.2*	*0.0*	*0.0*	
11	*Carychium minimum*		4		1	
	Succinea putris		3			
	Zonitoides nitidus		6	2	1	
	% group 11		*1.2*	*1.8*	*28.6*	
12	*Euconulus alderi*		1			
	Galba truncatula		9			
	Oxyloma elegans		4	1	1	
	Succinella oblonga		4			**Totals**
	% group 12		*1.7*	*0.9*	*14.3*	
Total Terrestrial Molluscs		**0**	**1082**	**113**	**7**	**1202**
Number of Terrestrial Species		**0**	**35**	**18**	**6**	**35**
14	*Pisidium casertanum*		16			
	Sphaerium corneum				1	
	% group 14		*66.7*		*0.3*	
15a	*Bithynia tentaculata* shells				22	
	Bithynia tentaculata opercula		1		342	
	Lymnaea stagnalis				23	
	Planorbis carinatus 🟩				4	
	Radix balthica		3		1	
	% group 15a		*16.7*		*98.7*	
15b	*Valvata piscinalis*		4		4	
	% group 15b		*16.7*		*1.0*	
Total Aquatic Molluscs		**0**	**24**	**0**	**397**	**421**
Number of Aquatic Species		**0**	**4**	**0**	**6**	**7**
Aquatic Molluscs as a proportion of Total Molluscs (%)			**2.2**	**0.0**	**98.3**	
Total Molluscs		**0**	**1106**	**113**	**404**	**1623**
Degree of surface dissolution of the shells			some/ moderate /f. severe	some/ moderate /f. severe	some/ moderate /f. severe	
7	earthworm granules	x	xx	xx	x	
	bone fragments - larger mammals			x		
	bone fragments - small vertebrates				x	
	insect fragments				x	
	wood fragments	xx	xxx	xxx (*Carex* etc)	xx	
	charcoal fragments	x	x	x	x	
	plant remains	x (*Abies* needles)	xxx (*Carex sp,* *Rubus sp.,* *Sambucus* etc)	xxx (*Carex* etc)	xxxx (*Carex* etc)	
	Cenococcum	x	xxxx	xx	x	
13-15	*Chara* oospores				xxxx	
13-15	ostracod valves				x	

For a description of the ecological groups see Figure 2

Note 1 Sampled by Thomas Bolliger in April and July 1989
Shell material borrowed from the PIMUZ

Note 2 Sample 1 seems to come from **below** the **Middle lignite**, while Samples 2, 3 and 4 come from **above** the **Middle Lignite**. It's not clear whether Samples 2 and 3 are slightly earlier, contemporary or slightly later than Sample 4

KEY

🟩	Species typical of interglacial warm periods
🟦	Interglacial Marker Species last present in Swiss molluscan faunas during the Eemian
🟨	Biostratigraphical Marker Species that disappears from Swiss molluscan faunas after the Middle Pleistocene

Table 19 : The Molluscan Faunas from Grandson, VD

Sampled : between 1942 and 1944
Analysis : Nigel Thew 2018

Site		Lignite mine, Grandson, VD		
Layer / stratigraphic position		**5-10 cm just beneath the lowest lignite layer c.475.50 m asl** (Note 1)	**between the lowest and middle lignite layers c.477 m asl** (Note 2)	
Sediment description		brownish-grey laminated very organic marly-silt	grey laminated fairly organic sandy marly-silt with thin organic bands	
First analysed by		J. Favre	Thew	
Residue available for sorting by NT			x	
Malacozone		**Gr-1a**	**Gr-1b**	
Probable age (pollen Welten 1988, stratigraphy, AAR Dating)		later Middle Pleistocene MIS 7e	later Middle Pleistocene MIS 7e	
Ecological Groups	**Species**			
1	🟩 *Clausilia cruciata*		1	
	Ena montana		1	
	🟩 *Macrogastra attenuata*		1	
	🟩 *Macrogastra ventricosa*		3	
	% group 1	*0.0*	*1.6*	
3	🟩 *Euomphalia strigella*		2	
	Merdigera obscura		1	
	🟩 *Monachoides incarnatus*		7	
	% group 3	*0.0*	*2.6*	
4	🟩 *Aegopinella nitens*		1	
	Trochulus montanus		3	
	% group 4	*0.0*	*1.1*	
6	*Arianta arbustorum*		22	
	Fruticicola fruticum		3	
	Trochulus sericeus	1	32	
	% group 6	*4.8*	*15.0*	
7	*Cepaea hortensis*		7	
	Euconulus fulvus		3	
	Nesovitrea hammonis		2	
	% group 7	*0.0*	*3.2*	
8	🟩 *Pomatias elegans*		1	
	% group 8	*0.0*	*0.3*	
9	*Pupilla muscorum*	2		
	% group 9	*9.5*	*0.0*	
11	*Carychium minimum*		1	
	Succinea putris	5	71	
	Vertigo antivertigo	1		
	Zonitoides nitidus		1	
	% group 11	*28.6*	*19.2*	
12	*Euconulus alderi*		2	
	Galba truncatula	2	16	
	Oxyloma elegans	10	197	
	Succinella oblonga		2	**Totals**
	% group 12	*57.1*	*57.1*	
Total Terrestrial Molluscs		**21**	**380**	**401**
Number of Terrestrial Species		**6**	**23**	**25**
13	*Pisidium obtusale*	8	7	
	% group 13	*1.2*	*0.5*	
14	*Armiger crista*	8		
	Gyraulus laevis		4	
	Pisidium casertanum		55	
	Planorbis planorbis	15	7	
	Sphaerium corneum	121	89	
	Stagnicola palustris/corvus	61	61	
	% group 14	*29.5*	*15.7*	
15a	*Bathyomphalus contortus*		3	
	Bithynia tentaculata shells	101	161	
	Bithynia tentaculata opercula	93	142	
	Hippeutis complanatus	8	8	
	Lymnaea stagnalis	153	127	
	Pisidium milium	2	1	
	🟩 *Pisidium nitidum* var. *arenicola*		8	
	Pisidium subtruncatum	3	38	
	🟩 *Planorbis carinatus*	52	77	
	Radix balthica	10	104	
	🟩 *Segmentina nitida*	15	24	
	Valvata cristata	10	21	
	% group 15a	*64.3*	*52.0*	
15b	🟩 *Anisus vorticulus*	3		
	Pisidium amnicum		88	
	🟩 *Pisidium henslowanum*		5	
	Pisidium lilljeborgii		3	
	🟩 *Pisidium moitesserianum*		1	
	Unio sp.		2	
	Valvata piscinalis	32	337	
	% group 15b	*5.0*	*31.8*	
Total Aquatic Molluscs		**695**	**1373**	**2068**
Number of Aquatic Species		**16**	**23**	**25**
Aquatic Molluscs as a proportion of Total Molluscs (%)		**97.1**	**78.3**	
Total Molluscs		**716**	**1753**	**2469**
Degree of surface dissolution of the shells		some/ moderate /f. severe	some/ moderate /f. severe	
Evidence of alteration				
7	earthworm granules		x	
	wood fragments	x	xx	
	charcoal fragments	x	x	
	plant remains	xx c *Carex* , rr *Potomageton* , r *Ranunculus Bat* , unident seeds, *Salix* leaves	xx c *Carex* , r *Potamogeton* , r *Ranunculus Bat* , r *Zannichellia palustris* , unident seeds, *Abies* needles, *Betula* seeds and scales	
13-15	*Chara* oospores	xx	1	
13-15	ostracod valves		4	

For a description of the ecological groups see Figure 2

KEY

🟩 Species typical of interglacial warm periods

Note 1 Sample from Musée d'Histoire Naturelle, Geneva. Taken by Adrien Jayet between 1942 and 1944. Only partially analysed by Jules Favre, leaving numerous shells/fragments unidentified. All material has been reanalysed by NT

Note 2 Sample from Musée cantonal de Géologie, Lausanne. Taken by the lignite mines's geologist H. Badoux in 1944, then washed by Marc Weidmann in March 1970, but never analysed.

Table 20 : The Molluscan Faunas from Fisibach, AG

Sampled : M. Büchi 2016, H.R. Graf + D. Kälin 2022, M. Büchi + D. Kälin 2023
Analysis : N. Thew 2017, 2022 + 2023

Site		**Bauernmühle, Fisibach, AG**					
Sampling location		2022 (2672 614/1269 132; 388 m asl)	2023 (2672 620-630/1269 110-130; 388-391 m asl)			2016 (2672 670/1269 080; 391 m asl)	
Sample		Fis22-1	Fis23-1	Fis23-2	Fis23-3	Fis16-1	
Sediment description		grey silty-sand with a little fine gravel and some sub-rounded Alpine stones to 6 cm; fairly abundant root concretions	beige (grey-beige in sample 23-1) silty sand + some sub-rounded/sub-angular Alpine stones to 2 cm; more sand + stones in sample 23-2; very abundant root concretions			grey-beige silty sand with a little fine gravel and some sub-rounded Alpine stones to 6 cm; abundant root concretions	
Sample size (kg)		7.5	23.2	18.9	19.1	1.8	
Malacozone		**Fis-1**	**Fis-2**	**Fis-3a**	**Fis-3b**	**Fis-4**	
Possible age (stratigraphy, molluscs)		late MIS 6?					
Ecological Groups	**Species**						
4	*Clausilia rugosa parvula*		2				
	Trochulus villosus	1					
	% group 4	*1.3*	*0.4*	*0.0*	*0.0*	*0.0*	
6	*Arianta arbustorum*	2	4	1			
	Trochulus sericeus	18	224	97	96	14	
	% group 6	*26.7*	*41.7*	*37.1*	*20.5*	*23.0*	
7	*Trochulus hispidus*	31	295	145	333	41	
	% group 7	*41.3*	*53.9*	*54.9*	*71.2*	*67.2*	
9	*Pupilla muscorum*	6	7	16	12	4	
	% group 9	*8.0*	*1.3*	*6.1*	*2.6*	*6.6*	
10	*Pupilla sterri*				5		
	% group 10	*0.0*	*0.0*	*0.0*	*1.1*	*0.0*	
12	*Pupilla alpicola*	16	13	4	20	2	
	Succinella oblonga	1	2	1	2		**Totals**
	% group 12	*22.7*	*2.7*	*1.9*	*4.7*	*3.3*	
Total Terrestrial Molluscs		**75**	**547**	**264**	**468**	**61**	**1415**
Number of Terrestrial Species		**7**	**7**	**6**	**6**	**4**	**9**
15a	*Bithynia tentaculata* shells			1	1		
Total Aquatic Molluscs		**0**	**0**	**1**	**1**	**0**	**2**
Number of Aquatic Species		**0**	**0**	**1**	**1**	**0**	**1**
Aquatic Molluscs as a proportion of Total Molluscs (%)		**0**	**0**	**0.4**	**0.2**	**0**	
Total Molluscs		**75**	**547**	**265**	**469**	**61**	**1417**
Total Molluscs per kilo of sediment		**10**	**24**	**14**	**25**	**34**	
Redeposited Middle Pleistocene shell fragments (with signs of abrasion)		*Cepaea hortensis* (2), *Helicigona lapicida* (1), *Isognomostoma isognomostomos* (1)	*Cepaea hortensis* (2), *Isognomostoma isognomostomos* (1)	*Isognomostoma isognomostomos* (1)			
Redeposited Tertiary? shell fragments (marine species, white, no recrystallisation)				1 *Glycymeris* sp. frag.			
Redeposited shell frags from upper part of the OSM (pale brown/brownish-grey/grey; some recrystalisation)			4		2	3	
7	earthworm granules	x	xx	x	x	x	
	charcoal		(x)	(x)	x		
	bird egg-shell		1				
	bone fragments - larger mammals			1		1	

For a description of the ecological groups see Figure 2

KEY

▨ Pioneer species typical of colder periods

Table 21 : The Molluscan Faunas from Herterenhof, Wettingen, AG

Sampled : C. Friedlaender 1941
Provisional analysis : J. Favre 1941
Analysis : Nigel Thew 2022

Site (Note 1)		**Herterenhof, 500 m E of Wettingen, AG** In a sand quarry on the NE flank of the Sulperg [Sulzberg] (est 2668 320/1257 290; 485 m asl)		
Sample label (Favre 1941)		"sable loessoide"	"couche blanche crayeuse"	
Sediment description		olive-grey silty-sand + bluish-grey sandy-silt; iron staining in places	white powdery tufa with plant impressions	
Sample size (kg)		unknown	unknown	
Residue available for sorting		x	x	
Probable age (stratigrapghy, pollen, molluscs)		final MIS 6		
Ecological Groups	**Species**			
4	*Eucobresia diaphana*		53	
	Trochulus villosus		13	
	% group 4	*0.0*	*4.9*	
6	*Arianta arbustorum*	146	406	
	Cochlicopa lubrica	15	31	
	Columella columella		21	
	Punctum pygmaeum		6	
	Trochulus sericeus	2	57	
	Vitrea crystallina	21	383	
	% group 6	*81.8*	*67.4*	
7	*Euconulus fulvus*		26	
	Limax/Deroceras sp.	3	21	
	% group 7	*1.3*	*3.5*	
9	*Pupilla muscorum*	2	195	
	% group 9	*0.9*	*14.5*	
11	*Succinea putris*		10	
	Zonitoides nitidus		2	
	% groupe 11	*0.0*	*0.7*	
12	*Oxyloma elegans*	24	52	
	Succinella oblonga	12	58	
	Vertigo genesii		7	**Totals**
	% group 12	*16.0*	*8.7*	
Total Terrestrial Molluscs		**225**	**1341**	**1566**
Number of Terrestrial Species		**8**	**16**	**16**
Degree of surface dissolution of the shells		(moderate) /f. severe/severe	moderate/f. severe	
7	earthworm granules (Note 2)	x	xx	
	charcoal fragments		x	
	plant impressions		xx grasses c unident plant frags c deciduous bush/tree leaves r	

For a description of the ecological groups see Figure 2

KEY

- 🟪 Pioneer species typical of colder periods
- 🟧 Pioneer species typical of both colder periods + the start of warmer periods

Note 1 sampled by C. Friedlaender in 1941 and provisionally examined by J. Favre. Totally reanalysed by N. Thew, including a majority of previously unidentified shells + fragments. The site was published, with a brief mention of some mollusc species, in Friedlaender 1942.
Shell material borrowed from the PIMUZ Zürich

Note 2 the granules were mostly very small (<0.5 mm)

Stratigraphy in Friedlaender 1942 + Welten 1982: deposits up to c.20 m thick

TOP up to 6 m	brown-beige bedded loessic silts with soil horizons	
up to 5 m	grey-beige loessic sandy-silt, + grey sand, stained reddish by Fe in places	
up to 1.5 m	compact dark grey sandy clay-silt with brown blotches at base	
2-4 m	reddish-brown to black peat with wood pieces + bands of brown organic silt with clay + grey-beige silty-sand; sandy at summit	
0.1-0.2 m	grey-brown organic clay-silt	
0.1-0.2 m	grey loessic silt with some sand + olive-grey silty-sand + wood pieces + rare pebbles	
0.1 m	white powdery tufa with impressions from plants	mollusc sample
up to 1 m	grey loessic silt with some sand + olive-grey silty-sand + wood pieces + rare pebbles	mollusc sample
2-4 m	interbedded grey/grey-beige silty-sands with some pebbles, beige silt with clay, sand with some pebbles, grey-brown organic silt + fine-coarse sand near base	
	major erosion surface	
up to 4-5 m	basal moraine (very compact sandy clay-silt with striated pebbles) - Riss	
BASE	Upper Marine Molasse	

Table 22 : The Molluscan Faunas from Niederweningen, ZH

Analysed : Nigel Thew 2015 and 2018-2022

Location / Core / Column		Core NW07/3 2670 703 /1262 190	Core NW18/2 2670 514/1262 322													Core NW18/3 2670 428/1262 363												Excavation 2015 (for house construction, Murzlenstrasse)				Excavation July 1990 (for a new schoolhouse) 2670 796/1262 132 (Note 5)			
																												Column A 2670 369/1262 404		Column B 2670 409/1262 380					
Sample			-2		-1	1		-	2	3	4	5	6		7	-2		-1	OSL	1		2	3	4	5		6	NW15/1	NW15/2	NW15/3a	NW15/3b	NW90/1	NW90/2	NW90/3	
Sediment description		grey detritic silt with some sand + plant debris	grey detritic sandy-silt + plant debris + few stones to 1.2 cm		blue-grey marly silt/marly-silt + few stones to 0.6 cm	blue-grey marly-silt + tufaceous concretions + few stones to 0.5 cm		thin grey-black peat	grey-brown fairly organic tufaceous sandy-silt + some stones to 1 cm	grey-black peat + two bands grey-brown tufaceous sandy-silt	grey-brown fairly organic tufaceous sandy-silt + some stones to 1 cm	grey-black peat + two bands of grey-brown tufaceous sandy-silt	grey-brown fairly organic tufaceous sandy-silt + some stones to 1.5 cm		grey-brown organic silt + some stones to 1 cm/ over grey-black peat	grey detritic sandy silt/silt + few stones to 0.6 cm + plant debris		blue-grey sandy marly-silt/marly-silt + plant debris to 3 cm	blue-grey marly-silt + plant debris	blue-grey marly-silt + moderate stones to 2.5 cm		brownish-grey tufaceous sandy-silt + moderate stones to 2 cm	grey-black peat	brownish-grey tufaceous sandy-silt	grey-brown fairly organic tufaceous sandy-silt + some small stones		dark grey-brown fairly organic silt/ over grey-black peat	grey tufaceous silt with some sand	grey tufaceous silt with some sand	light creamy-grey silty-tufa/over grey-brown organic silt	light creamy-grey silty-tufa/under grey-black humified peat	blue-grey fairly marly silt with some fine sand	grey-brown organic silt with fine sand + little fine gravel + thin sandy bands	dark brown humified silty-peat + few stones + few thin sandy bands at base = **Upper Peat**	
Sample weight (kg)		0.5	1.85		1.79	2.52			0.48	macro Note 3	1.71	macro Note 3	1.36		0.55	2.21		0.95		3.03		3.05	macro Note 3	2.75	1.20		macro Note 3	2.5	3.0	2.0	1.5				
Malacozones		NW-1	NW-1		NW-2	NW-3a			NW-3b2		NW-3c		NW-4		-	NW-0		NW-2		NW-3b1		NW-4a		NW-4b	NW-4c		-	NW-3b2		NW-4a		NW-5a		NW-5b	
Probable age (stratigraphy, molluscs, pollen)		Late Riss late MIS 6	Late Riss late MIS 6		early Eemian MIS 5e	middle Eemian MIS 5e		middle Eemian MIS 5e	middle Eemian MIS 5e		middle Eemian MIS 5e		middle/later Eemian MIS 5e		later Eemian MIS 5e	late? Riss MIS 6		early Eemian MIS 5e		middle Eemian MIS 5e		middle/later Eemian MIS 5e		middle/later Eemian MIS 5e	middle/later Eemian MIS 5e		later Eemian MIS 5e	middle Eemian MIS 5e		middle/later Eemian MIS 5e		Mid Würm early MIS 3			
Estimated water depth (Note 2)		7	6		5	4		0+1	3	0+1	3	0+1	1+2		0	1?		1	0/1	0/1		1	0	2	0/1		0 then 1	2	3	2	2	4?	4	2	
Ecological Group	**Species**				Note 1																														
1	*Aegopinella ressmanni*					x			xx		xx		xx							x		xx		xxx	xxx				x	x	x				
	Aegopis verticillus										x		xx									xx		xx	xxx					xx	xx				
	Clausilia cruciata					x			xx		xx		xx							x		x		x	x					x	x				
	Cochlodina fimbriata												x											x	x										
	Daudebardia brevipes												x									x		x	x					xx	x				
	Daudebardia rufa												x									x		x	x					x					
	Discus perspectivus					x			xxx		xxx		xx							x		xx		xxx	xxx			x	xx	xxx	xxx				
	Ena montana					x							x																						
	Macrogastra attenuata				x	xx			xx		xxx		xxx							xx		xx		xxx	xx			x	x	x	x				
	Macrogastra ventricosa					xx			xx		xxx		xx							xx		xx		xxx	xx			xx	xx	xx	xx				
	Trochulus edentulus												x																						
	% group 1																																0.0	0.0	
2	*Vertigo pusilla*					x			x															x						x					
	% group 2																																0.0	0.0	
3	*Acanthinula aculeata*								x		x		x									x		xx	x					x					
	Acicula lineata					x			xx		x		x							x		x		xx	xx					x	xx				
	Aegopinella pura								x		x									x		x		xx	xx					x	xx				
	Clausilia dubia					x			x		x		x							x		x		x	x					x					
	Cochlodina laminata				x	x			x		xx		xx							x		xx		xx	xx			x	x	xx	xx				
	Euomphalia strigella								x		x		x					1		x		x		x				x	x	x	x				
	Helicigona lapicida								xx		xx		xx							x		x		xx	xx			x	x	x	xx				
	Helicodonta obvoluta				xx	xxx			xxx		xxx		xxx					7		xx		xxx		xxx	xxx			xx	xxx	xxx	xxx				
	Macrogastra plicatula					x			x		x		x							x		x		x	x			x	x	x	x				
	Merdigera obscura																								x										
	Monachoides incarnatus				x	xxx			xxx		xxx		xxx							xxx		xxx		xxx	xxx			xx	xx	xxx	xxx				
	Pagodulina pagodula				x	x			xx		xx		xx							x		xx		xx	xx					xx	x				
	Platyla polita								x		x													x	x					x					
	Ruthenica filograna					xx			xx		xx		x							x		xx		xx	xx					x	x				
	Semilimax semilimax					x			x		xx		xx							x		x		xx	xx					x	x				
	Sphyradium doliolum					x			x		x		x							x		x		x					x	x					
	% group 3																																0.0	0.0	
4	*Aegopinella nitens*				x	x			x		x		x					2		x		x		x	x			x	x	xx	x				
	Clausilia bidentata				xx	xx			xx		xx		xx					1		xx		xx		xx	x			x	x	xx	x				
	Clausilia rugosa parvula					x			x		x		x							x		x		x	x			x	x	xx	x				
	Discus rotundatus				xx	xxx			xxx		xxx		xxx					1		xxx		xxx		xxx	xx			xx	xx	xxx	xx				
	Discus ruderatus			x		x	x															x												3		
	Limax maximus/cinereoniger										xx											x		x	x										
	Milax/Tandonia sp.								x		xx		x									x		xx	x					x					
	Neostyriaca corynodes					x																													
	Oxychilus cellarius				x	x			x		x		x							x		x		xx	xx					x	x				
	Trochulus villosus					x																											1	1	
	Vitrea diaphana								x		xx		xx							x		xx		xxx	xxx				x	xx	xx				
	Vitrea subrimata					x																		x											
	% group 4																																6.2	7.7	
6	*Arianta arbustorum*		x		x	xx			x		xx		xxx					2		x		xx		xxx	xxx			x	x	xxx	xx		3		
	Carychium tridentatum				xx	xx			xxx		xx		xx							x		x		xx	x			x	xx	x	x				
	Cochlicopa lubrica				xx	xxx			xx		xx		xx					1		xx		xx		xx	xx			xx	xx	x	x				
	Columella columella																																2		
	Columella edentula				x						x																			x					
	Fruticola fruticum				xx	xxx			xxx		xxx		xxx					4		xxx		xx		xxx	xx			xxx	xxx	xxx	xxx				
	Punctum pygmaeum				x						x		x									x		x					x						
	Trochulus sericeus				x	xx			xx		xx		xx					3		xx		xx		xxx	xxx			xx	x	xx	x		3	5	
	Vitrea crystallina				x	x			xx		x		xx							x		x		xxx	xxx					x	x				
	% group 6																																12.3	38.5	
7	*Cepaea hortensis*				x	xxx			xxx		xxx		xxx					1		xxx		xx		xx	xx			xx	xx	xx	xx				
	Euconulus fulvus				x	x			xx		xx		xx							x		x		x	x			x	x	x	x				
	Limax/Deroceras sp.					x			x		xx		x					1		x		x		xx	x			xx	x	x	x		2		
	Nesovitrea hammonis				xx	xx			xx		xx		x							xx		x		x	x			xx	xx	x	x				
	Vitrea contracta								x		x		x									x		x											
	% group 7																																3.1	0.0	
8	*Cochlicopa lubricella*				x	x			x		x		x							x		x		x	x										
	% group 8																																0.0	0.0	
9	*Pupilla muscorum*										x		x					1		x				x									7	2	
	Vallonia costata				xx	x			x		x		x							x		x		xx	x			x	x	x					
	Vallonia pulchella					x																		x											
	Vertigo pygmaea			Hiatus			Hiatus							Hiatus			Hiatus				Hiatus			x		Hiatus									
	% group 9																																10.8	15.4	
10	*Jaminia quadridens*				x																														
	% group 10																																		
11	*Carychium minimum*					x			xx		x		x							x		x		xx				x	x	x	x				
	Cochlicopa nitens																												x						
	Succinea putris					x			xx		x		x							x		x		x	x			xx	xxx	x	xx				
	Vallonia enniensis								x																			x	xx						
	Vertigo antivertigo				x	x			x		x		x									x		x					x						
	Zonitoides nitidus				xxx	xx			xx		xx		xx					1		xx		xx		xx	xx			xx	xx	x	x				
	% group 11																																0.0	0.0	
12	*Euconulus alderi*								x		x		x											x											
	Galba truncatula		x		x	xx			xx		x		x							xx		x		xx	xx			x	x	x	x		14	1	
	Oxyloma elegans		x		xx	xx			xx		xx		x					1		xx		xx		xx	xx			x	x	xx	x		16	4	
	Pupilla alpicola																																9		
	Succinella oblonga		x						x		x		x							x		x		xx	x					x					
	Vertigo angustior				x	x			x											x		x							x						
	Vertigo genesii																			xx		x								x			5		Totals
	% group 12																																67.7	38.5	
Total Terrestrial Molluscs															sterile	sterile		27									note 4					0	65	13	78
Number of Terrestrial Species		0	5		29	46			51		53		53		sterile	sterile		14		46		53		59	48		note 4	29	36	50	39	0	11	5	11
13	*Anisus leucostoma*				x	xx			xx		xxx		x							x		x		xx	x			x	xx	x	x		3		
	Anisus spirorbis										x																	x	xx						
	Aplexa hypnorum								x		xx																		x	x					
	Pisidium obtusale								x		x																								
	Pisidium obtusale var. *lapponicum*	x	x		x																												63	3	
	% group 13																																9.9	5.8	
14	*Armiger crista*	x	xx		xx	x																							xx				85	7	
	Gyraulus laevis	x	xxx		xxx	x			x																				x				10		
	Pisidium casertanum	xx	x		xx	xxx			xxx		xxx		xx							xx		xx		xx	xx			xxx	xxxx	x	xx		1		
	Pisidium personatum				x	x			x		xx		x									x		xx				x	xx	x	x				
	Radix labiata		x		x	x			xx		xxx		x							x		x		xx	x			x	x	x	x				
	Sphaerium corneum	xxx	xxx		xxx	xxx			x		xx		x					1				x		x									17		
	Stagnicola palustris/corvus					xx			x		xx									x				x				x	x			1	8	3	
	% group 14																																18.2	19.2	
15a	*Bathyomphalus contortus*					x			x		x		x																x						
	Bithynia tentaculata shells				x	x			x																			x	x		x				
	Bithynia tentaculata opercula				x	x			x		x									x		x		x					x				1		
	Hippeutis complanatus					x																													
	Pisidium milium	xx	xx		xx	x			x		x							1						x				x	x	x	x		5	1	
	Pisidium nitidum	xx	xxxx		xxx	x																		x									12	1	
	Pisidium subtruncatum	xx	xxx		xxx	xx			xxx		xx		x							x		x		xxx	x			x	xx	x	xx		67	2	
	Planorbis carinatus					x					x																			x					
	Radix balthica	x	x		x	x			xx		x													x				x	xx	x	x		26	6	
	Segmentina nitida					x																													
	Valvata cristata					x			x		xxx		x											x				x	xx	x					
	Valvata pulchella																												x						
	% group 15a																																16.7	19.2	
15b	*Lymnaea stagnalis*				x	x					x																		x						
	Pisidium hibernicum	x	xx		x																														
	Pisidium lilljeborgii	x	x																																
	Pisidium tenuilineatum										x											x													
	Valvata piscinalis	x	xxxx		xxx	xx			x																								368	29	
	% group 15b																																55.3	55.8	
Total Aquatic Molluscs															sterile	sterile		2									note 4					1	666	52	719
Number of Aquatic Species		12	13		16	20			16		18		8		sterile	sterile		2		6		8		12	4		note 4	12	18	10	8	1	13	8	13
Aquatic Molluscs as a proportion of Total Molluscs (%)		100.0	a>>>>>>t		a>>>t	a<t			a<<<t		a<<<t		a<<<<<<t		-			a<<t		a<<<<<<t		a<<<<<<t		a<<<<<t	a<<<<<<t			a<<<t	a<<<t	a<<<<t	a<<<<t	100.0	91.1	80.0	
Total Molluscs		fairly abundant	very abundant		moderate	moderate			abundant		extremely abundant		abundant		sterile	sterile		poor		fairly abundant		abundant		extremely abundant	abundant		note 4	abundant	abundant	very abundant	very abundant	1	731	65	797
Degree of surface dissolution of the shells		moderate /f. severe	moderate /f. severe		(some)/ moderate /f. severe	some/ moderate /f. severe			some/ moderate		some/ moderate		moderate /f. severe		complete	?		moderate /f. severe		some/ moderate /f. severe		some/ moderate /f. severe		some/ moderate /f. severe	some/ moderate /f. severe		complete	some/ moderate				some/ moderate /f. severe	some/ moderate /f. severe	moderate /f. severe	
	fragments of redeposited Tertiary molluscs		x		x	x			x									xx		x		x													
7	earthworm granules		(x)		x	xx			xx		xx		xxx					(x)		xx		xx		xxxx	xxxx			xx	xx	xx	xx	xx	xx	x	
	insect remains				x	xx			x		x		xx									x		x									xx	xx	
	tooth/bone fragments - small vertebrates				xx	xxx			x		xx		x							x		xx		x	x					x		x	xx	xx	
	bone fragments - larger mammals		x		x	xxx					x									xx		xxx			x							x mammoth tusk	x	xx	
	wood fragments				xx	xx			xx		xx		xxxx		xxxx			xx (incl roots)		xx		xxx		xxx	xxx		xxxxx	xxx	xxx	xx	xxx	x	xx	xxxx	
	charcoal fragments								x		x				x					x		xx		x	x			x	x	x	x	x	xx	x	
	plant material	xx	xx		x	x			x		xx		xxxx		xxxx			x		x		xxx		xxx	xxx		xxxx	x	x	x	x	x	xx	xx	
	moss frags																					x													
	uncarbonised seeds	x				x *Sambucus, unident*			xx *Rubus, Sambucus* , unident		xx *Sambucus* , unident		xx *Sambucus* , unident		xxx *Sambucus* unident seeds					x *Sambucus*		xxx *Rubus Sambucus* unident seeds		xxx *Carex Rubus Sambucus* unident seeds	xxx *Carex Rubus Sambucus* unident seeds		xxx			x	4	x	xx *Carex Potomageton Ranunculus Bat Gypsophila* sp. *Rubus* sp. *Sambucus* unident seeds	xx *Carex Potomageton Rubus* sp. *Sambucus* unident seeds	
	Cenococcum		x						xx		x		x		x					x		xx		xx									xx	xx	
13-15	ostracod valves		x		1															x		x										x	xx		
13-15	*Chara* oospores	x	x		1				x																							x	xx		
15	fish bones																														2			x	
	tufa (travertine) fragments				xx	xx			xxxxx		xxxxx		xxx					(x)		x		x		xxxx	xx			xxxxx	xxxxxx	xxxxx	xxxxxx				

For a description of the ecological groups see Figure 2

Note 1 The frequency of the terrestrial frags has been exagerated by approx x 10 to show relative frequencies between species

Note 2: 0= marshy conditions, with only brief episodes of flooding; 1= marshy/shallow seasonal water, present for several months of the year, with long periods of drying out; 2= shallow water present for most of the year; 3= shallow, almost
Estimated water depth: permanent water, with only brief periods of drying out; 4= shallow permament water up to 1 m deep; 5=shallow permanent water between 1 to 2 m deep; 6=shallow permament water up to 2 m deep; 7= permanent water up to 3 m deep

Note 5 Shell material borrowed from the PIMUZ

Note 3: macro = sample analysed for plant macroremains but not for molluscs

Note 4 Although this sample was not processed for molluscan analysis, no shells were found during processing to analyse plant macroremains

KEY

- 🟩 Species typical of interglacial warm periods
- ▨ Species typical of interglacial warm periods that can also be found in mild interstadials early in a cold period
- ▧ Interglacial species that seems to have first appeared during the Eemian
- 🟪 Pioneer species typical of colder periods
- 🟧 Pioneer species typical of both colder periods + the start of warmer periods
- 🟦 Interglacial Marker Species last present in Swiss molluscan faunas during the Eemian
- 🟩 First appearance of an important molluscan marker species
- 🟥 Very organic samples that have not been analysed for molluscs

Estimated number of individuals	
fairly abundant	several hundred
abundant	>1000
very abundant	2000-4000
extremely abundant	>4000

Total number of species for Malacozones NW-2 to NW-4	
Terrestrial	71
Aquatic	23

Table 23 : The Molluscan Faunas from Les Tuileries, Yverdon, VD and 'Giez'/Grandson,VD

Analysed : Nigel Thew 2010-2014 (unpublished) + 2018

Site (Note 1)		**Les Tuileries, Yverdon, VD** (1960: 2537 490/1183 230, surface c.478 m + 1966: 2537 430/1183 200, surface c.480 m asl)										**Giez'/Grandson, VD** (est. 2538 525/1184 440; surface c.479 m asl)
Profile / Year of sampling (Jayet and Portmann)		**1960**			**1966** (c.60 m west of 1960 profile)							**1960's** (c.1.4 km NE of Les Tuileries)
Layer (from Jayet)		*Banc principal partie inf*	*Banc principal partie moyen*	*Banc principal partie moyen*	*Lentille oblique*	*Lentille contournée*	*Lentille sous niveau (banc) principal SW*	*Niveau (banc) principal SW*	*Banc supèrieur*	*Terre rouge* (below modern soil)		
Sediment description		light yellowish-grey sandy tufaceous silt with a little fine gravel	light creamy-grey very tufaceous silt with some sand	light creamy-grey very tufaceous silt with some sand	yellowish-grey sandy fairly tufaceous silt with a little fine gravel	light yellowish-grey sandy tufaceous silt with a little fine gravel	light yellowish-grey sandy tufaceous silt with a little fine gravel	light creamy-grey very tufaceous silt with some sand	light creamy-grey very tufaceous silt with some sand	reddish-brown sandy silt with gravel and stones		light yellowish-grey fairly marly silt with some sand and a little fine gravel; frequent rootlet concretions
First analysed by (note 1)		Thew	Jayet	Thew	Jayet	Jayet	Jayet	Jayet	Jayet	Thew		Thew (some provisional work by Jayet)
Sample weight (kg - if known)		0.85		0.10						0.45		approx. 1.5
Residue available for sorting by NT		x		x						x		x
Malacozones		**LT-2**	**LT-3**		**LT-1**	**LT-2**		**LT-3**	**LT-4**			**Gi-1** (contemporary with LT-3)
Probable age (stratigraphy, molluscs)		early to mid Eemian MIS 5e			late Riss late MIS 6	early to mid Eemian MIS 5e			mid to late Eemian MIS 5e	Holocene		early to mid Eemian MIS 5e
Ecological group	**Species**											
1	🟩 *Cochlodina fimbriata*											4
	🟦 *Discus perspectivus*								1			
	🟩 *Trochulus edentulus*							1				
	% group 1	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.5*	*2.1*			*0.1*
3	🟩 *Acanthinula aculeata*			1								5
	🟩 *Aegopinella pura*											20
	Cepaea sylvatica		3					2	5			5
	Clausilia dubia	15		3				2	1			3
	🟩 *Cochlodina laminata*		14	3				1	1			94
	🟩 *Euomphalia strigella*	30	14	46		3	5	33	3			294
	🟩 *Helicigona lapicida*								1			
	🟩 *Helicodonta obvoluta*		17	49				3	1			316
	🟩 *Monachoides incarnatus*								1			1
	🟦 *Platyla dupuyi*			2								
	🟩 *Platyla polita*											1
	% group 3	*3.8*	*27.4*	*42.3*	*0.0*	*4.6*	*15.6*	*20.4*	*27.1*			*26.8*
4	🟩 *Aegopinella nitens*		12	34				1	1			73
	Clausilia bidentata											29
	Clausilia rugosa parvula											25
	🟩 *Discus rotundatus*		20	15				2	1			163
	Discus ruderatus	30	2	4		8	1	8				35
	Eucobresia diaphana	1						1				
	🟩 *Limax maximus/cinereoniger*							1				2
	🟩 *Oxychilus cellarius*			3				1	1			79
	Trochulus montanus											1
	Trochulus villosus											3
	% group 4	*2.6*	*19.4*	*22.8*	*0.0*	*12.3*	*3.1*	*7.0*	*6.3*			*14.9*
6	*Arianta arbustorum*	2	2	1	1	1	2	8	12			5
	🟩 *Carychium tridentatum*	35		3		1	1	2				16
	Cochlicopa lubrica	118	8	12		10	2	8	2			117
	Columella edentula	5										
	🟩 *Fruticola fruticum*	67	14	18		1	10	57	5			419
	Punctum pygmaeum	32		1								8
	Trochulus sericeus	64	2	8		9	1	6	1			49
	Vitrea crystallina	15		1								23
	% group 6	*28.5*	*14.9*	*17.9*	*2.5*	*33.8*	*50.0*	*40.3*	*41.7*			*23.1*
7	*Cepaea hortensis*	4	38	3		2		25	9			394
	Euconulus fulvus	38			2							13
	Limax/*Deroceras* sp.	6	3	1	1			7				22
	Nesovitrea hammonis	197	4	16		4	4	15	1			273
	Vitrea contracta	17		2				3				1
	% group 7	*22.1*	*25.7*	*8.9*	*7.5*	*9.2*	*12.5*	*24.9*	*20.8*			*25.5*
8	*Abida secale*					1						1
	Cochlicopa lubricella	12		1		1		2				34
	% group 8	*1.0*	*0.0*	*0.4*	*0.0*	*3.1*	*0.0*	*1.0*	*0.0*			*1.3*
9	*Pupilla muscorum*	3			14	1						
	Vallonia costata	156	14	5	11	6	3	3				89
	Vallonia pulchella	30	5			5						18
	% group 9	*15.9*	*10.9*	*2.0*	*62.5*	*18.5*	*9.4*	*1.5*	*0.0*			*3.9*
11	*Carychium minimum*	38										2
	Vertigo antivertigo	26										
	🟩 *Vertigo moulinsiana*	3										
	Zonitoides nitidus	72		3		10	3	9	1			83
	% group 11	*11.7*	*0.0*	*1.2*	*0.0*	*15.4*	*9.4*	*4.5*	*2.1*			*3.1*
12	*Euconulus alderi*	9										14
	Galba truncatula	85		3		1						7
	Oxyloma elegans	64	3	8								15
	Succinella oblonga	14			11	1						1
	% group 12	*14.5*	*1.7*	*4.5*	*27.5*	*3.1*	*0.0*	*0.0*	*0.0*		**Totals**	*1.3*
Total Terrestrial Molluscs		**1188**	**175**	**246**	**40**	**65**	**32**	**201**	**48**	**sterile**	**1995**	**2757**
Number of Terrestrial Species		**29**	**17**	**26**	**6**	**17**	**10**	**24**	**18**	**sterile**	**42**	**41**
13	*Aplexa hypnorum*											3
	Pisidium obtusale											1
	% group 13	*0.0*	*0.0*	*0.0*			*0.0*	*0.0*				*9.8*
14	*Armiger crista*	1										
	Gyraulus laevis	25										
	Pisidium casertanum	17	1	3		1		3	1			3
	Pisidium personatum		1									
	Planorbis planorbis											1
	% group 14	*14.1*	*11.8*	*10.3*			*0.0*	*4.5*				*9.8*
15a	*Bithynia tentaculata* shells	22		1			1	2				1
	Bithynia tentaculata opercula	2						1				2
	Hippeutis complantus	1										
	Lymnaea stagnalis	13										
	Pisidium milium	11										
	Pisidium nitidum	15										
	Pisidium subtruncatum	137						1				1
	Radix balthica	48	13	21	1	1	6	19	2			23
	Valvata cristata								1			
	% group 15a	*81.9*	*76.5*	*75.9*			*58.3*	*34.3*				*65.9*
15b	*Pisidium amnicum*	9		2		1	4	40				3
	Valvata piscinalis	3	2	2			1	1				3
	% group 15b	*3.9*	*11.8*	*13.8*			*41.7*	*61.2*				*14.6*
Total Aquatic Molluscs		**304**	**17**	**29**	**1**	**3**	**12**	**67**	**4**	**sterile**	**437**	**41**
Aquatic Molluscs as a proportion of Total Molluscs (%)		**20.4**	**8.9**	**10.5**	**2.4**	**4.4**	**27.3**	**25.0**	**7.7**	**sterile**	**21.9**	**1.5**
Number of Aquatic Species		**12**	**4**	**5**	**1**	**3**	**4**	**6**	**3**	**sterile**	**14**	**9**
Total Molluscs		**1492**	**192**	**275**	**41**	**68**	**44**	**268**	**52**	**sterile**	**2432**	**2798**
Total Molluscs per 1kg of sample		**1755**		**2750**						**sterile**		**1865**
7	earthworm granules	xxx	xxxx	xxx				xxxx				xxx
	white calcareous balls (note 2)					1						
	insect fragments			x								
	plant material	uncarbonised plant material	uncarbonised plant material incl. *Picea* needles	uncarbonised plant material	small carbonised twig			uncarbonised plant material incl. *Picea* needles	uncarbonised plant material incl. a *Betula* seed			1 uncarbonised *Picea* needle
	charcoal fragments	x	x	x	x			x				x
13-15	*Chara* oospores	1										
13-15	ostracod valves	xx										
	lignite fragments		x									
	tufa (travertine) fragments	xxx		xxxx								x

For a description of the ecological groups see Figure 2

Note 1 all shell material has been reanalysed by Thew
All shell material borrowed from the Muséum d'Histoire Naturelle, Genève

Note 2 eggs from larger terrestrial snail taxa

KEY

🟩	Species typical of interglacial warm periods
🟦	Interglacial Marker Species last present in Swiss molluscan faunas during the Eemian

Table 24 : The Molluscan Faunas from Zell, LU

Sampled : L. Forcart 1940, A. Jayet 1948, D. Kälin 2019
Modern shells : sampled A. Erni 1940
Analysed : Nigel Thew 2018, 2021

Site		**Zell, LU - Hochterrasse**						
Location / Analysed by/ Sample		**Kiesgrube Meier** Kälin 2019		**Kiesgrube Meier** (2637 210/1220 455) Forcart 1940 unchecked (Note 1)	**Kiesgrube Meier** (est. 2637 190/1220 450) Jayet 1948 reanalysed by Thew (Note 2)	**Modern shells** collected in 1940 by A. Erni from around the gravel quarry reexamined by Thew		
		Zell 1 (2636 552/1220 110)	**Zell 2** (2636 552/1220 112) c.1 m above Zell 1					
Sediment description		grey silt with some sand and a little fine gravel to 0.6 cm	yellow-olive-grey sandy-silt with some fine gravel to 1 cm	yellowish-grey tufaceous silty-sands/grey sandy silts + some fine gravel to 1 cm; reddish in places due to iron staining				
Sample weight (kg - if known)		25.0	26.0					
Residue available for sorting by NT		x	x		(Note 3)			
Malacozone		**Ze-1a**	**Ze-1b**	**Ze-2**				
Probable age (stratigraphy, molluscs, pollen)		early Eemian MIS 5e		middle Eemian MIS 5e		Modern 1940		
Ecological Group	**Species**							
1	🟦 *Aegopinella ressmanni*	xx	xx		2			
	🟩 *Clausilia cruciata*		(x)			x		modern shells wrongly identified as C. parvula
	🟦 *Discus perspectivus*			x	5			
	Ena montana	xx	xx		1			
	🟩 *Macrogastra attenuata*	x	x		1	x		modern shells wrongly identified as*M. plicatula*
	🟩 *Macrogastra ventricosa*		(x)	x		x		
	🟩 *Trochulus edentulus*	xx	x		4			
	% group 1				*10.7*			
2	*Vertigo alpestris*			x				
	Vertigo pusilla			x				
	% group 2				*0.0*			
3	🟩 *Acanthinula aculeata*			x				
	🟥 *Acicula lineata*			🟨 x? (Note 4)				
	🟦 *Acicula lineolata*				4			
	🟩 *Aegopinella pura*	(x)	(x)		1	x		modern shells wrongly identified as*A. nitidula*
	Clausilia dubia	(x)	x					
	🟩 *Cochlodina laminata*	(x)	x	x	2	x		
	🟩 *Euomphalia strigella*			x				
	🟩 *Helicodonta obvoluta*		(x)	x	18	x		
	🟩 *Macrogastra plicatula*		(x)	x				
	🟩 *Macrogastra plicatula* densely ribbed form				3			
	🟩 *Monachoides incarnatus*	x	x	x	1	x		
	🟦 *Pagodulina pagodula*			x	1			
	🟦 *Ruthenica filograna*			x	4			
	🟩 *Semilimax semilimax*	xx	xx	x				
	% group 3				*28.1*			
4	🟩 *Aegopinella nitens*					x		modern shells wrongly identified as*A. nitidula*
	🟦 *Aegopinella nitidula*	(x)	x	🟨 x (Note 5)	6			
	Clausilia bidentata			x	5			
	Clausilia rugosa parvula			x				
	🟩 *Discus rotundatus*			x	14	x		
	🟩 *Limax maximus/cinereoniger*		(x)	x				
	🟩 *Milax/Tandonia* sp.	(x)	(x)					
	Trochulus clandestinus/striolatus	x	x					
	Vitrea subrimata	x	x	x		x		
	% group 4				*20.7*			
5	*Pyramidula pusilla*				1			
	% group 5				*0.8*			
6	*Arianta arbustorum*	xx	xx	x	16	x		
	🟩 *Carychium tridentatum*		(x)		4			
	Cochlicopa lubrica	xx	xx	x	3	x		
	Columella edentula	(x)						
	🟩 *Fruticola fruticum*	x	x	x	2			
	Punctum pygmaeum	(x)	x	x	1			
	Trochulus sericeus	x	x		2			
	Vertigo substriata	(x)	(x)					
	Vitrea crystallina	xx	xx	x	4			
	Vitrina pellucida	(x)	(x)					
	% group 6				*26.4*			
7	*Cepaea hortensis*	(x)	(x)	🟨 x (Note 6)	9			
	Euconulus fulvus	x	xx					
	Limax / *Deroceras* sp.	x	xx	x (Note 7)	4			
	Nesovitrea hammonis	(x)						
	Trochulus hispidus		(x)					
	Vitrea contracta			x				
	% group 7				*10.7*			
8	*Cochlicopa lubricella*	(x)	(x)					
	% group 8				*0.0*			
9	*Vallonia costata*				2			
	Vallonia pulchella			x				
	% group 9				*1.7*			
11	*Carychium minimum*			x				
	Cochlicopa nitens	(x)	(x)		1			
	Succinea putris	x	x	x		x		
	Zonitoides nitidus	(x)						
	% group 11				*0.8*			
12	*Euconulus alderi*	(x)	(x)					
	Galba truncatula		(x)					
	Oxyloma elegans	(x)	(x)					
	Succinella oblonga			x		x		
	🟧 *Vertigo genesii*			x				
	% group 12				*0.0*		**Totals for subfossil molluscs**	
Total Terrestrial Molluscs		**Fairly abundant**	**Abundant**		**121**			
Number of Terrestrial Species		**33**	**37**	**33**	**28**	**14**	**59**	
14	*Pisidium casertanum*		1					
	Stagnicola palustris/corvus				1			
15b	*Pisidium amnicum*			x				
	Valvata piscinalis	1						
Number of Aquatic Species		**1**	**1**	**1**	**1**		**4**	
Degree of surface dissolution of the shells **Evidence of alteration**		moderate /f severe	some/moderate /f severe	?	some/moderate			
7	earthworm granules	xx	xx	?	x			
	charcoal	xxx	x	xx	x			
	tooth/bone fragments - small vertebrates	x						

For a description of the ecological groups see Figure 2

Note 1 the Forcart shells lodged with the Naturhistorisches Museum, Basel may have been lost? The modern shells are still available

Note 2 borrowed from the Muséum d'Histoire Naturelle, Genève

Note 3 no residue, but there was still sediment present inside the larger shells

Note 4 the shells may well be *A. lineolata* , like those in the Jayet sample

Note 5 the shells should be checked to ensure that there are no specimens of *Aegopinella ressmanni*

Note 6 the shells were identified as *Cepaea nemoralis* , but they are more likely to be *C. hortensis*

Note 7 Forcart identified *Deroceras laeve* and *D. reticulatum/agreste*

KEY

🟩	Species typical of interglacial warm periods
🟥	Interglacial species that seems to have first appeared during the Eemian
🟦	Interglacial Marker Species last present in Swiss molluscan faunas during the Eemian
🟨	May be an incorrect identification, so needs to be checked
🟧	Pioneer species typical of both colder periods + the start of warmer periods

Table 25 : The Molluscan Faunas from Thungschneit, Thalgut and Ried, BE

Sampled : C. Schlüchter 1971/72
First analysed : M. Wüthrich 1972
Published : Schlüchter 1976
Analysed + reanalysed : Nigel Thew 2015-2022

Site (Note 1)		**Thungschneit-Räbeli, BE** (est. 2611 450/1182 750; 549/560 m asl)													**"Schürliacher", Bümberg, BE** (est. 2611 200/1183 400; c.565 m asl; Note 7)		
Sample		T23	T22	T21	T20	T19	T18	T17	T15	T14	T13	T12	T11		S1	S2	
Sediment description		grey sands with some silt	grey laminated lacustrine sandy-silts with some sandy, silty and clay-silt bands												grey laminated lacustrine sandy-silts		
Sample weight (kg - if known)			0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1		?	?	
Residue available for sorting																	
Malacozone		**?**	**Ts-1**												**SB-1**		
Probable age (OSL, pollen, stratigraphy, molluscs)		Middle Pleistocene / late Riss MIS 6?	Middle Pleistocene? (MIS 11?) or Eemian Interglacial MIS 5e? (Note 2)												same age as Thungschneit silts		
Ecological group	**Species**																
1	*Aegopinella ressmanni*																
	Clausilia cruciata																
	Discus perspectivus																
	Ena montana																
	Macrogastra attenuata																
	Macrogastra ventricosa																
	% group 1																
3	*Aegopinella pura*																
	Cochlodina laminata																
	Helicodonta obvoluta																
	Macrogastra plicatula																
	Monachoides incarnatus																
	Pagodulina pagodula																
	Semilimax semilimax																
	Urticicola umbrosus																
	% group 3																
4	*Aegopinella nitens*																
	Discus rotundatus																
	Discus ruderatus																
	Oxychilus cellarius																
	Trochulus clandestinus																
	% group 4																
6	*Arianta arbustorum*																
	Carychium tridentatum																
	Cochlicopa lubrica																
	Columella columella																
	Fruticola fruticum																
	Punctum pygmaeum																
	Trochulus sericeus																
	Vertigo substriata																
	Vitrea crystallina																
	% group 6																
7	*Cepaea hortensis*																
	Euconulus fulvus																
	Limax /*Deroceras* sp.																
	Nesovitrea hammonis																
	% group 7																
8	*Abida secale*																
	% group 8																
9	*Pupilla muscorum*																
	Vallonia costata																
	Vallonia pulchella																
	Vertigo pygmaea																
	% group 9																
11	*Carychium minimum*																
	Succinea putris																
	Vertigo antivertigo																
	Zonitoides nitidus																
	% group 11																
12	*Euconulus alderi*																
	Galba truncatula																
	Oxyloma elegans																
	Succinella oblonga																
	Vertigo angustior																
	Vertigo geyeri																
	% group 12																
Total Terrestrial Molluscs																	
Number of Terrestrial Species																	
13	*Anisus leucostoma*																
	Pisidium obtusale																
	% group 13																
14	*Armiger crista*																
	Gyraulus laevis																
	Pisidium casertanum																
	Radix labiata																
	Sphaerium corneum																
	Stagnicola palustris/corvus																
	% group 14																
15a	*Bithynia tentaculata* shells																
	Bithynia tentaculata opercula	(Note 3)	1	1		1		5		5	1	1	1		24	58	
	Lymnaea stagnalis																
	Pisidium milium																
	Pisidium nitidum																
	Pisidium subtruncatum																
	Planorbarius corneus																
	Planorbis carinatus																
	Radix balthica																
	Valvata cristata																
	% group 15a																
15b	*Anodonta cygnea*																
	Gyraulus acronicus																
	Gyraulus albus																
	Pisidium amnicum																
	Pisidium henslowanum																
	Pisidium hibernicum																
	Pisidium lilljeborgii																
	Pisidium tenuilineatum																
	Unio sp.	(Note 4)				4											
	Valvata piscinalis					16								**Totals**			**Totals**
	% group 15b																
Total Aquatic Molluscs		**0**	**1**	**1**	**0**	**21**	**0**	**5**	**0**	**5**	**1**	**1**	**1**	**36**	**24**	**58**	**82**
Number of Aquatic Species		**0**	**1**	**1**	**0**	**3**	**0**	**1**	**0**	**1**	**1**	**1**	**1**	**3** (Note 5)	**1**	**1**	**1**
Aquatic Molluscs as a proportion of Total Molluscs (%)																	
Total Molluscs		**0**	**1**	**1**	**0**	**21**	**0**	**5**	**0**	**5**	**1**	**1**	**1**	**36**	**24**	**58**	**82**
7	earthworm granules																
	insect fragments																
	tooth/bone fragments - small mammals															1	
	mineralised wood frags																
	plant material	(Note 6)	3 *Heracleum* seeds				1 *Heracleum* seed										
	Cenoccocum																
13-15	*Chara* oospores	x	x	x		x						xx	xx				
13-15	ostracod valves	x	xx	xxx	x	xxx	xxx	x	xxx	xxx	xxx	xxx	xxx				

Site (Note 1)		**Thalgut, BE** (2608 990/1186 615; 610 m asl)				**Totals for all samples**	**Ried, BE** (2609 680/1184 400; c.582 m asl)		
Sample		Th-3	Th-11	hand-collected shells	bulk sample		R-2 (Note 9)	R-1	
Sediment description		laminated lacustrine seds: darkish-grey silt with organic bands, grey sandy-silt and silty-sand, light creamy-grey sandy-marly-silt + bands of sand with fine gravel					light yellow-olive-grey silt with some fine sand + rare stones to 1 cm; sandier in upper part		
Sample weight (kg - if known)		0.1	0.1		0.7		33.0	5.0	
Residue available for sorting					x (Note 11)		x (Note 11)		
Malacozone		**Th-1**					**Rd-1**	**Rd-2**	
Probable age (OSL, pollen, stratigraphy, molluscs)		early/middle Eemian MIS 5e					MIS 7	MIS 7 / early MIS 6	
Ecological group	**Species**								
1	*Aegopinella ressmanni*				3	**3**	129		
	Clausilia cruciata						28	9	
	Discus perspectivus	1			7	**8**	2		
	Ena montana				1	**1**	1	5	
	Macrogastra attenuata						33	5	
	Macrogastra ventricosa						2		
	% group 1					***12.5***	*7.1*	*4.9*	
3	*Aegopinella pura*						6		
	Cochlodina laminata						1		
	Helicodonta obvoluta				11	**11**			
	Macrogastra plicatula				1	**1**		2	
	Monachoides incarnatus				1	**1**	89	2	
	Pagodulina pagodula				1	**1**			
	Semilimax semilimax						141		
	Urticicola umbrosus						6	1	
	% group 3					***14.6***	*8.8*	*1.3*	
4	*Aegopinella nitens*				1	**1**	10		
	Discus rotundatus	1				**1**	2		
	Discus ruderatus				1	**1**	11		
	Oxychilus cellarius						6		
	Trochulus clandestinus						1		
	% group 4					***3.1***	*1.1*	*0.0*	
6	*Arianta arbustorum*				15	**15**	4	2	
	Carychium tridentatum				1	**1**	4	5	
	Cochlicopa lubrica				1	**1**	241	8	
	Columella columella							4	
	Fruticola fruticum				3	**3**	448	3	
	Punctum pygmaeum		1			**1**	8	1	
	Trochulus sericeus		1		14	**15**		14	
	Vertigo substriata						2		
	Vitrea crystallina				4	**4**	242		
	% group 6					***41.7***	*34.4*	*9.6*	
7	*Cepaea hortensis*				10	**10**	16	3	
	Euconulus fulvus				1	**1**	15		
	Limax /*Deroceras* sp.						17	5	
	Nesovitrea hammonis				1	**1**	97		
	% group 7					***12.5***	*5.3*	*2.1*	
8	*Abida secale*							1	
	% group 8					***0.0***	*0.0*	*0.3*	
9	*Pupilla muscorum*							114	
	Vallonia costata		2		1	**3**	109	138	
	Vallonia pulchella						157	10	
	Vertigo pygmaea							32	
	% group 9					***3.1***	*9.6*	*76.4*	
11	*Carychium minimum*						143	2	
	Succinea putris						408		
	Vertigo antivertigo	2				**2**	32		
	Zonitoides nitidus						221		
	% group 11					***2.1***	*29.1*	*0.5*	
12	*Euconulus alderi*						48		
	Galba truncatula				1	**1**	63	3	
	Oxyloma elegans				8	**8**	12	2	
	Succinella oblonga				1	**1**		9	
	Vertigo angustior						4		
	Vertigo geyeri							5	**Totals**
	% group 12					***10.4***	*4.6*	*4.9*	
Total Terrestrial Molluscs		**4**	**4**	**0**	**88**	**96**	**2759**	**385**	**3144**
Number of Terrestrial Species		**3**	**3**	**0**	**22**	**25**	**37**	**25**	**45**
13	*Anisus leucostoma*						5	10	
	Pisidium obtusale						5		
	% group 13				*0.0*	***0.0***	*50.0*	*76.9*	
14	*Armiger crista*				1	**1**			
	Gyraulus laevis							1	
	Pisidium casertanum	9		4	65	**78**	2	1	
	Radix labiata						3		
	Sphaerium corneum				20	**20**			
	Stagnicola palustris/corvus						5		
	% group 14				*9.9*	***10.5***	*50.0*	*15.4*	
15a	*Bithynia tentaculata* shells	1		5	238	**244**			
	Bithynia tentaculata opercula		2	1	75	**78**			
	Lymnaea stagnalis				56	**56**			
	Pisidium milium				2	**2**			
	Pisidium nitidum	4		2	9	**15**			
	Pisidium subtruncatum	5	3	1	40	**49**		1	
	Planorbarius corneus				2	**2**			
	Planorbis carinatus				2	**2**			
	Radix balthica	1		7	146	**154**			
	Valvata cristata				4	**4**			
	% group 15a				*66.2*	***64.4***	*0.0*	*7.7*	
15b	*Anodonta cygnea*			2	3	**5**			
	Gyraulus acronicus				2	**2**			
	Gyraulus albus				19	**19**			
	Pisidium amnicum		5	4	24	**33**			
	Pisidium henslowanum				1	**1**			
	Pisidium hibernicum				2	**2**			
	Pisidium lilljeborgii			1	8	**9**			
	Pisidium tenuilineatum	2	2		2	**6**			
	Unio sp.								
	Valvata piscinalis	1	4	8	146	**159**			**Totals**
	% group 15b				*23.9*	***25.1***	*0.0*	*0.0*	
Total Aquatic Molluscs		**23**	**16**	**35**	**867**	**941**	**20**	**13**	**33**
Number of Aquatic Species		**7**	**5**	**9**	**21**	**21**	**5**	**4**	**7**
Aquatic Molluscs as a proportion of Total Molluscs (%)		**85.2**	**80.0**	**100.0**	**90.8**	**90.7**	**0.7**	**3.3**	
Total Molluscs		**27**	**20**	**35**	**955**	**1037**	**2779**	**398**	**3177**
7	earthworm granules						xx (Note 10)	xxx	
	insect fragments				x	**x**			
	tooth/bone fragments - small mammals						1		
	mineralised wood frags						xx	x	
	plant material			seeds, tree bark frags (Note 8)	bark frags, *Picea* needles, moss frags	**xx**			
	Cenoccocum				x	**x**			
13-15	*Chara* oospores	x			x	**x**			
13-15	ostracod valves	x	x		31	**xx**			

For a description of the ecological groups see Figure 2

All shell material borrowed from the Naturhistorisches Museum Bern

Note 1 All samples were taken by Christian Schlüchter in 1971/72, except where otherwise stated

Note 2 Pollen analyses by Welten (1982, diag. 9) suggest these silts may be late Riss + Eemian, although they lie at a similar altitude to much earlier (MIS 11?) lake deposits documented at Jaberg and Thalgut

Note 3 All *B. tentaculata* operculae have been lost apart from the 5 from sample T17

Note 4 The *Unio* sp. were identified by Max Wüthrich and recorded by Schlüchter, but have since been lost

Note 5 Schlüchter mentions other molluscs found in these silts by earlier researchers, including Lymnaeidae + Planorbidae

Note 6 Schlücter mentions seeds from *Betula, Heracleum* and *Potamogeton* + remains from *Abies*, *Acer* and *Alnus*

Note 7 These samples seem to come from the same body of silty-sands as at Thungschneit, but were sampled c.10 years after Thungschneit within the Bümberg gravel pit, c.650+ m to the north

Note 8 Schlüchter mentions remains from *Abies*, *Betula*, *Corylus*, *Picea*, *Pinus*, *Quercus* + *Salix*

Note 9 This sample was first processed in 2022 by Daniel Kälin, so the shells have never previously been analysed

Note 10 All the granules are small (<1 mm)

Note 11 Sample from Thalgut processed by NT in 2019, sample from Ried processed by D. Kälin in 2021

🟩	Species typical of interglacial warm periods
🟩	Species typical of interglacial warm periods that can also be found in mild interstadials early in a cold period
🟪	Pioneer species typical of colder periods
🟧	Pioneer species typical of both colder periods + the start of warmer periods
🟦	Interglacial Marker Species last present in Swiss molluscan faunas during the Eemian
🟨	Biostratigraphical Marker Species that disappears from Swiss molluscan faunas after the Middle Pleistocene

Table 25 : The Molluscan Faunas from Spiezberg, BE

Sampled : 2005
Analysis : N. Thew 2023

Site		**Spiezberg, BE - drill core RB 1-05 : 20 m terrace of the Thunersee** (2617 757/1171 488; c.592 m asl; mean level of the Thunersee today = 558 m asl)																												
Sample depth in core (cm) * see Note 1		**1600-1580**	**1580-1560**	**1560-1540***	**1540-1520**	**1520-1500**	**1500-1480**	**1480-1460**	**1460-1440**	**1440-1420***	**1420-1400**	**1400-1385**	**1385-1360**	**1360-1340**	**1340-1320**	**1320-1300**	**1300-1280**	**1280-1260**	**1260-1240**	**1240-1220**	**1220-1200**	**1200-1180**	**1180-1160**	**1160-1140**	**1140-1120**	**1120-1100**	**1100-1080**	**1080-1060**	**1060-1030**	
Sediment description		grey sandy-silt with some fine gravel		grey laminated marly-silt										grey-brown rather organic fairly marly silt					grey-brown very organic marly silt	brownish-grey organic marly-silt		brownish-grey moderately organic fairly marly silt; more sandy above 1155 cm			grey fairly marly sandy-silt; some fine gravel above 1053 cm bedding is inclined at 40° above 1150 cm					
Sample size (kg)		1.882	1.971	2.394	1.845	1.780	1.848	2.252	1.486	1.570	1.798	1.945	2.028	1.945	1.307	1.823	2.006	2.015	2.669	1.788	1.608	1.933	1.610	2.310	2.606	1.527	3.070	2.952	2.497	
Malacozone		**Spb-1a**		**Spb-1b**	**Spb-2**		**Spb-3a**			**Spb-3b**	**Spb-3c**	**Spb-3d**		**Spb-3e**	**Spb-4**			**Spb-5a**	**Spb-5b**	**Spb-6**		**Spb-7**			**Spb-8**					
Estimated water depth (Note 2)		**5**		**4**	**2**		**3**					**4**		**3**	**2**			**3**	**4**	**2**		**1**			**0**					
Probable Age (pollen, molluscs, stratigraphy)		early Eemian		early/middle Eemian																					middle Eemian					
Ecological Groups	**Species**																													
1	🟩 *Cochlodina fimbriata*																									6				
	🟩 *Macrogastra attenuata*																								1					
	% group 1	0.0	0.0	0.0	0.0			0.0	0.0	0.0	0.0	0.0	0.0				0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.3	50.0	0.0	0.0	0.0	
3	*Clausilia dubia*											1																		
	▨ *Cochlodina laminata*			2																										
	▨ *Euomphalia strigella*	1	1							1																1				
	▨ *Helicodonta obvoluta*		1							1		9					1			6			1	1		1	4	2	3	
	▨ *Monachoides incarnatus*																										1			
	% group 3	16.7	18.2	18.2	0.0			0.0	0.0	22.2	0.0	38.5	0.0				100.0	0.0	0.0	75.0	0.0	0.0	3.0	3.3	0.0	16.7	13.9	11.8	7.1	
4	▨ *Aegopinella nitens*																										1			
	Clausilia bidentata								1																					
	▨ *Discus rotundatus*									1															1		6			
	🟧 *Discus ruderatus*		1					1																						
	🟩 *Milax/Tandonia* sp.																										1			
	Trochulus clandestinus																												1	
	% group 4	0.0	9.1	0.0	0.0			25.0	50.0	11.1	0.0	0.0	0.0				0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.3	0.0	22.2	0.0	2.4	
6	*Arianta arbustorum*	1	1	3						1		1	1					1											1	
	▨ *Carychium tridentatum*	1																												
	Cochlicopa lubrica								1												1	15	5	5	2		1	7	1	
	▨ *Fruticicola fruticum*												2						1			6	18	10	1	2	3		1	
	Trochulus sericeus		1									2						1		1		2							4	
	% group 6	33.3	18.2	27.3	0.0			0.0	50.0	11.1	0.0	11.5	33.3				0.0	66.7	6.3	12.5	8.3	65.7	69.7	50.0	25.0	16.7	11.1	41.2	16.7	
7	*Cepaea hortensis*	2	2	3	1			1		2	1	5						1	4			1	2	3	2		6		23	
	Euconululus fulvus																					2						1		
	Limax/Deroceras sp.																						1		4		3	1		
	Nesovitrea hammonis		1	1				1				2										1	2	11		2	9	5	7	
	% group 7	33.3	27.3	36.4	100.0			50.0	0.0	22.2	100.0	26.9	0.0				0.0	33.3	25.0	0.0	0.0	11.4	15.2	46.7	50.0	16.7	50.0	41.2	71.4	
9	*Vallonia costata*																											1		
	Vallonia pulchella																								1		1			
	% group 9	0.0	0.0	0.0	0.0			0.0	0.0	0.0	0.0	0.0	0.0				0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.3	0.0	2.8	5.9	0.0	
11	*Succinea putris*			1								3	3						2		1		4						1	
	Zonitoides nitidus											1	1								2									
	% group 11	0.0	0.0	9.1	0.0			0.0	0.0	0.0	0.0	15.4	44.4				0.0	0.0	12.5	0.0	25.0	0.0	12.1	0.0	0.0	0.0	0.0	0.0	2.4	
12	*Galba truncatula*	1	1							1		1							1		2									
	Oxyloma elegans		2	1				1		2		1	2						8	1	6	8								
	% group 12	16.7	27.3	9.1	0.0			25.0	0.0	33.3	0.0	7.7	22.2				0.0	0.0	56.3	12.5	66.7	22.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**Totals**
Total Terrestrial Molluscs		**6**	**11**	**11**	**1**	**0**	**0**	**4**	**2**	**9**	**1**	**26**	**9**	**0**	**0**	**0**	**1**	**3**	**16**	**8**	**12**	**35**	**33**	**30**	**12**	**12**	**36**	**17**	**42**	**337**
Number of Terrestrial Species		**5**	**9**	**6**	**1**	**0**	**0**	**4**	**2**	**7**	**1**	**10**	**5**	**0**	**0**	**0**	**1**	**3**	**5**	**3**	**5**	**7**	**7**	**5**	**7**	**5**	**11**	**6**	**9**	**28**
13	*Anisus leucostoma*		1				1														1									
	Aplexa hypnorum	1																												
	% group 13	0.3	0.1	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.3									
14	*Pisidium casertanum*	27	**83**	33	1	2	20	18	5	9	9	34	24	6			2	2	39	3										
	Planorbis planorbis		1										1					3	17	1										
	Radix labiata	46	203	74	7	2	20	24	11	16	31	106	94	15	2	1		14	279	2	8									
	Sphaerium corneum	14	133	51	1	1	5	8	3	10		18	14						5											
	Stagnicola palustris/corvus		1										3	5				3	11	3										
	% group 14	22.8	25.0	24.6	22.0	8.5	24.3	31.3	15.1	16.7	20.3	20.1	16.2	17.3	100.0	9.1	66.7	17.5	19.9	75.0	50.0									
15a	*Bithynia tentaculata* shells	89	553	298	10	16	39	42	31	72	89	347	286	57		2	1	65	482	1	7									
	Bithynia tentaculata opercula	61	341	56	2	6	4	7	8	10	11	50	35	7	1			12	56											**667**
	Hippeutis complanatus									1																				
	Pisidium milium		1			1							1																	
	Pisidium nitidum	7	**31**	3	1	3	2			3		6	6					2	25											
	Pisidium subtruncatum	16	17	11	1	4	7	11	5	7	3	6	8	2		1			17											
	Radix balthica	19	25	12	1		10	7	6	12	8	33	25	4				7	287	2										
	% group 15a	34.3	37.3	50.4	31.7	40.7	31.4	37.5	33.3	45.5	50.8	49.9	38.7	42.0	0.0	27.3	33.3	58.7	46.0	25.0	43.8									
15b	*Pisidium amnicum*	5	17	15	1	9	5	5	6	5	2	13	5																	
	▨ *Pisidium henslowanum*	14	42	4			4	1	1			5	5																	
	Pisidium hibernicum			2								2	1						3											
	Pisidium lilljeborgii	2	15	4								1	1					1	13											
	▨ *Pisidium moitessierianum*			1																										
	Valvata piscinalis var. *piscinalis*	142	559	135	18	21	72	44	58	74	55	214	368	61		7		29	585											
	% group 15b	42.7	37.6	25.0	46.3	50.8	43.8	31.3	51.6	37.8	28.9	29.9	45.1	40.7	0.0	63.6	0.0	23.8	34.1	0.0	0.0									
Total Aquatic Molluscs (excluding *Bithynia tentaculata* opercula)		**382**	**1682**	**643**	**41**	**59**	**185**	**160**	**126**	**209**	**197**	**785**	**842**	**150**	**2**	**11**	**3**	**126**	**1763**	**12**	**16**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**7394**
Number of Aquatic Species		**12**	**15**	**13**	**9**	**9**	**11**	**9**	**9**	**10**	**7**	**12**	**15**	**7**	**2**	**4**	**2**	**9**	**12**	**6**	**3**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**19**
***Bithynia tentaculata* shells / opercula**		**1.5**	**1.6**	**5.3**	**5.0**	**2.7**	**9.8**	**6.0**	**3.9**	**7.2**	**8.1**	**6.9**	**8.2**	**8.1**	**0.0**	**>>**	**>>**	**5.4**	**8.6**	**>>**	**>>**									
***Bithynia tentaculata* opercula / Total Aquatic Molluscs** (%)		**16.0**	**20.3**	**8.7**	**4.9**	**10.2**	**2.2**	**4.4**	**6.3**	**4.8**	**5.6**	**6.4**	**4.2**	**4.7**	**50.0**	**0.0**	**0.0**	**9.5**	**3.2**	**0.0**	**0.0**									
Total aquatic gastropods / Total bivalves		**3.5**	**4.0**	**4.2**	**7.2**	**2.0**	**3.3**	**2.7**	**5.3**	**5.1**	**13.1**	**8.2**	**12.0**	**17.8**	**>>**	**10.0**	**0.5**	**24.2**	**16.3**	**3.0**	**>>**									
Aquatic Molluscs as a proportion of Total Molluscs (%)		**98.5**	**99.4**	**98.3**	**97.6**	**100.0**	**100.0**	**97.6**	**98.4**	**95.9**	**99.5**	**96.8**	**98.9**	**100.0**	**100.0**	**100.0**	**75.0**	**97.7**	**99.1**	**60.0**	**57.1**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	
Total Molluscs		**388**	**1693**	**654**	**42**	**59**	**185**	**164**	**128**	**218**	**198**	**811**	**851**	**150**	**2**	**11**	**4**	**129**	**1779**	**20**	**28**	**35**	**33**	**30**	**12**	**12**	**36**	**17**	**42**	**7731**
Total molluscs per kilo of sediment		**206**	**859**	**273**	**23**	**33**	**100**	**73**	**86**	**139**	**110**	**417**	**420**	**77**	**2**	**6**	**2**	**64**	**667**	**11**	**17**	**18**	**20**	**13**	**5**	**8**	**12**	**6**	**17**	
Degree of shell fragmentation		rather fragmented		strongly fragmented											very strongly fragmented						strongly fragmented									
Shell discoloration Fe = orangey red iron staining by oxidation Bl = bluish-grey iron staining by reduction		Fe = some Bl = some		Fe = mod Bl = mod	Fe = strong Bl = some	Fe = strong		Fe = some Bl = some	Fe = strong Bl = some	Fe = some Bl = mod	Bl = mod	Bl = strong	Fe = strong Bl = some	Fe = some Bl = some				Fe = strong	Fe = some Bl = some	Fe = some	Fe = mod	Fe = strong								
grey-brown frags. of redeposited Tertiary molluscs													1									2		2	1				5	
7	earthworm granules																	1				1	2	10	5	1	5	14		
	larger mammal bone frags		6	1																										
	small mammal bone frags												1																	
	insect frags	x		x	x			x		x	x	x	x		x						x									
	wood fragments	xx	xx	x	x	xx	xx	xx	xxx	xxx	xx		xx	x				x	xx	xx	xx	xx	xx	xx						
	tree resin		1																											
	needles		(x)	x	x	x	x	xx	x	xx	xx	xxx	xxx	x	x	x	x	x	xx	xx	x									
	plant remains/seeds		x *Betula* *Rubus* *Carex*				x			x	x	xx *Rubus*	xx *Rubus*					x *Potamogeton*	xx *Carex*, *Zanichiella palustris*	xx *Carex*	x	xx *Carex*	x							
	Cenoccocum											1																		
	moss fragments	x	x				x	x				x	x											x						
	charcoal fragments																													
15	fish remains		1 bone				1 tooth						3 scales																	
15	fish otoliths		3					1					4																	
13-15	*Chara*																		67											
13-15	ostracod valves	9	**23**	6	1	1	5	4	1	**8**	**8**	8	15	4					5											**98**
	grey Calcareous concretions	x	x	xx	xx	xx	x	x	x	x	xx	xx	x	xx	xx	x	xx	xx	x											
	Fe concretions	x		xx		xx	x	x	x	x	xx		x	xx	xx	x	xx	xx		xx	xx	xxx	x	x						
	Alpine clasts	xxx	xxxx	xxx			x		x	x		x				x	xx			x	xx				xx	x			x	

For a description of the ecological groups see Figure 2

23 bivalves or ostracod valves include articulated pairs

Note 1 14C on a branch at 14.3 m > 58,000 BP; too low to measure
14C on a branch at 15.6 m 46400 +4500/-2900 BP

Note 2 **water depth estimations** 0 = above high water-level, 1 = high water-level, 2 = mean high lake-level,
3 = above mean lake-level, 4 = mean lake-level, 5 = below mean lake-level

KEY

🟩	Species typical of interglacial warm periods
▨	Species typical of interglacial warm periods that can also be found in mild interstadials early on in a cold period
🟧	Pioneer species typical of both colder periods + the start of warmer periods

Table 27 : The Molluscan Faunas from Flurlingen, ZH

Analysed : Nigel Thew 2018

Site		**Flurlingen, ZH** (est. 2689 910/1282 080; c.460 m asl)			
Sediment description		yellowish-grey/creamy-grey fairly sandy silty-tufa; heavily cemented			
First analysed by		Wehrli 1894; not checked (Note 1)	Gutzwiller 1894 then Forcart 1943, 1963 reanalysed by Thew (Note 2)	Penck 1902; not checked (Note 3)	
Malacozone		**Fl-1**			
Probable age (stratigraphy, molluscs, pollen, U-Th dating)		mid to late Eemian MIS 5e			
Ecological Group	**Species**				
1	*Aegopinella ressmanni*		2		
	Daudebardia brevipes		1		
	Discus perspectivus		2		
	Macrogastra ventricosa		1		
3	*Euomphalia strigella*		1		
	Helicodonta obvoluta		3	x	
	Laciniaria biplicata	2			
	Monachoides incarnatus	2			
4	*Aegopinella nitens*		2		
	Discus rotundatus		4		
	Oxychilus cellarius	1	1	x	
	Trochulus caelatus		1		
6	*Arianta arbustorum*		3	x	
	Fruticola fruticum	6	3	x	
	Trochulus sericeus			x	
7	*Cepaea hortensis*		1		
12	*Oxyloma elegans*	1	1		**Totals**
	Succinella oblonga	1			
Total Terrestrial Molluscs		**13**	**26**	**5+**	**39**
Number of Terrestrial Species		**6**	**14**	**5**	**18**
14	*Radix labiata*		1		
	Stagnicola palustris/corvus	1	3		
15a	*Lymnaea stagnalis*			x	probably *Stagnicola palustris/corvus*
Total Aquatic Molluscs		**1**	**4**	**1+**	**5**
Number of Aquatic Species		**1**	**2**	**1**	**2 or 3**
Total Molluscs		**14**	**30**	**6+**	**50+**
7	worm granules	xx	xx	xx	

For a description of the ecological groups see Figure 2

KEY

🟩	Species typical of interglacial warm periods
🟪	Interglacial species that seems to have first appeared during the Eemian
🟦	Interglacial Marker Species last present in Swiss molluscan faunas during the Eemian
🟥	Species considerably outside of its present distribution area
🟨	Identification is unlikely/would need to be checked

Note 1 the Wehrli material was destroyed during WWII when Schaffhausen was accidentally bombed by the American airforce

Note 2 borrowed from the Naturhistorisches Museum, Basel

Note 3 the whereabouts of the Penck material is unknown

Table 28 : The Molluscan Fauna from Bürgerspital, Basel, BS

Analysis : Nigel Thew 2018

Site (Note 1)		**Bürgerspital, Basel** (est. 2610 810/1268 145; c.255 m asl)	
Sample location		**base of the Niederterrasse** Spitalstrasse, Basel	
Sediment description		finely bedded grey/olive-grey silty-sand and sandy-silt with a little fine gravel + plant remains	
Residue available for sorting by NT		x	
Malacozone		**Bs-1**	
Probable Age (stratigraphic position, molluscs)		early to mid Eemian MIS 5e	
Ecological Groups	**Species**		
1	🟦 *Aegopinella ressmanni*	4	
	🟩 *Cochlodina fimbriata*	11	
	Ena montana	63	
	🟩 *Isognomostoma isognomostomos*	1	
	🟩 *Macrogastra ventricosa*	4	
	🟩 *Trochulus edentulus*	5	
	% group 1	*1.3*	
2	*Vertigo alpestris*	5	
	Vertigo pusilla	26	
	% group 2	*0.5*	
3	🟩 *Acanthinula aculeata*	41	
	🟥 *Acicula lineata*	94	
	🟩 *Aegopinella pura*	41	
	Clausilia dubia	18	
	🟩 *Cochlodina laminata*	19	
	🟩 *Euomphalia strigella*	3	
	🟩 *Helicodonta obvoluta*	10	
	🟩 *Macrogastra plicatula*	16	
	Merdigera obscura	17	
	Nesovitrea petronella	7	
	Orcula dolium	205	
	🟩 *Platyla polita*	15	
	% group 3	*7.2*	
4	🟩 *Aegopinella nitens*	187	
	Clausilia rugosa parvula	42	
	🟩 *Discus rotundatus*	524	1 coiling to the left
	Discus ruderatus	16	
	Eucobresia diaphana	6	
	Neostyriaca corynodes	39	
	🟩 *Oxychilus cellarius*	53	
	Trochulus montanus	27	
	Trochulus villosus	102	
	% group 4	*14.7*	
6	*Arianta arbustorum*	105	
	🟩 *Carychium tridentatum*	435	
	Cochlicopa lubrica	624	
	Columella edentula	40	
	🟩 *Fruticicola fruticum*	2	
	Punctum pygmaeum	66	
	Trochulus sericeus	367	
	Vertigo substriata	3	
	Vitrea crystallina	781	
	% group 6	*35.7*	
7	*Cepaea hortensis*	7	
	Euconulus fulvus	24	
	Limax/Deroceras sp.	1	
	Nesovitrea hammonis	201	
	% group 7	*3.4*	
8	*Cochlicopa lubricella*	71	
	% group 8	*1.0*	
9	*Pupilla muscorum*	9	
	Vallonia costata	1240	
	Vallonia pulchella	219	
	Vertigo pygmaea	14	
	% group 9	*21.8*	
10	*Chondrula tridens*	22	
	Granaria frumentum	5	
	% group 10	*0.4*	
11	*Carychium minimum*	175	
	Succinea putris	7	
	🟩 *Vallonia enniensis*	1	
	Vertigo antivertigo	13	
	Zonitoides nitidus	298	
	% group 11	*7.3*	
12	*Euconulus alderi*	95	
	Galba truncatula	258	
	Oxyloma elegans	64	
	Succinella oblonga	25	
	Vertigo angustior	11	
	% group 12	*6.7*	
Total Terrestrial Molluscs		**6784**	
Number of Terrestrial Species		**59**	
13	*Anisus leucostoma*	13	
	Aplexa hypnorum	1	
	Pisidium obtusale	8	
	% group 13	*3.9*	
14	*Pisidium casertanum*	13	
	Pisidium personatum	1	
	Planorbis planorbis	2	
	% group 14	*2.8*	
15a	*Bathyomphalus contortus*	3	
	Bithynia tentaculata shells	28	
	Hippeutis complanatus	6	
	Pisidium subtruncatum	6	
	🟩 *Planorbis carinatus*	41	
	Radix balthica	281	
	Valvata cristata	2	
	% group 15a	*64.7*	
15b	*Ancylus fluviatilis*	2	
	Gyraulus acronicus	2	
	Gyraulus albus	5	
	🟩 *Radix auricularia*	11	
	Valvata piscinalis	19	
	% group 15b	*6.9*	
15c	*Bythiospeum rhenanum rhenanum*	122	
	Bythinella cf. *bavarica*	1	
	% group 15c	*21.7*	
Total Aquatic Molluscs		**567**	
Number of Aquatic Species		**20**	
Aquatic Molluscs as a proportion of Total Molluscs (%)		**7.7**	
Total Molluscs		**7351**	
Degree of surface dissolution of the shells		some/ moderate/ f. severe	
7	earthworm granules	x	
	white balls (mollusc eggs?)	3	
	wood fragments	x	
	charcoal fragments	xx	
13-15	*Chara* oospores	1	
13-15	ostracod valves	1 (articulated)	

For a description of the ecological groups see Figure 2

Note 1 Borrowed from the Naturhistorisches Museum, Basel. First analysed by F. Waltersdorf assist by L. Forcart (Woltersdorf 1954). Reanalysed by NT in 2018, including numerous previously unidentified shells and fragments that represent around two-thirds of the total fauna.

KEY

🟩	Species typical of interglacial warm periods
🟥	Interglacial species that seems to have first appeared during the Eemian
🟦	Interglacial Marker Species last present in Swiss molluscan faunas during the Eemian

Table 29 : The Molluscan Fauna from Bad Zurzach, AG

Analysis : Nigel Thew 1996

Site		**Bad Zurzach, AG** (2664 350/1270 960; 341 m asl)		
Sample depth in core (m)		**24.60-24.35**	**24.30-24.00**	
Sediment description		dark grey silts + fine sands with a little fine gravel		
Malacozone		**BZ-1**		
Probable Age (stratigraphic position, molluscs, 14C dating)		early to mid Eemian MIS 5e		
Ecological Groups	**Species**			
3	*Clausilia dubia*		3	
	🟩 *Cochlodina laminata*	2		
	🟩 *Helicodonta obvoluta*		1	
	🟩 *Macrogastra plicatula*	1	2	
	% group 3	*25.0*	*28.6*	
4	🟩 *Aegopinella nitens*	2	4	
	🟩 *Discus rotundatus*	1	2	
	% group 4	*25.0*	*28.6*	
6	*Arianta arbustorum*	1		
	🟩 *Carychium tridentatum*		1	
	Cochlicopa lubrica		2	
	🟩 *Fruticicola fruticum*	1	1	
	Trochulus sericeus		1	
	Vitrea crystallina	2	2	
	% group 6	*33.3*	*33.3*	
7	*Cepaea hortensis*		1	
	Nesovitrea hammonis	1		
	% group 7	*8.3*	*4.8*	
12	*Galba truncatula*	1		
	Succinella oblonga		1	**Totals**
	% group 12	*8.3*	*4.8*	
Total Terrestrial Molluscs		**12**	**21**	**33**
Number of Terrestrial Species		**9**	**12**	**16**
Degree of surface dissolution of the shells		some/ moderate	some/ moderate	

For a description of the ecological groups see Figure 2

KEY

🟩 Species typical of interglacial warm periods

Table 30 : The Molluscan Faunas from the Wolfbach Valley, near Hottingen, ZH

Sampled : D. Kälin 2021
Analysis : Nigel Thew 2021

Site		**Wolfbach Valley, Hottingen, ZH** D. Kälin 2021 (2685 250/1247 810; 531 m asl)		
Sample		lower part of the sampled deposit	upper part of the sampled deposit	
Sediment description		beige silt with some sand, little fine gravel to 1 cm + wood fragments	grey silt with sand, some fine gravel to 1 cm + wood fragments, plus thin bands of lignite	
Residue available for sorting by NT		x	x	
Malacozone		**Wb-1**	**Wb-2**	
Probable Age (stratigraphic position, molluscs)		early to mid Eemian MIS 5e (Note 1)		
Ecological Groups	**Species**			
1	🟦 *Aegopinella ressmanni*	1	2	
	🟦 *Discus perspectivus*	4	5	
	🟩 *Isognomostoma isognomostomos*	1		
	🟩 *Macrogastra attenuata*		6	
	% group 1	*21.4*	*9.1*	
3	🟩 *Helicodonta obvoluta*		4	
	🟩 *Monachoides incarnatus*		4	
	🟩 *Semilimax semilimax*	2	1	
	% group 3	*7.1*	*6.3*	
4	🟩 *Discus rotundatus*	1	7	
	🟩 *Oxychilus cellarius*		6	
	Trochulus clandestinus	1	8	
	Trochulus villosus		2	
	% group 4	*7.1*	*16.1*	
6	*Arianta arbustorum*	4	28	
	Cochlicopa lubrica	1	5	
	🟩 *Fruticicola fruticum*	1	5	
	Trochulus sericeus	6	19	
	Vitrea crystallina		2	
	% group 6	*42.9*	*41.3*	
7	*Cepaea hortensis*	3	17	
	Nesovitrea hammonis		3	
	% group 7	*10.7*	*14.0*	
8	*Cochlicopa lubricella*		1	
	% groupe 8	*0.0*	*0.7*	
9	*Pupilla muscorum*		3	
	Vallonia pulchella		1	
	% group 9	*0.0*	*2.8*	
11	*Succinea putris*		2	
	Zonitoides nitidus	2	5	
	% group 11	*7.1*	*4.9*	
12	*Euconulus alderi*		1	
	Galba truncatula	1	2	
	Succinella oblonga		4	**Totals**
	% group 12	*3.6*	*4.9*	
Total Terrestrial Molluscs		**28**	**143**	**171**
Number of Terrestrial Species		**12**	**25**	**26**
13	*Anisus leucostoma*		1	
	% group 13	*0.0*	*8.3*	
14	*Pisidium casertanum*	1	9	
	Radix labiata		2	
	% group 14	*100.0*	*91.7*	
Total Aquatic Molluscs		**1**	**12**	**13**
Number of Aquatic Species		**1**	**3**	**3**
Aquatic Molluscs as a proportion of Total Molluscs (%)		**3.4**	**7.7**	
Total Molluscs		**29**	**155**	**184**
Degree of surface dissolution of the shells		some/ moderate	some/ moderate	
Redeposited shells from the upper part of the OSM (brown/light brown/pale brownish-grey; some recrystalisation)		xx	xx	
Redposited shells from a lower part of the OSM (black, dark grey, sometimes white; notable recrystalisation)		x	x	
7	earthworm granules	(x)	(x)	
bone fragments - larger mammals			x	
bone/tooth fragments - small mammals			1	
wood fragments		xxx	xx	
charcoal fragments		x	x	
needles		xx *Picea* sp.	x *Picea* sp.	
unburnt seeds			x *Rubus* sp. *Ranunculus* sect. *Batrachium*	
burnt seeds			2	
Cenococcum		x		

For a description of the ecological groups see Figure 2

Note 1 A ^{14}C date on a piece of wood gave a value of >45,000 BP

KEY

🟩 Species typical of interglacial warm periods

🟦 Interglacial Marker Species last present in Swiss molluscan faunas during the Eemian

Table 31 : The Molluscan Faunas from Port Valais, VS

Sampled : M. Burri 1961, + L. Chaix early 1980'
Preanalyis : M. Burri + L. Chaix
Reanalysed : Nigel Thew 2023

Site (Note 1)		**Port Valais, VS - 20 m terrace of Lac Léman** Burri 1961: 2556 080/1135 780; 389 m asl Chaix early 1980's: sampled nearby					
Sampled by		Burri 1961	Chaix early 1980's				
Sample level		sables fins + limons argileux	Level 1, Sample 7 'craies'	Level 2, Sample 5	Level 3a, Sample 3 'base limons'	Level 3b, Sample 1 'craie supérieur'	
Sediment description		diffusely bedded fine sands + silts with some clay	light grey silty-marl with some sand; some staining by Fe	light brownish-grey fairly organic marly-silt with some sand	lightish grey marly-silt with some sand; stained reddish by Fe	light grey silty-marl with some sand; stained reddish by Fe	
Malacozones		**PV-1**	**PV-2**	**PV-3**	**PV-4**	**PV-5**	
Probable age (regional stratigraphy, molluscs)		late? Eemian / late? MIS 5e					
Ecological Group	**Species**						
2	*Vertigo pusilla*				1		
	% group 2		*0.0*	*0.0*	*0.5*	*0.0*	
3	🟩 *Acicula lineata*		1		2		
	▨ *Aegopinella pura*			2	2		
	Merdigera obscura				1		
	🟩 *Oxychilus glaber*				1		
	% group 3		*100.0*	*28.6*	*3.2*	*0.0*	
4	▨ *Aegopinella nitens*				2		
	Clausilia rugosa parvula				1		
	🟩 *Cochlostoma septemspirale*				1		
	▨ *Discus rotundatus*				1		
	🟩 *Milax/Tandonia* sp.				1		
	% group 4		*0.0*	*0.0*	*3.2*	*0.0*	
6	*Arianta arbustorum*				1		
	▨ *Carychium tridentatum*				2		
	Cochlicopa lubrica				6		
	▨ *Fruticola fruticum*				6		
	Punctum pygmaeum				1		
	Trochulus sericeus				8		
	% group 6		*0.0*	*0.0*	*13.0*	*0.0*	
7	*Limax / Deroceras* sp.				3		
	Nesovitrea hammonis				6		
	Trochulus hispidus					1	
	Vitrea contracta			1			
	% group 7		*0.0*	*14.3*	*4.9*	*100.0*	
8	*Cochlicopa lubricella*				1		
	% group 8		*0.0*	*0.0*	*0.5*	*0.0*	
9	*Pupilla muscorum*				9		
	Vallonia costata			2	90		
	Vallonia excentrica				1		
	Vallonia pulchella			1	27		
	Vertigo pygmaea				1		
	% group 9		*0.0*	*42.9*	*69.2*	*0.0*	
10	*Granaria frumentum*				1		
	Truncatinella cylindrica				2		
	% group 10		*0.0*	*0.0*	*1.3*	*0.0*	
12	*Galba truncatula*				1		
	Oxyloma elegans			1			
	Succinella oblonga				6		
	% group 12		*0.0*	*14.3*	*3.8*	*0.0*	
Total Terrestrial Molluscs		**0**	**1**	**7**	**185**	**1**	**194**
Number of Terrestrial Species		**0**	**1**	**5**	**28**	**1**	**31**
13	*Anisus leucostoma*			1			
	% group 13	*0.0*	*0.0*	*0.5*	*0.0*	*0.0*	
14	*Pisidium casertanum*		1	1	1		
	% group 14	*0.0*	*0.2*	*0.5*	*0.4*	*0.0*	
15a	*Bathyomphalus contortus*		1				
	Bithynia tentaculata shells	40	141	64	81	138	
	Bithynia tentaculata opercula		185	114	259	462	**1020**
	Pisidium sp. (Note 2)	6					
	Pisidium milium			2	3		
	Pisidium nitidum		1	14	43	1	
	Pisidium subtruncatum			5	3		
	Planorbis carinatus	1	22	7	8	8	
	Radix balthica		2				
	Valvata cristata		381	49	46	42	
	% group 15a	*31.8*	*88.8*	*72.3*	*81.8*	*93.6*	
15b	*Gyraulus albus*		2	4		1	
	Lymnaea stagnalis		3	4	4		
	Pisidium hibernicum				1		
	▨ *Pisidium tenuilineatum*			1	1		
	▨ *Radix auricularia*			1			
	Valvata piscinalis var. *piscinalis*	97	63	42	34	12	
	Valvata piscinalis var. *antiqua*	4					
	% group 15b	*68.2*	*11.0*	*26.7*	*17.8*	*6.4*	
Total Aquatic Molluscs (not including *Bithynia tentaculata* opercula)		**148**	**617**	**195**	**225**	**202**	**1387**
Number of Aquatic Species		**>4**	**10**	**13**	**11**	**6**	**16**
***Bithynia tentaculata* shells / opercula**			**0.8**	**0.6**	**0.3**	**0.3**	
Aquatic Molluscs as a proportion of Total Molluscs (%)		**100.0**	**99.8**	**96.5**	**54.9**	**99.5**	
Total Molluscs		**148**	**618**	**202**	**410**	**203**	**1581**
Degree of surface dissolution of the shells			moderate	moderate	some/ moderate /f. severe	moderate /f. severe	
16	*Cecilioides acicula*				2	3	
7	earthworm granules				x		
	insect fragments			x			
13-15	ostracod valves		x				
13-15	*Chara* oospores		xxx			xx	

For a description of the ecological groups see Figure 2

Note 1 borrowed from the Muséum d'Histoire Naturelle, Genève

Note 2 the *Pisidium* were given species names by Burri, but given the difficulty of separating species in this genus, these are highly unlikely to be correct

KEY

🟩	Species typical of interglacial warm periods
▨	Species typical of interglacial warm periods that can also be found in mild interstadials early in a cold period

Table 32 : The Molluscan Faunas from Muntschemier-Gugglerracher, BE and Boudry/Champ le Sage West, NE

Sampled: 1996 and 1998
Analysis: Nigel Thew 2021 and 1998

Site		**Muntschemier-Gugglerracher, BE** gravel quarry 1996 2576 340/1205 310; surface 460 m asl	**Boudry-Champ le Sage West, NE** A5 motorway trench 1998 2555 630/1200 650; surface 439 m asl (note 2)
Location		channel cut into Lower Seeland Schotter + covered by Upper Seeland Schotter (note 1)	lacustrine silts with sand beneath the delta gravels
Sample altitude		c.450.0 m asl	c.431 m asl
Sample		MG 1	M IS
Sample weight (kg)		0.8	3.5
Sediment		beige bedded fine sands with some silt, some m-c sand + little fine gravel (to 1.3 cm)	bluish-grey grey laminated silts with some sand and a few small pebbles
Malacozone		**MG-1**	**CSW-1**
Probable age (stratigraphy, molluscs)		MIS 5d-5a possibly MIS 5c	MIS 5d-5a possibly MIS 5a
Estimated mean water depth/ mean level Lake Neuchâtel		0 (seasonal flow) c.449/450 m asl (note 3)	c.2-3 m c. 433/434 m asl
Ecological group	**Species**		
4	*Clausilia rugosa parvula*	1	
	Trochulus villosus	1	
	% group 4	*2.2*	*0.0*
6	*Arianta arbustorum*	15	
	Fruticicola fruticum	2	
	Trochulus sericeus	10	
	% group 6	*30.0*	*0.0*
7	*Cepaea hortensis*	4	
	Nesovitrea hammonis	1	
	% group 7	*5.6*	*0.0*
11	*Succinea putris*	42	
	Zonitoides nitidus	4	
	% group 11	*51.1*	*0.0*
12	*Oxyloma elegans*	6	3
	Succinella oblonga	4	1
	% group 12	*11.1*	*100.0*
Total Terrestrial Molluscs		**90**	**4**
Number of Terrestrial Species		**11**	**2**
14	*Gyraulus laevis*	1	
	Pisidium casertanum	6	42
	Radix labiata	18	
	Sphaerium corneum	79	23
	% group 14	*13.5*	*12.3*
15a	*Bithynia tentaculata* apices	162	102
	Bithynia tentaculata opercula	103	93
	Lymnaea stagnalis	19	6
	Pisidium milium		9
	Pisidium nitidum	1	34
	Pisidium subtruncatum		19
	Planorbis carinatus	33	
	Planorbis carinatus var. *turgidus*		26
	Radix balthica	232	117
	% group 15a	*58.2*	*59.1*
15b	*Pisidium amnicum*	1	
	Pisidium hibernicum		10
	Pisidium lilljeborgii		1
	Pisidium moitesserianum	4	
	Valvata piscinalis	212	141
	% group 15b	*28.3*	*28.7*
Total Aquatic Molluscs (excluding *B. tentaculata* operculae)		**768**	**530**
Number of Aquatic Species		**12**	**12**
Aquatic Molluscs as a proportion of Total Molluscs (%)		**89.5**	**99.3**
Total Molluscs		**858**	**534**
Condition of the shells/ degree of surface dissolution		very fragmented/ moderate-fairly severe- (severe)	fairly fragmented/ moderate-fairly severe
Redeposited shells from the upper part of the OSM (brown/light brown/pale brownish-grey; some recrystalisation)		x	
Redposited shells from a lower part of the OSM (black, dark grey; notable recrystalisation)		x	
charcoal		x	
bone fragments - small mammals		1	
13-15	*Chara* oospores		1

For a description of the ecological groups see Figure 2

Note 1 The channel was exposed from c.450.50 m asl to a depth of 1.5 m and for a width of c.10 m from its south-eastern edge; the channel shape and bedding suggest a meandering river

2 First published in Liniger and Thew 2016

3 The same channel was observed at Treiten/Ryffli, with deposits up to 452.10 m asl

Table 33: The Molluscan Faunas from the Jura Cement quarry, Jakobsberg/Unteregg, Auenstein/Veltheim, AG

Sampled: 2010 + 2018
Analysis: Nigel Thew 2015-2022

Site		**Jura Cement quarry Jakobsberg/Unteregg, Auenstein, AG**	**Jura Cement quarry Jakobsberg/Unteregg, Veltheim, AG**
Sample		Sample 18.05.2018 (Note 1) 2653 801/1252 549; surface at 400 m asl	Sample 2 / 20.07.2010 (Note 2) est. 2653 800/1252 750 surface at c.410 m asl
Sediment description		laminated darkish-grey silt with some clay and sand + little fine gravel (<0.5 cm)	orangy-reddish-brown silt with some sand + some fine gravel + rare stones to 3 cm; moderate Fe-Mn concretions
Sample size (kg)		0.1	2.15
Dating evidence			OSL dates 64.6 ± 7.9 BP, 63.8 ± 5.1 BP
Probable age (OSL dates, stratigraphy, molluscs)		early MIS 6	MIS 4
Ecological Groups	**Species**		
4	*Clausilia rugosa parvula*		204
	Trochulus villosus		127
	% group 4		*18.1*
6	*Arianta arbustorum* var. *alpicola*		25
	Cochlicopa lubrica		19
	Columella columella		63
	Trochulus sericeus		451
	Vitrea crystallina		34
	% group 6		*32.4*
7	*Limax/Deroceras sp.*		16
	% group 7		*0.9*
8	*Abida secale*		279
	% group 8		*15.3*
9	*Pupilla muscorum*		388
	Vallonia costata		7
	% group 9		*21.6*
12	*Succinella oblonga* var. *elongata*		213
	% group 12		*11.7*
Total Terrestrial Molluscs		**0**	**1826**
Number of Terrestrial Species		**0**	**12**
15a	*Pisidium nitidum*	2	
	Radix balthica	32	
15b	*Valvata piscinalis*	1	
Total Aquatic Molluscs		**35**	**0**
Number of Aquatic Species		**3**	**0**
Total Molluscs per kilo of sediment		**350**	**849**
Degree of surface dissolution of the shells		moderate /f. severe	f.severe /severe
7	earthworm granules	(x)	(x)
	charcoal fragments		x
	moss fragments	x	
	bone fragments - larger mammals		xx (mammoth)
13-15	ostracod valves	4	

For a description of the ecological groups see Figure 2

KEY

🟪	Pioneer species typical of colder periods

Note 1 sampled by Ursula Menkveld-Gfeller

Note 2 sampled by Pierre Bigler from the sediment around one or more mammoth tusks

Table 34 : The Molluscan Faunas from Riehen, BL, Allschwil, BL and Fuchshag, Bottmingen, BL

For all sampling + analytical details see table below

Site		**Ludwig-Courvoisier Strasse (1999/45), Riehen, BS - Profile 3** (2616 250/1270 030; 305 m asl; Note 1)																	
Layer		**5a3**		**5a2**		**5a1**				**3**			**2c**				**2b**		
Sample		**17**	**16**	**15**	**14**	**13**	**12**	**11**	**10**	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**	
Sediment description		alternating thin layers (3-10 cm thick) light brown/brownish-grey loessic silt, with some sand + some fine gravel to 2 cm; moderately humic, with precipitated FeO$_2$ 5a3 medium humic, more gravel, 5a2 more humic, medum gravel, 5a1 least humic, least gravel; sharp lower limit, diffuse upper limit; palaeosol with cryostructures								light brown loessic silt; loessic concretions to 3 cm; slightly humic; diffuse lower limit, fairly sharp upper limit; slightly weathered palaeosol			2c: finely banded pale yellow / light grey loessic silt, fairly sharp lower and upper limits; 2b: light brown loessic silt, weakly humic, erosive upper limit; 2 pale yellow loessic silt, erosive upper limit, some modern bioturbation; dipping gently towards NE; manganese and iron precipitates + calcareous rootlet tubes; cryostructures						
Sample size (kg)		1.13	1.72	1.89	2.13	2.05	2.08	2.0	1.84	1.78	1.78	1.87	1.77	1.43	1.43	1.53	1.45	1.04	
Sample residue available for resorting		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
Dating evidence					(14-11) ESR 48 ± 5 k BP (12) OSL6 - 17.9 ± 2.9 k BP								(6) OSL1 19.6 ± 3.3 k BP (5) OSL7 17.5 ± 2.8 k BP						
Malacozone		**Rie-1a**		**Rie-1b**															
Probable age (molluscs, stratigraphy)		early Middle Würm early MIS 3								mid Middle Würm mid MIS 3			mid Middle Würm mid MIS 3						
Ecological Groups	**Species**																		
1	*Ena montana*	(x)	(x)		(x)	(x)						(x)		(x)			(x)		
	% group 1																		
3	*Clausilia dubia*	(x)	x	(x)	(x)	(x)						(x)		(x)			(x)		
	Orcula dolium	x	x		x	xx						x		x			(x)	(x)	
	% group 3																		
4	*Clausilia rugosa parvula*	xx	xx	xx	xxx	xx						xx		xx			x	x	
	Discus ruderatus			(x)	(x)									(x)					
	Eucobresia nivalis		(x)		(x)	(x)								(x)					
	Neostyriaca corynodes	xx	xx	x	xxx	x						xx		xx			x	x	
	Trochulus montanus/striolatus	(x)	x	(x)	xx	x						x		x			(x)	xx	
	Trochulus villosus	xxx	xxxx	xx	xxx	xx						xx		xx			x	x	
	% group 4																		
6	*Arianta arbustorum* var. *alpicola*	xx	xx	x	x	x						x		x			(x)	(x)	
	Cochlicopa lubrica	x	x	x	x	(x)						(x)		(x)			(x)	(x)	
	Columella columella			(x)	(x)	(x)						(x)		(x)			(x)	xx	
	Punctum pygmaeum		(x)	(x)	(x)	(x)						(x)		(x)					
	Trochulus sericeus	xxx	xxxx	xx	xxxx	xxx						xxx		xxx			xxx	xx	
	Vertigo substriata				(x)														
	Vitrea crystallina	x	xx	x	xx	xx						x		x			x	x	
	% group 6																		
7	*Euconulus fulvus*	(x)	(x)		(x)	(x)						(x)		(x)					
	Limax/Deroceras sp.	(x)	x	(x)	x	(x)						(x)		(x)				(x)	
	Nesovitrea hammonis				(x)	(x)													
	Trochulus hispidus											x		x			x	x	
	% group 7																		
8	*Abida secale*	(x)	x	(x)	x	(x)						(x)		x			(x)	(x)	
	% group 8																		
9	*Pupilla muscorum*	xx	xxx	xx	xxxx	xxx						xx		xxx			xx	xxx	
	Vallonia costata	x	x	(x)	xx	x						x		x			(x)	(x)	
	Vertigo pygmaea		(x)		(x)	(x)						(x)		(x)				(x)	
	% group 9																		
10	*Pupilla sterri*													(x)			(x)		
	% group 10																		
12	*Pupilla alpicola*	x	xx	xx	xx	x						xx		xx			(x)	xx	
	Oxyloma elegans																		
	Succinella oblonga var. *elongata*	xx	xx	x	xx	xx						x		x			x	xx	**Totals**
	% group 12																		
Total Terrestrial Molluscs		**c.150**	**c.600**	**c.150**	**c.1000**	**c.700**						**c.300**		**c.500**			**c.150**	**c.250**	
Number of Terrestrial Species		**18**	**21**	**18**	**25**	**23**						**22**		**25**			**19**	**17**	**27**
14	*Planorbis planorbis*																		
	Pisidium casertanum																		
15a	*Bithynia tentaculata* opercula											1							
15b	*Pisidium amnicum*																		
Degree of surface dissolution of the shells		some/ moderate /(f. severe)	some/ moderate /(f. severe)	some/ moderate	some/ moderate	none/ some/ moderate						none/ some/ moderate		none/ some/ moderate			none/ some/ moderate	some/ moderate	
16	*Cecilioides acicula*																2		
Redeposited shells from upper part of the OSM (brown/pale brownish-grey; some recrystalisation)																			
Redposited shells from lower part of the OSM (black, dark grey, occ. white; notable recrystalisation)					(x)												(x)		
7	earthworm granules	xx	xxx	xx	xxxx	xxx						x		xx			x	x	
	bone fragments - larger mammals				(x)														
	teeth fragments - small mammals				(x)														
	mineralised insect fragments	(x)										(x)							
	charcoal fragments				x									(x)				(x)	

Site		**Allschwil, BL** (2608 025/1265 750; 335-341 m asl; Note 2)				**Fuchshag, Bottmingen, BL -** sandpit in **Birsig Valley** (est. 2609 430/1263 840; c.345 m asl; Notes 3 and 6)		
Layer / **Sample**		**Layer 15** Niederesch-bacher Zone (Note 4)	**Layer 16** gulley infill (Note 5)	**Layer 20** Erbenheimer Nassböden E2 or E4		loess très fin à corpuscules	loess sableux	
Sediment description		brownish-beige rather humic, modferately loessic sandy silt with a little gravel	brownish humic loessic silt	pale grey-beige loessic silt (= gley soil?)		pale yellow-grey-beige loessic silt with some fine sand + rare stones to 0.5 cm + loessic concretions + some Fe-Mn concretions	pale yellow-olive-grey loessic silty fine sand with some medium-coarse sand + rare stones to 1 cm + some small calcareous nodules	
Sample size (kg)						1.7	2.6	
Sample residue available for resorting		No (Note 1)				x	x	
Dating evidence			^{14}C 25800-22650 cal BP (20,000 ± 700 BP)					
Malacozone		**Als-1**	**Als-2**	**Als-3**		**Bott-1**	**Bott-2**	
Probable age (molluscs, stratigraphy)		early Middle Würm early MIS 3	Late Würm? early MIS 2?	Late Würm MIS 2		late Middle Würm late MIS 3	late Middle Würm late MIS 3	
Ecological Groups	**Species**							
1	*Ena montana*							
	% group 1	*0.0*		*0.0*		*0.0*	*0.0*	
3	*Clausilia dubia*					4	2	
	Orcula dolium							
	% group 3	*0.0*		*0.0*		*0.3*	*0.2*	
4	*Clausilia rugosa parvula*	42		39		1	4	
	Discus ruderatus							
	Eucobresia nivalis							
	Neostyriaca corynodes					16	7	
	Trochulus montanus/striolatus							
	Trochulus villosus	2				4		
	% group 4	*15.4*		*9.6*		*1.6*	*1.1*	
6	*Arianta arbustorum* var. *alpicola*	3	cc			41	5	
	Cochlicopa lubrica	1				1	1	
	Columella columella	18		12		3	78	
	Punctum pygmaeum							
	Trochulus sericeus	15				25		
	Vertigo substriata							
	Vitrea crystallina	2				1	1	
	% group 6	*13.6*		*2.9*		*5.5*	*8.4*	
7	*Euconulus fulvus*					3		
	Limax/Deroceras sp.					1	2	
	Nesovitrea hammonis							
	Trochulus hispidus	59	cc	79		597	653	
	% group 7	*20.6*		*19.4*		*46.9*	*64.8*	
8	*Abida secale*	1				33		
	% group 8	*0.3*		*0.0*		*2.6*	*0.0*	
9	*Pupilla muscorum*	32		32		346	183	
	Vallonia costata	4						
	Vertigo pygmaea	1						
	% group 9	*12.9*		*7.9*		*27.0*	*18.1*	
10	*Pupilla sterri*							
	% group 10	*0.0*		*0.0*		*0.0*	*0.0*	
12	*Pupilla alpicola*			4		7		
	Oxyloma elegans					1	2	
	Succinella oblonga var. *elongata*	106		241	**Totals**	198	73	**Totals**
	% group 12	*37.1*		*60.2*		*16.1*	*7.4*	
Total Terrestrial Molluscs		**286**		**407**	**693**	**1282**	**1011**	**2293**
Number of Terrestrial Species		**13**	**>2**	**6**	**14**	**17**	**12**	**17**
14	*Planorbis planorbis*						1	
	Pisidium casertanum						1	
15a	*Bithynia tentaculata* opercula							
15b	*Pisidium amnicum*						1	
Degree of surface dissolution of the shells		moderate	?	some/ moderate		some/ moderate	some/ moderate	
16	*Cecilioides acicula*							
Redeposited shells from upper part of the OSM (brown/pale brownish-grey; some recrystalisation)						x	xx	
Redposited shells from lower part of the OSM (black, dark grey, occ. white; notable recrystalisation)								
7	earthworm granules	xxx	?	xxx		xxxx	xx	
	bone fragments - larger mammals							
	teeth fragments - small mammals					4		
	mineralised insect fragments							
	charcoal fragments					(x)	(x)	

For a description of the ecological groups see Figure 2

KEY

🟪 Pioneer species typical of colder periods

Note 1 Riehen: sampled P. Rentzel 1999; analysed N. Thew 2022-2023; underlain by Hochterrasse

Note 2 Allschwil: sampled 1989/90 and published 1991 G. Zollinger; first studied K. Münzing 1990; reanalysed N. Thew 1994; underlain by Tiefere Deckenschotter

Note 3 Fuchshag, Bottmingen: sampled M. Reinhardt late 1930's or 1940's; first examined J. Favre same time period; reanalysed N.Thew 1998 and 2023; underlain by Tiefere Deckenschotter

Note 4 As no sample residues were available for resorting the number of species must be seen as a mimimum, with smaller and fragile taxa being under-represented

Note 5 No shells were available for reanalysis; original scanning K. Münzing

Note 6 'Don de M. le Prof. M. Reinhardt Bâle'
'Envoyé par M. le Prof. M. Rheinhard'

Table 35 : The Molluscan Fauna from Baden, AG

Sampled : A. Heim 1919
Analysis : Nigel Thew 2018

Site (Note 1)		**Grand Casino, Baden, AG** (est. 2665 550/1259 270; c.382 m asl)
Sample location		dark silty basal infill of a doline through the Niederterrasse, west bank of the Limmat
Sediment description		darkish blue-grey silt with clay, some sand + some small stones (up to 1.2 cm)
Sample size (kg)		0.35
Malacozone		**Bad-1**
Probable age (molluscs, stratigraphy)		early Middle Würm early MIS 3
Ecological Groups	**Species**	
1	*Ena montana*	15
	% group 1	*1.2*
4	*Clausilia rugosa parvula*	17
	Eucobresia diaphana	17
	Trochulus clandestinus	17
	Trochulus villosus	241
	% group 4	*22.6*
6	*Arianta arbustorum*	307
	Cochlicopa lubrica	32
	Punctum pygmaeum	1
	Trochulus sericeus	242
	Vitrea crystallina	6
	Vitrina pellucida	7
	% group 6	*46.1*
7	*Euconulus fulvus*	1
	Limax/Deroceras sp.	14
	Nesovitrea hammonis	17
	% group 7	*2.5*
8	*Abida secale*	99
	% group 8	*7.7*
9	*Pupilla muscorum*	5
	Vallonia costata	188
	Vallonia pulchella	46
	Vertigo pygmaea	6
	% group 9	*19.0*
12	*Pupilla alpicola*	1
	Succinella oblonga	11
	% group 12	*0.9*
Total Terrestrial Molluscs		**1290**
Number of Terrestrial Species		**21**
Degree of surface dissolution of the shells		some/moderate /f. severe
7	earthworm granules	xxxx
	charcoal fragments	x

For a description of the ecological groups see Figure 2

KEY

🟪 Pioneer species typical of colder periods

Note 1 sampled by Prof Albert Heim, 30th October 1919
Shell material borrowed from ETHZ collection, Zürich

Table 36 : The Molluscan Fauna from Bertigny, Pont-la-Ville, FR

Sampled : L. Mornod and A. Jayet mid 1940's
Provisional analysis : J. Favre mid 1940's
Analysis : Nigel Thew 1998 + 2019

Site (Note 1)		**Creux d'Enfer, Bertigny, Pont-la-Ville, FR**
Sample		"sables argileux gris interglaciaires"
Sediment description		compact darkish grey silty fine sand with bands of grey sandy-silt + some organic debris
Sample dry weight (kg)		0.70
Residue available for sorting by NT		x
Possible age (stratigrapghy, molluscs, pollen)		Mid Würm early-mid MIS 3
Ecological Groups	**Species**	
4	*Clausilia rugosa parvula*	10
	Trochulus villosus	3
	% group 4	*0.8*
6	*Arianta arbustorum*	4
	Cochlicopa lubrica	2
	Columella columella	89
	Trochulus sericeus	193
	Vitrea crystallina	8
	% group 6	*17.6*
7	*Limax/Deroceras* sp.	1
	Nesovitrea hammonis	1
	Trochulus hispidus	95
	% group 7	*5.8*
9	*Pupilla muscorum*	115
	% group 9	*6.8*
10	*Pupilla sterri*	14
	% group 10	*0.8*
11	*Succinea putris*	844
	% groupe 11	*50.2*
12	*Galba truncatula*	75
	Oxyloma elegans	1
	Vertigo genesii	226
	% group 12	*18.0*
Total Terrestrial Molluscs		**1681**
Number of Terrestrial Species		**16**
13	*Pisidium obtusale*	2
	% group 13	*2.2*
14	*Pisidium casertanum*	59
	% group 14	*63.4*
15a	*Bithynia tentaculata* shells	6
	Pisidium subtruncatum	11
	Radix balthica	15
	% group 15a	*34.4*
Total Aquatic Molluscs		**93**
Number of Aquatic Species		**5**
Aquatic Molluscs as a proportion of Total Molluscs (%)		**5.2**
Total Molluscs		**1774**
7	worm granules	x (3)
	small mammals	5 tooth frags.
	wood fragments	xx
	charcoal fragments	x
	plant remains	xx 1 *Potomageton* , r *Ranunculus Bat* , r *Carex* sp. unident seeds
13-15	ostracod valves	20

For a description of the ecological groups see Figure 2

KEY

🟪	Pioneer species typical of colder periods
🟧	Pioneer species typical of both colder periods + the start of warmer periods

Note 1 Sampled by L. Mornod and A. Jayet in the mid 1940's and provisionally analysed by J. Favre. Totally reanalysed by Thew, including a majority of previously unidentified shells and fragments. The site was published with a brief description of some mollusc species in Mornod 1947.
Shell material borrowed from the Muséum d'Histoire Naturelle, Genève

Table 37 : The Molluscan Fauna from Sihlbrugg, ZH

Sampled : T. Bolliger 1989/1990
Analysis : Nigel Thew 2018

Site (Note 1)		**Sihlbrugg 'Ost', ZH** (est. 2686 160/1229 990; c.590 m asl)
Sediment description		compact dark brownish-grey silt with sand and organic detritus
Sample weight (kg)		0.15
Residue available for sorting by NT		x
Malacozone		**Si-1**
Possible age (stratigrapghy, molluscs)		Mid Würm early-mid MIS 3?
Ecological Groups	**Species**	
6	*Arianta arbustorum*	6
	Trochulus sericeus	25
	Vitrea crystallina	1
	% group 6	*65.3*
7	*Limax/Deroceras* sp.	1
	% group 7	*2.0*
9	*Pupilla muscorum*	2
	% group 9	*4.1*
11	*Succinea putris*	9
	% group 11	*18.4*
12	*Galba truncatula*	3
	Oxyloma elegans	1
	Vertigo genesii	1
	% group 12	*10.2*
	Total Terrestrial Molluscs	**49**
	Number of Terrestrial Species	**9**
	Total Molluscs per kg	**327**
7	worm granules	x
	insect remains	xx
	small mammals	1 tooth frag.
	charcoal	x
	wood fragments	xxx
	plant remains	xx m *Carex* , r *Potomageton* , m *Ranunculus* sect. *Batrachium* unident seeds and bud-scales
	Cenococcum	x
13-15	ostracod valves	1

For a description of the ecological groups see Figure 2

KEY

🟧 Pioneer species typical of both colder periods + the start of warmer periods

Note 1 Sample taken by T. Bolliger 1989/1990
Shell material borrowed from the PIMUZ

Table 38 : The Molluscan Fauna from Münsingen, BE

Sampled : C. Schlüchter 1971/72
First analysed : M. Wüthrich
Published : C. Schlüchter 1976
Reanalysed : Nigel Thew 2018

Site (Note 1)		**Münsingen, BE** (2608 425 /1192 330; 522 m asl)
Stratigraphic context		discontinuous layer of silty-sand at the summit of the Wichtrach-Schotter (Niederterrasse)
Sediment		banded grey silty-sand with some sandy-silt
Probable Age (based on stratigraphy and molluscan biostratigraphy)		Bølling-Allerød Interstadial late Bølling or early Allerød
Ecological Groups	**Species**	
3	*Clausilia dubia*	1
	% group 3	*0.04*
6	*Cochlicopa lubrica*	26
	Punctum pygmaeum	58
	Trochulus sericeus	6
	% group 6	*3.3*
7	*Euconulus fulvus*	7
	Nesovitrea hammonis	132
	% group 7	*5.1*
8	*Abida secale*	3
	% group 8	*0.1*
9	*Pupilla muscorum*	14
	Vallonia costata	2
	Vallonia pulchella	735
	Vertigo pygmaea (Note 2)	1169
	% group 9	*70.5*
11	*Zonitoides nitidus*	13
	% group 11	*0.5*
12	*Euconulus alderi*	171
	Galba truncatula	84
	Oxyloma elegans	47
	Succinella oblonga	255
	% group 12	*20.5*
	Total Terrestrial Molluscs	**2723**
	Number of Terrestrial Species	**16**
14	*Radix labiata*	4
	Total Aquatic Molluscs	**4**
	Number of Aquatic Species	**1**
	Total Molluscs	**2727**
7	earthworm granules	x
13-15	ostracod valves	x

For a description of the ecological groups see Figure 2

Note 1 shell material borrowed from Naturhistorisches Museum Bern
Note 2 Includes 770 juveniles and 1 specimen of a 4-tooth variety

Table 39 : The Molluscan Fauna from Binz, Zürich

Sampled : Daniel Nievergelt March 2013
Analysed : Nigel Thew Sept 2015

Site		**Räffelstrasse, Binz, Zürich, ZH** (2681 120/1346 370; 422.50 m asl)
Sediment description		blue-grey to olive-grey finely bedded silt with clay and a little fine sand, around a *Pinus sylvestris* stump
Sample number		Moll 1
Sample sieved (kg)		2.0
Radiocarbon dates		earliest: 12037 ± 30 BP 13900 cal BP
Biozone (*Pinus* stumps, radiocarbon dates + molluscs)		early Allerød
Ecological groups	**Species**	
4	*Discus ruderatus*	39
	Eucobresia diaphana	3
	Nesovitrea petronella	48
	% group 4	*17.6*
6	*Cochlicopa lubrica*	87
	Punctum pygmaeum	5
	Trochulus sericeus	113
	% group 6	*40.1*
7	*Euconulus fulvus*	25
	Limax/Deroceras sp.	8
	% group 7	*6.5*
9	*Pupilla muscorum*	77
	Vallonia costata	52
	Vallonia pulchella	53
	% group 9	*35.6*
12	*Oxyloma elegans*	1
	% group 12	*0.2*
Total Terrestrial Molluscs (Note 1)		**511**
Total Terrestrial Mollusc species		**12**
7	earthworm granules	xx
	insect fragments	x
	uncarbonised seeds	xx (Note 2)

For a description of the ecological groups see Figure 2

Note 1 Shell surfaces show traces of moderate (most) to fairly severe (few) weathering
Note 2 19 *Carex* seeds from 2 species + 1 *Pinus* needle tip

Table 40 : The Molluscan Faunas from the Dättnau Valley, ZH

Sampled : K.F. Kaiser late 1970´s
Analysed : K.F. Kaiser late 1970´s
Published : Klaus Kaiser 1979, 1989, 1993, with Ueli Eicher 1987
Reanalysed : Nigel Thew 1995-1999

Site		**Dättnau Valley, ZH** (2694 125 / 1260 463; 487.5 m asl)																																																																											
Sample depths (cm)		830-826	826-820	820-815	815-810	810-800	800-790	790-780	780-771	771-767	767-760	760-744	744-735	735-730	730-717	717-710	710-700	700-690	690-680	680-675	675-672	672-665	665-653	653-650	650-640	640-630	630-624	624-620	620-610	610-600	600-592	592-590	590-580	580-570	570-560	560-550	550-539	539-530	530-520	520-510	510-500	500-490	490-485	485-477	477-471	471-465	465-460	460-450	450-440	440-430	430-420	420-413	413-408	408-400	400-390	390-380	380-371	371-367	367-357	357-350	350-344	344-330	330-320	320-310	310-300	300-290	290-280	280-270	270-260	260-250	250-240	240-230	230-220	220-210	210-200	200-190	190-180	180-170	
Sample numbers (note 1)		74	73	72	71	70	69	68b	68a	68	67	66	65	64	60	59	58	57	56	55	54	53	52b	52a	52	51	50	49	48	47	46	45	44	43	42	41	40	39	38	37	36	35	34	33	32	31	30	29a	29	28	27	26	25	24	23	22	21	20	19	18a	18	17	16	15	14	13	12	11 (note 2)	10	9 (note 2)	8	7	6	5	4 (note 2)	3	2	1	77 samples
Sediment description		sandy-silt with some stones			clay-silt		silty-sand	clay-silt		sandy-silt with some small stones	sandy-silt		sandy-silt with some small stones	clay-silt		sandy-silt		clay-silt			sandy-silt	clay-silt					sandy-silt		clay-silt			sandy-silt	clay-silt											sandy-silt	clay-silt	sandy-silt	clay-silt						sandy-silt	clay-silt				sandy-silt	silt	sandy-silt	silt	sandy-silt with some small stones			silt			sandy-silt	silt				clay-silt					sandy-silt	
Malacozones		Da-1a			Da-1b					Da-1c				Da-2a					Da-2b							Da-3a					Da-3b																Da-3c						Da-3d					Da-4a			Da-4b									Da-5a					Da-5b		?		
Dating evidence (^{14}C)										c.12,350 BP / 14,300 cal BP first pine trees appeared locally																																																				~10,850/10,800 BP / 12,900 cal BP last pine trees died																						
Local Pollen data in Core B3 (Kuttel and Welten)		*Betula* dominant								modest rise in *Pinus*								*Pinus* locally common			*Pinus* dominant, falling *Betula*							decrease in Cyperaceae																																		increased non-arboreal pollen											decreased non-arboreal pollen						rise in *Corylus*			*Corylus* dominant	
Regional Biozone		**Bølling** ***Betula* phase**																			**Allerød**																																																																
Ecological groups	**Species**																																																																															
1	*Ena montana*																																											1												1																					1							
	% group 1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.7	0.0	0.0	0.0	0.0			
3	*Clausilia dubia*																																																																						1					1				
	Eucobresia diaphana																									1				4		2			1									1				8	3	1	3	1				3			1																2				
	Trochulus montanus													1	1		1		1	1		2	3		5	1	2	3	5	3	4		2	3	9	3	2	6	2	3	1					1	2	1	1		1					1							1				1	1	1		1	1			1				
	% group 3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	14.3	3.4	0.0	4.5	0.0	0.7	3.0	0.0	2.1	2.0	0.0	3.0	1.6	2.7	3.8	2.1	4.3	2.3	1.9	1.0	1.6	2.7	1.2	1.5	1.4	0.6	1.9	0.7	0.0	0.0	0.7	0.0	1.6	2.2	3.0	3.0	1.0	3.4	1.1	0.0	0.0	0.0	1.9	0.0	0.0	16.7	0.0	0.0	0.0	3.4	0.0	0.0	0.0	7.1	2.1	5.3	3.7	5.3	6.7	0.0	0.0	8.9	0.0			
4	*Aegopinella nitens*																																																																											1			
	Clausilia rugosa parvula																																																																										1				
	Discus ruderatus																		3				2							1	18	21	24		2	6		3	14					2			1			2	2				6	9					1									1				1	4				
	Trochulus villosus																																	1	11	6	1	20	18	8	14	4		7	6	6	15	25	5	6	13	9	8	22	8	17	4	4	2	1	6	3	4	10	2	5	9	4	6	11	5	3	6	6	6	1			
	% group 4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.1	0.0	0.0	0.0	1.3	0.0	0.0	0.0	0.0	0.0	0.0	0.6	10.5	20.2	12.2	0.5	3.5	4.7	0.8	5.4	9.7	5.0	9.3	3.3	0.0	6.3	8.6	9.7	17.6	8.4	3.8	8.2	12.6	10.2	19.5	24.2	17.9	12.6	13.3	80.0	33.3	20.0	33.3	13.0	13.8	20.0	11.1	27.8	64.3	8.3	31.6	44.4	26.3	20.0	30.0	25.9	24.4	40.0			
6	*Arianta arbustorum*	2			3			3					1	2	2				1			2			1		1	1		1	1							1		1	1	1		1		2						1			1							1	2	1			1	1	1				1	1		1			
	Carychium tridentatum																																																																					1									
	Cochlicopa lubrica		1					1	2			1			2		2	1	9	6	4	23	39	8	35	30	9	7	33	34	21	16	27	22	43	21	17	34	25	10	5	8	1	4	6	8	2	35	20	27	32	11	2	16	9	12	3				1	1	1	6	5	1	1	5	1	3	3	3	2	3	3	1			
	Columella edentula																																														1	1		1	4			1																									
	Punctum pygmaeum	11	11	1				3	3								1		1			2	1	1	5	1	2	2	13	3	4	3	6	5	19	12	2	19	5	2	3	5		4	1	2	1	14	5	3	6	4	5	3	1	7								1				2		3			1	1					
	Trochulus sericeus	2	2				1	4					2	2	4	1	2	1	6	2	1	1	10	1	5	2	1	2	12	3	7	1	4	6	11	8	5	10	6	2	3	3	1	1	1	1	2	2	1	1	1	3	4	1	1	1	1				1	4	2	2		1	1	3	2	1	1	1	1	1	1				
	Vertigo substriata																												3	2	2			3	3	3	1	9	5		1			5	3		1	18	10		1																								1				
	Vitrea crystallina																																																																										1				
	Vitrina pellucida						1						1			1									1																																																						
	% group 6	10.1	13.2	2.1	60.0	0.0	28.6	14.7	14.3	0.0	0.0	16.7	28.6	57.1	27.6	33.3	22.7	8.0	12.1	24.2	18.5	29.2	33.6	21.7	28.3	27.0	17.6	15.2	25.2	26.2	20.5	19.2	18.9	19.3	20.2	17.1	18.8	17.1	12.5	9.4	8.6	14.2	33.3	10.5	15.7	21.0	7.7	23.6	27.1	32.7	37.0	21.6	26.8	23.1	15.4	9.7	13.3	0.0	0.0	0.0	9.5	26.1	17.2	20.0	27.8	11.1	21.4	22.9	21.1	29.6	21.1	26.7	25.0	22.2	13.3	40.0			
7	*Euconulus fulvus*		3					1		1			1		1				7	2	2	9	11	1	11	9	3	4	8	8	8	3	7	5	1	1	1	3	2	1	3	1	1	1	2	1	5	14	14	2	7	10	3	8	8	6	3			1			2		3			3			1		1	1	2				
	Nesovitrea hammonis	1	1					3	4	1		1			1		3	1	26	5	2	32	36	12	47	44	20	27	57	24	32	20	34	36	13	7	38	43	31	2	12	8		19	12	5	21	54	28	27	33	30	6	11	7	19	1			1	3	2	3	5	5	3		1	1	1	1		2	2	3				
	% group 7	0.7	3.8	0.0	0.0	0.0	0.0	5.3	11.4	25.0	0.0	16.7	7.1	0.0	6.9	0.0	13.6	4.0	23.6	21.2	14.8	42.7	31.5	28.3	34.9	43.4	31.1	39.2	26.9	19.5	23.4	22.1	20.9	21.9	3.7	3.1	29.3	10.8	10.0	1.9	9.9	7.5	16.7	14.0	20.0	9.7	28.6	22.9	31.6	29.6	33.6	45.5	22.0	20.9	19.2	12.1	13.3	0.0	0.0	40.0	14.3	8.7	17.2	10.0	44.4	16.7	0.0	8.3	5.3	3.7	10.5	0.0	15.0	11.1	11.1	0.0			
8	*Abida secale*	4	1				1	17	4	1				1	5	1	4	1	3	2	2	1	6		3	3	3		1		6			4	1				1					1			6	1				2									5	1										1			1				
	Cochlicopa lubricella	5	2					3	1	1			1					2	4														1		1		1		1					1				1	3	1						1															1								
	% group 8	6.0	2.8	0.0	0.0	0.0	14.3	26.7	14.3	25.0	0.0	0.0	7.1	14.3	17.2	16.7	18.2	12.0	5.0	6.1	7.4	1.0	4.0	0.0	1.8	2.5	4.1	0.0	0.4	0.0	3.5	0.0	0.5	2.1	0.5	0.0	0.8	0.0	0.6	0.0	0.0	0.0	0.0	1.4	0.0	0.0	6.6	0.7	2.3	1.0	0.0	2.3	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	23.8	4.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.3	6.7	0.0	0.0	2.2	0.0			
9	*Pupilla muscorum*	2	5				2	4	3				1		1					3	1	1	2		1				2	8	9	2	2	9	9	5	1	5	6	1	5	4		1		1		1	1						1	12	2			1								2											
	Vallonia costata	7	2		1			6	3	1	1		1		3		2	3	18	4	2	4	6	3	8	15	6	15	9	6	6	5	6	6	5	2	11	5	1	1	1	1		5	6	3	2	21	6	4	7	3	2	5	2	13		1	1		3	4	3	4	2	2	1	3				1	1	3	7	1			
	Vallonia pulchella	80	28	1		2	1	17	15	1		1	2	1	7	2	6	7	52	8	11	14	21	18	33	7	24	17	88	60	46	28	74	43	131	94	27	175	133	56	87	71		78	29	22	26	91	33	17	8	10	7	18	25	96	4			1	1	6	10	19	1	2		18	3	2	2	3	5	8	10				
	Vertigo pygmaea	5						2							1	1						1												1		2			1	2		1																										1											
	% group 9	63.1	33.0	2.1	20.0	100.0	42.9	38.7	60.0	25.0	50.0	16.7	28.6	14.3	41.4	50.0	36.4	40.0	50.0	45.5	51.9	20.8	19.5	45.7	25.3	18.0	40.5	40.5	40.9	45.1	35.7	33.7	41.8	31.6	38.6	39.9	29.3	43.4	42.9	37.7	61.6	64.2	0.0	58.7	50.0	41.9	30.8	38.0	30.1	21.4	12.6	14.8	22.0	25.3	35.9	58.5	20.0	20.0	16.7	40.0	19.0	43.5	44.8	46.0	16.7	22.2	7.1	50.0	15.8	7.4	10.5	26.7	30.0	40.7	37.8	20.0			
10	*Pupilla sterri*	1					1	4				1	4				1	2	3				6		2	5					2	1																																															
	% group 10	0.7	0.0	0.0	0.0	0.0	14.3	5.3	0.0	0.0	0.0	16.7	28.6	0.0	0.0	0.0	4.5	8.0	2.1	0.0	0.0	0.0	4.0	0.0	1.2	4.1	0.0	0.0	0.0	0.0	1.2	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0			
11	*Carychium minimum*																																	2	54	24	1	51	29	3	2	1						1																															
	Cochlicopa nitens																												4	2	2	1	4	17	18	7	6	16	13	3	1	2		3	3	2	2	5	2	2	1	3	4	5	2	1						1	1	2		1			2			1							
	% group 11	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.7	1.2	1.2	1.0	2.0	10.2	19.1	12.0	5.3	15.7	12.8	3.8	2.0	2.5	0.0	2.1	4.3	3.2	2.2	2.0	1.5	2.0	0.8	3.4	9.8	5.5	2.6	0.5	0.0	0.0	0.0	0.0	0.0	4.3	3.4	4.0	0.0	5.6	0.0	0.0	10.5	0.0	0.0	6.7	0.0	0.0	0.0	0.0			
12	*Euconulus alderi*																					1	4	1	2	1		1	1	1			1	7	2		2	4	4		2			1	1	1	1	1	1	1				1	7	3	2											2											
	Galba truncatula	27	50	45	1			1			1	2						1	2			1	1		5	1	1		6	3			4	13	38	49	14	17	19	46	4	9		5		3	1	2								1	4												1	1	1				1				
	Oxyloma elegans																	3			2		1											2	3	6	2	4	6	11	2	1	3	3		4				3						5	4		1							3		2	1	2	3								
	Succinella oblonga	2						5		2					1			3	3			2		1	2	2	2			1	3	1		2	1	2	1	1	7	6	4						2	1									2		1																				
	Vertigo genesii							1											1																																																												
	% group 12	19.5	47.2	95.7	20.0	0.0	0.0	9.3	0.0	25.0	50.0	33.3	0.0	0.0	3.4	0.0	0.0	28.0	4.3	0.0	7.4	4.2	4.0	4.3	5.4	3.3	4.1	1.3	2.9	3.0	1.8	1.0	2.6	12.8	11.7	22.1	14.3	6.1	10.9	39.6	7.9	8.3	50.0	6.3	1.4	12.9	4.4	1.3	0.8	4.1	0.0	0.0	0.0	1.1	9.0	4.3	40.0	0.0	33.3	0.0	0.0	0.0	0.0	0.0	0.0	16.7	0.0	8.3	10.5	11.1	21.1	0.0	0.0	0.0	2.2	0.0			**Totals**
Total Terrestrial Molluscs		149	106	47	5	2	7	75	35	8	2	6	14	7	29	6	22	25	140	33	27	96	149	46	166	122	74	79	242	164	171	104	196	187	376	258	133	426	329	159	151	120	6	143	70	62	91	297	133	98	119	88	41	91	78	207	30	5	6	5	21	23	29	50	18	18	14	48	19	27	19	15	20	27	45	5	sterile	sterile	6461
Total Terrestrial Molluscs per 10 cm thickness of sediment		373	177	94	10	2	7	75	39	20	3	4	16	14	22	9	22	25	140	66	90	137	124	153	166	122	123	198	243	164	214	520	196	187	376	258	121	473	329	159	151	120	12	179	117	103	182	297	133	98	119	126	82	114	78	207	33	13	6	7	35	16	30	50	18	18	14	24	19	14	19	15	20	27	23	5	sterile	sterile	
Total Number of Terrestrial Species		13	11	3	3	1	6	16	8	7	2	5	9	5	12	5	9	11	16	9	9	15	15	9	16	14	12	9	14	17	16	13	14	19	21	18	18	19	21	18	18	15	4	19	11	15	17	20	15	15	14	13	9	11	13	17	11	2	5	5	8	9	10	9	6	8	6	14	10	11	10	9	9	10	16	5	sterile	sterile	33
13	*Anisus leucostoma/spirorbis*									3	17	5						1	1																22	8		3	7	6																																							
	Pisidium obtusale																																																																									1 (note 3)				
14	*Armiger crista*										10																																																																				
	Gyraulus laevis							1		1	29	19																																																																			
	Radix labiata										9	2																																																																			
Total Aquatic Molluscs								1		4	65	26						1	1																22	8		3	7	6																																				1		sterile	sterile	145
Total Aquatic Molluscs per 10 cm thickness of sediment								1		10	93	16						1	1																22	8		3	7	6																																				1		sterile	sterile	
Total Number of Aquatic Species								1		2	4	3						1	1																1	1		1	1	1																																				1		sterile	sterile	5
Aquatic Molluscs as a proportion of Total Molluscs (%)		0.0	0.0	0.0	0.0	0.0	0.0	1.3	0.0	33.3	97.0	81.3	0.0	0.0	0.0	0.0	0.0	3.8	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.5	3.0	0.0	0.7	2.1	3.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.2	0.0	-	-	
Total Molluscs		149	106	47	5	2	7	76	35	12	67	32	14	7	29	6	22	26	141	33	27	96	149	46	166	122	74	79	242	164	171	104	196	187	398	266	133	429	336	165	151	120	6	143	70	62	91	297	133	98	119	88	41	91	78	207	30	5	6	5	21	23	29	50	18	18	14	48	19	27	19	15	20	27	46	5	sterile	sterile	6606
ostracod valves																																				x				x																																									

For a description of the ecological groups see Figure 2

Note 1 the standard 10 cm of sediment thickness from the sample boxes weighed around 2 kgs

▨ Pioneer species typical of both colder periods + the start of warmer periods

Note 2 includes an additional preliminary sample

Note 3 pair of valves from same individual

Table 41 : The Molluscan Fauna from Boppelsen-Cholholz, ZH

Sampled : A. Jayet 1948
First analysed : A. Jayet assisted by J. Favre 1948/49
Published : A. Jayet 1949
Reanalysed : Nigel Thew 1998

Site (Note 1)		**Boppelsen-Cholholz, ZH** (2673 800/1258 850; c.680 m asl)		
Sample location		upper part of Höhere Deckenschotter gravel terrace	surface	
Sediment description		slightly pinkish-brown tufaceous silt with some sand and stones	surface leaf litter	
Residue available for sorting by NT		no		
Malacozone		**Bp-1**	**Bp-2**	
Probable Age (molluscs)		early Boreal	1948	
Ecological Groups	**Species**		Note 2	
1	*Ena montana*	11	cc	
	🟩 *Macrogastra ventricosa*	1		
	% group 1	*1.3*		
2	*Vertigo pusilla*	32		
	% group 2	*3.5*		
3	🟩 *Acanthinula aculeata*	19		
	🟩 *Acicula lineata*		r	
	🟩 *Aegopinella pura*	7		
	🟩 *Helicigona lapicida*		cc	
	🟩 *Helicodonta obvoluta*		cc	
	🟩 *Macrogastra plicatula*	26	cc	
	Merdigera obscura	2		
	% group 3	*5.9*		
4	🟩 *Aegopinella nitens*	71	c	
	Clausilia rugosa parvula	4	fc	
	🟩 *Cochlostoma septemspirale*		cc	
	🟩 *Discus rotundatus*	3	fc	
	Discus ruderatus	9		
	Eucobresia diaphana	1		
	🟩 *Helix pomatia*		c	
	Trochulus villosus	63	cc	
	Vitrea subrimata		fc	
	% group 4	*16.5*		
6	*Arianta arbustorum*	38	fc	
	🟩 *Carychium tridentatum*	257		
	Cochlicopa lubrica	19		
	Columella edentula	3		
	Punctum pygmaeum	16		
	Trochulus sericeus	34	fc	
	Vertigo substriata	1		
	Vitrea crystallina	66		
	% group 6	*47.5*		
7	*Cepaea hortensis*	3	fc	
	Euconululus fulvus	3		
	Limax/Deroceras sp.	1		
	Nesovitrea hammonis	24		
	% group 7	*3.4*		
8	*Abida secale*	19	fr	
	% group 8	*2.1*		
9	*Vallonia costata*	133		
	Vallonia pulchella	38		
	% group 9	*18.7*		
10	*Jaminia quadridens*	1		
	% group 10	*0.1*		
12	*Succinella oblonga*	9		**Totals**
	% group 12	*1.0*		
Total Terrestrial Molluscs		**914**		
Number of Terrestrial Species		**30**	**16**	**36**
Degree of surface dissolution of the shells		moderate		
7	earthworm granules	x		
	Cenoccocum	x		
	charcoal fragments	xx		

For a description of the ecological groups see Figure 2

KEY

🟩 Species typical of interglacial warm periods

r = rare, fr = fairly rare, fc = fairly common, c = common, cc = very common

Note 1 The sample was taken by Jayet in l948, then first analysed by him in 1948/49 and published in 1949. It was reanalysed by NT in 1998.
Shell material borrowed from the Muséum d'Histoire Naturelle, Genève

Note 2 These identifications have been taken from Jayet 1949 but modified slightly. For example, Jayet's *Aeogpinella nitidula* is almost certainly *A. nitens*

Table 42 : The Molluscan Faunas from Wildbach, Embrach, ZH

Sampled : Daniel Kälin 2022
Analysed : Nigel Thew 2022

	Site	**Wildbach, Embrach, ZH** (2686 036/1263 999; 399 m asl)		
	Sample	**lower level**	**upper level**	
	Sediment description	grey-black organic silts with sand + some stones + tufaceous concretions	darkish grey silt with sand + rare stones + frequent pisoliths up to 6 cm	
	Sample weight (kg)	4.2	5.3	
	Malacozones	**Wb-1**	**Wb-2**	
	Probable age (stratigraphy, molluscs)	early Boreal	mid-late Boreal	
Ecological Group	**Species**			
1	*Clausilia cruciata*	(x)	x	
	Cochlodina fimbriata		(x)	
	Ena montana		x	
	Isognomostoma isognomostomos		xx	
	Macrogastra attenuata		(x)	
	Macrogastra ventricosa		(x)	
2	*Vertigo pusilla*		(x)	
3	*Acanthinula aculeata*	(x)	(x)	
	Aegopinella pura	(x)	(x)	
	Clausilia dubia		(x)	
	Cochlodina laminata		(x)	
	Macrogastra plicatula	x	xx	
	Merdigera obscura		(x)	
	Nesovitrea petronella	x	(x)	
	Orcula dolium		(x)	
	Platyla polita		(x)	
4	*Aegopinella nitens*	x	xxx	
	Clausilia rugosa parvula	(x)	(x)	
	Discus rotundatus		xx	
	Discus ruderatus	(x)	(x)	
	Eucobresia diaphana		(x)	
	Milax/Tandonia sp.		(x)	
	Oxychilus cellarius		(x)	
	Trochulus villosus	xx	xxx	
6	*Arianta arbustorum*	x	xxx	
	Carychium tridentatum	x	xx	
	Cochlicopa lubrica	x	xx	
	Columella edentula	(x)	(x)	
	Fruticola fruticum	xx	x	
	Punctum pygmaeum		(x)	
	Trochulus sericeus	xx	xx	
	Vertigo substriata	(x)		
	Vitrea crystallina	xx	xx	
7	*Cepaea hortensis*	x	x	
	Limax/Deroceras sp.		(x)	
	Nesovitrea hammonis	(x)	x	
8	*Abida secale*		(x)	
9	*Vallonia costata*	xx	x	
	Vallonia pulchella		(x)	
11	*Carychium minimum*	(x)	(x)	
	Cochlicopa nitens		(x)	
	Succinea putris	xx	(x)	
	Vertigo antivertigo		(x)	
	Zonitoides nitidus	xx	x	
12	*Euconulus alderi*	(x)	(x)	
	Galba truncatula		(x)	
	Oxyloma elegans		x	**Totals**
	Succinella oblonga	(x)	(x)	
	Total Terrestrial Molluscs	**c.150**	**>600**	
	Number of Terrestrial Species	**25**	**47**	**48**
14	*Pisidium casertanum*	x	xx	
	Pisidium personatum	(x)	xxx	
	Radix labiata	(x)	x	
	Stagnicola palustris/corvus		(x)	
15a	*Bathyomphalus contortus*		(x)	
	Pisidium milium		xxx	
	Pisidium subtruncatum	(x)	xxx	
	Radix balthica	x	xx	
	Valvata cristata		(x)	**Totals**
15b	*Valvata piscinalis*	(x)	(x)	
	Total Aquatic Molluscs	**c.25**	**c.200**	
	Number of Aquatic Species	**6**	**10**	**10**
	Total Molluscs	**<200**	**>800**	
	Degree of surface dissolution of the shells	some/ moderate	some/ moderate	
7	earthworm granules	x	x	
	tusk-shaped tubes		5	
	wood fragments	x	x	
	plant material	xx	x	
	uncarbonised seeds	x		
	Cenococcum	x		
13-15	ostracod valves	1	4	

For a description of the ecological groups see Figure 2

Table 43 : The Molluscan Faunas from Oberbipp/Steingasse, BE

Analysed : Nigel Thew 2019

Site		**Oberbipp/Steingasse, BE** (2616 765/1234 395; alt. surface 487 m asl)									
Context		**Sediments beneath the dolmen**		**Inside the dolmen**				**Post-abandonment disturbances of the dolmen**			
								south-west	**south-east**	**north-west**	
Layer / part of layer		**pre-172 lower**	**pre-172 upper**	**150**	**144/12+11**	**144/10-7**	**144/12-7**	**144/12-7**	**144/12-7**	**144/12-7**	
Squares		2	2	2	2	2	3	1	4, 5, 6	0, 7, 8	
Samples		127230	127224a	127224b	127116	126705	126706 127118	126704 127114	126707, 126708, 127709, 127120, 127122	126701, 126702, 126703, 127108, 127110, 127112	
Residues available for sorting by NT		x	x	x	x	x					
Sample size (litre)		12.0	23.0	1.0	5.0	23.9					
Sedimentary description		brownish-grey silt with some clay and numerous tufaceous concretions	grey-brown silt with some clay and numerous tufaceous concretions	brownish-olive-grey silt with freq. small granitic frags. + abundant bone	brownish-grey silt with numerous small granitic fragments (weathered from the megaliths) and abundant human bone			brownish-grey silt with some clay and fairly numerous small granitic fragments + a little human bone			
Presence of archaeological material		x	x	x	x	x					
Archaeological Period		Middle Mesolithic		Late Neolithic				Early/Middle Bronze Age disturbances of the dolmen			
Malacozone		**ObS-1a**	**ObS-1b**	**ObS-2a**		**ObS-2b**	**ObS-2**	**ObS-3a**	**ObS-3b**	**ObS-3c**	
Regional biozone		**early to mid Boreal**		**Subboreal**							
Ecological Group	**Species**										
1	*Clausilia cruciata*	x	17		3	6				2	
	Cochlodina fimbriata		3								
	Ena montana	xx	83		2	18				41	
	Isognomostoma isognomostomos			1	1	4				3	
	Macrogastra attenuata	xx	19		6	5					
	Macrogastra ventricosa	xx	18					1		20	
	% group 1		*2.4*		*2.9*	*3.7*	*0.0*	*2.0*	*0.0*	*1.3*	
2	*Vertigo pusilla*	x	22			1					
	% group 2		*0.4*		*0.0*	*0.1*	*0.0*	*0.0*	*0.0*	*0.0*	
3	*Acanthinula aculeata*	x	25		1					1	
	Acicula lineata	x	2								
	Aegopinella pura	x	21		2	7				1	
	Clausilia dubia	xx	85		2	9		1		4	
	Cochlodina laminata	xx	49		4	8			1	23	
	Helicigona lapicida			1	1	6				16	
	Helicodonta obvoluta			1	1	5			1	24	
	Macrogastra plicatula	xx	44			2				10	
	Merdigera obscura	xx	41		2	4				2	
	Monachoides incarnatus			7	8	10	1			7	
	Orcula dolium	x	1		1					1	
	Platyla polita	x	2								
	% group 3		*4.7*		*5.4*	*5.7*	*1.1*	*2.0*	*1.3*	*1.8*	
4	*Aegopinella nitens*	xxxx	842		55	56	2	1	2	202	
	Balea perversa		1								
	Clausilia rugosa parvula	xx	97		2	6			1	1	
	Discus rotundatus	xxx	132		5	19		2	2	36	
	Discus ruderatus	x	19								
	Eucobresia diaphana	x	5		1						
	Helix pomatia								2*	1*	
	Limax maximus/cinereoniger	x	x			1				2	
	Milax/Tandonia sp.	x	19		1	3					
	Oxychilus cellarius	x	25		2	18			2	12	
	Trochulus montanus	x	4		2	2		1	1	2	
	Trochulus villosus	xxxx	707		59	45	1	1	1	156	
	Vitrea subrimata	x	22								
	% group 4		*32.4*		*31.1*	*16.9*	*3.4*	*10.0*	*6.0*	*8.3*	
6	*Arianta arbustorum*	xxxx	1251		141	387	76	28	114	3705	
	Carychium tridentatum	xxx	69			1		1	1	2	
	Cochlicopa lubrica	xx	257		6	22				7	
	Columella edentula	x	7								
	Fruticola fruticum	xxx	141		11	28	2	5	10	256	
	Punctum pygmaeum	x	14								
	Trochulus sericeus	xx	332		46	126	1	1	8	54	
	Vitrea crystallina	xxx	206		4	7					
	Vitrina pellucida		1								
	% group 6		*39.4*		*51.0*	*64.4*	*90.8*	*70.0*	*88.7*	*81.4*	
7	*Cepaea hortensis*	xx	169		17	45	4	5	2	313	
	Euconulus fulvus	x	10								
	Limax/Deroceras sp.	x	19			2				3	
	Nesovitrea hammonis	xx	88		6	4				8	
	% group 7		*4.9*		*5.6*	*5.7*	*4.6*	*10.0*	*1.3*	*6.6*	
8	*Abida secale*	x	59		2						
	Cochlicopa lubricella	x	35		1	3					
	% group 8		*1.6*		*0.7*	*0.3*	*0.0*	*0.0*	*0.0*	*0.0*	
9	*Vallonia costata*	xxx	628		6	16		2	3	15	
	Vallonia excentrica					1				2	
	Vallonia pulchella	x	47			3		1	1	5	
	Vertigo pygmaea		1							1	
	% group 9		*11.7*		*1.5*	*2.3*	*0.0*	*6.0*	*2.7*	*0.5*	
11	*Carychium minimum*	x	18								
	Vertigo antivertigo	x	6								
	Vertigo moulinsiana		1								
	Zonitoides nitidus	x	44								
	% group 11		*1.2*		*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	
12	*Euconulus alderi*	x	1								
	Galba truncatula	x	3								
	Oxyloma elegans	x	15		6	4				3	
	Succinella oblonga	xx	55		1	3				1	**Totals**
	% group 12		*1.3*		*1.7*	*0.8*	*0.0*	*0.0*	*0.0*	*0.1*	
Total Terrestrial Molluscs (*excluding intrusive shells)		**thousands**	**5782**	**10**	**408**	**887**	**87**	**50**	**150**	**4941**	**12315**
Number of Terrestrial Species (*excluding intrusive shells)		**48**	**53**	**4**	**33**	**36**	**6**	**13**	**15**	**35**	**59**
13	*Aplexa hypnorum*	x	2								
14	*Pisidium casertanum*	x	10		1	1					
	Radix labiata	x	5		1						
	Stagnicola corvus/palustris	x	2								
15a	*Bithynia tentaculata* opercula								1		
Total Aquatic Molluscs		**some**	**19**	**0**	**2**	**1**	**0**	**0**	**1**	**0**	**23**
Number of Aquatic Species		**4**	**4**	**0**	**2**	**1**	**0**	**0**	**1**	**0**	**5**
Aquatic Molluscs as a proportion of Total Molluscs (%)		**<1.0**	**0.3**	**0.0**	**0.5**	**0.1**	**0.0**	**0.0**	**0.7**	**0.0**	
Total Molluscs		**thousands**	**5801**	**10**	**410**	**888**	**87**	**50**	**151**	**4941**	**12338**
Total Molluscs per litre of sample		**hundreds**	**252**	**4**	**82**	**37**					
Degree of surface dissolution of the shells		some/ moderate /(f. severe)	moderate /(f. severe)	f. severe /severe	f. severe /severe	f. severe /severe	f. severe /severe	f. severe /severe	moderate /f. severe	moderate /f. severe	
Presence of burnt shells			x								
16	*Cecilioides acicula*	x	16		8	3			3	3	**33**
7	earthworm granules	xxxx	xxxx	x	x	x					
	white calcareous balls (mollusc eggs?)	x	2			1					
	mineralised (calcite) seeds					2 *Sambucus*					
	charcoal fragments	x	xx	xx	xx	xx					
	mineralised (Fe) wood frags					x					
	Cenococcum	x	x	x	x	x					
	bone fragments - large mammals/human unburnt	xx	x	xxxxx	xxxxx	xxxxx					
	bone fragments - large mammals/human burnt			x	x	x					
	bone fragments - small mammals	x	xx		xx	xx					
	reptile scales/bones			xx	xx	xxx					
	frog bones	x	x	x	x	x					
	fish scales/bones			x	x	x					
	flint flakes	4	3	14	4	49					
	crystal fragments		x	x	x	x					
	pottery fragments			x	x	x					
	daub/burnt clay			x	x	x					
	burnt stones	x	x	x	x	x					
	tufa (travertine) fragments	xxxxx	xxxx	x	x	x					
13-15	ostracod valves	xx	5								

For a description of the Ecological Groups see Figure 2

Key

🟥	Pioneer species that disappeared from the Swiss Plateau + lower slopes of the Jura by ca. 6000 BC, during the Older Atlantic
🟨	Forest species that arrived and became widely present between the late Boreal/Older Atlantic and the Younger Atlantic in western CH
🟩	Species that arrived during the earlier part of the Subboreal after c.3300 BC
🟦	Species that arrived during the later part of the Subboreal after c.1200 BC
▨	Study samples, where all shell material could be sorted from sieve residues by NT
☐	Additional samples where only shell material >1 mm pre-sorted at Basel was available

Table 44 : The Molluscan Faunas from Steffisburg, BE, Belp-Neumatt, BE and Taubenhalde, Bern, BE

Sampled : Christian Schlüchter 1971/72
First examined : Max Wüthrich early 1970's
Reanalysed : Nigel Thew 2022

Site (Note 1)		**Steffisburg, BE - River Zulg floodplain and debris fan** 2613 655 / 1179 895; c.562 m asl; underpass for Thun-Nord/Steffisburg motorway feeder road, beneath Bernstrasse and the railway													**Belp-Neumatt, BE - River Gürbe floodplain** 2604 600 / 1194 220; c.513 m asl trench to construct Neumatt primary school								**Taubenhalde, Bern, BE - Aar floodplain** (est. 2600 150 / 1199 120; 505 m asl
Profile		South-western Profile lower sandy-silts					North-eastern Profile upper silty-sands								profile with peaty deposits		profile with sandy-silts						
Sediment		darkish grey sandy-silt + abundant organic detritus	grey silty-sand + organic detritus	darkish grey silty-sand + organic detritus	dark brown peat		yellow-grey, finely bedded silty fine sands								brown organic silt/silty-peat		darkish blue-grey silt with some clay and fine sand		grey sandy-silt		grey silty-sand with organic detritus		dark grey silt with bands of sandy(fine)-silt + organic detritus
Sample		**3**	**2**	**1**			**208**	**207**	**206**	**205**	**204**	**203**	**202**		**14**	**10**	**7**	**6**	**5**	**4**	**3**		
Sample material/residue available		Note 2																Note 3					Note 9
Dating evidence					Note 4										Note 5								
Malacozone		**St-1a**	**St-1b**	**St-2**	not sampled		**St-3**			**St-4**			**?**				**Bp-1**		**Bp-2**		**Bp-3**		**Tb-1**
Regional Biozone		**Older Atlantic**		**Sub-boreal?**	**Sub-boreal**		**Subboreal**			**Subboreal?**					**Older Atlantic**	**Sub-boreal**	**Subboreal**				**Sub-atlantic**		**Subboreal**
Ecological Group	**Sepcies**																						
1	*Clausilia cruciata*	1	3						1									1					
	Ena montana	2	2														1	1					
	🟨 *Isognomostoma isognomostomos*		🟨 2																				🟨 1
	Macrogastra attenuata																						1
	Macrogastra ventricosa	7	2								1												1
	🟨 *Trochulus edentulus*	🟨 6																					
	% group 1	*1.8*	*3.1*	*0.0*			*0.0*	*0.0*	*2.0*	*0.0*	*3.6*	*0.0*					*50.0*	*2.2*	*0.0*	*0.0*	*0.0*		*3.5*
2	*Vertigo alpestris*	1	1																				
	Vertigo pusilla	5	1																				
	% group 2	*0.7*	*0.7*	*0.0*			*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*					*0.0*	*0.0*	*0.0*	*0.00*	*0.0*		*0.0*
3	*Acanthinula aculeata*	9	4																				
	Acicula lineata	11	1							1													
	Aegopinella pura	7	4															3					2
	Cochlodina laminata	2	4				2	1			1												
	🟨 *Helicodonta obvoluta*	🟨 1							🟨 4									🟨 2					🟨 3
	Macrogastra plicatula		1																				
	Merdigera obscura							2															
	🟨 *Monachoides incarnatus*	🟨 1						🟨 1										🟨 2					🟨 2
	Platyla polita	4	2																				
	% group 3	*4.0*	*5.5*	*0.0*			*16.7*	*5.4*	*7.8*	*9.1*	*3.6*	*0.0*					*0.0*	*7.9*	*0.0*	*0.0*	*0.0*		*8.2*
4	*Aegopinella nitens*	155	62	3			1	11	1	1	3							11					10
	Clausilia rugosa parvula		2																				
	Discus rotundatus	59	17				1	2	1														13
	🟥 *Discus ruderatus*	🟥 4	🟥 3																				
	🟥 *Eucobresia glacialis*		🟥 1																				
	🟦 *Helix pomatia*																				🟦 1		
	Limax maximus/cinereoniger		1																				
	Oxychilus cellarius							2															
	Trochulus clandestinus							1															
	Trochulus villosus	3	5						2														
	Vitrea subrimata	1																					
	% group 4	*25.5*	*31.2*	*20.0*			*16.7*	*21.6*	*7.8*	*9.1*	*10.7*	*0.0*					*0.0*	*12.4*	*0.0*	*0.0*	*33.3*		*27.1*
6	*Arianta arbustorum*									1								13					3
	Carychium tridentatum	271	71	8			1	11	1	2													3
	Cochlicopa lubrica	67	27				2	13	24			1						6					4
	Columella edentula	3	1					1															
	Fruticola fruticum	7	2															7					10
	Punctum pygmaeum	8	2					3	1		2												
	Trochulus sericeus	19	7				1	7	4	2	6						1	12	1		1		5
	Vitrea crystallina	77	16								1							1		1			6
	Vitrina pellucida		3																				
	% group 6	*51.9*	*44.2*	*53.3*		Upper Gravel	*33.3*	*47.3*	*58.8*	*45.5*	*32.1*	*20.0*					*50.0*	*43.8*	*100.0*	*14.3*	*33.3*		*36.5*
7	*Cepaea hortensis*																	10			1		9
	Euconulus fulvus	7							2		1												
	Limax/Deroceras sp.		2															1					1
	Nesovitrea hammonis		6				1	6	2	1	6												
	Vitrea contracta		5																				
	% group 7	*0.8*	*4.5*	*0.0*			*8.3*	*8.1*	*7.8*	*9.1*	*25.0*	*0.0*					*0.0*	*12.4*	*0.0*	*0.0*	*33.3*		*11.8*
8	*Abida secale*	1																					
	Cochlicopa lubricella						1	1															
	% group 8	*0.1*	*0.0*	*0.0*			*8.3*	*1.4*	*0.0*	*0.0*	*0.0*	*0.0*					*0.0*	*0.0*	*0.0*	*0.0*	*0.0*		*0.0*
9	*Vallonia costata*	118	26	3			1	7	2	2	4							1					
	Vallonia pulchella							1			1	1						3					
	Vertigo pygmaea			1						1	1												
	% group 9	*13.5*	*8.9*	*26.7*			*8.3*	*10.8*	*3.9*	*27.3*	*21.4*	*20.0*					*0.0*	*4.5*	*0.0*	*0.0*	*0.0*		*0.0*
10	*Truncatellina cylindrica*							1															
	% group 10	*0.0*	*0.0*	*0.0*			*0.0*	*1.4*	*0.0*	*0.0*	*0.0*	*0.0*					*0.0*	*0.0*	*0.0*	*0.0*	*0.0*		*0.0*
11	*Carychium minimum*							1												2			5
	Vertigo antivertigo										1							1					
	Zonitoides nitidus	14	4				1											7					
	% group 11	*1.6*	*1.4*	*0.0*			*8.3*	*1.4*	*0.0*	*0.0*	*3.6*	*0.0*					*0.0*	*9.0*	*0.0*	*28.6*	*0.0*		*5.9*
12	*Galba truncatula*																	1		1			
	Oxyloma elegans								1			3						6		3			6
	Succinella oblonga		2					2	5														
	% group 12	*0.0*	*0.7*	*0.0*			*0.0*	*2.7*	*11.8*	*0.0*	*0.0*	*60.0*		**Totals**			*0.0*	*7.9*	*0.0*	*57.1*	*0.0*	**Totals**	*7.1*
16	*Cecilioides acicula*							1			1												
Total Terrestrial Molluscs excluding subterranean Group 16		**871**	**292**	**15**			**12**	**74**	**51**	**11**	**28**	**5**	**sterile**	**1359**	**sterile**	**sterile**	**2**	**89**	**1**	**7**	**3**	**102**	**85**
Number of Terrestrial Species excluding subterranean Group 16		**29**	**33**	**4**			**10**	**20**	**14**	**8**	**12**	**3**	**sterile**	**50**	**sterile**	**sterile**	**2**	**19**	**1**	**4**	**3**	**21**	**18**
13	*Anisus leucostoma*																1	12		3			3
	Aplexa hypnorum																		1	2			
	Pisidium obtusale											2							8				
	% group 13											*28.6*					*14.3*	*52.2*	*64.3*	*41.7*			*25.0*
14	*Pisidium casertanum*																		1				5
	Pisidium personatum																		4				1
	Radix labiata																5	4					2
	Stagnicola palustris/corvus																			3			
	% group 14											*0.0*					*71.4*	*17.4*	*35.7*	*25.0*			*66.7*
15a	*Hippeutis complanatus*																1	6		1			
	Pisidium milium											1											
	Pisidium nitidum											1											1
	Pisidium subtruncatum											3											
	Valvata cristata																	1		3			
	% group 15a											*71.4*					*14.3*	*30.4*	*0.0*	*33.3*			*8.3*
Total Aquatic Molluscs		**0**	**0**	**0**			**0**	**0**	**0**	**0**	**0**	**7**	**sterile**	**7**	**sterile**	**sterile**	**7**	**23**	**14**	**12**	**0**	**56**	**12**
Number of Aquatic Species		**0**	**0**	**0**			**0**	**0**	**0**	**0**	**0**	**4**	**sterile**	**4**	**sterile**	**sterile**	**3**	**4**	**4**	**5**	**0**	**9**	**5**
Aquatic Molluscs as proportion of Total Molluscs (%)		**0**	**0**	**0**			**0**	**0**	**0**	**0**	**0**	**58.3**	**-**		**-**	**-**	**77.8**	**20.5**	**93.3**	**63.2**	**0**		**12.4**
Total Molluscs		**871**	**292**	**15**			**12**	**74**	**51**	**11**	**28**	**12**	**sterile**	**1366**	**sterile**	**sterile**	**9**	**112**	**15**	**19**	**3**	**158**	**97**
7	earthworm granules	xxx	xx	?			?	?	?	?	?	?	?				?	xxx	?	?	?		x
13-15	*Chara*												2										
	ostracods											x	x				x	x	x	x			8
	wood fragments	xx	xx	x			x	x	x	x	x	x	x		xx	xx	x	x	x	x	x		x
	plant remains	Note 6													Note 8	Note 7							Note 10
	iron sphaeroids - slag?												x										
	quartz grains										x		x										

For a description of the ecological groups see Figure 2

Note 1 Both sites were sampled by Christian Schlüchter in the early 1970's, and first analysed by Max Wüthrich. All material has been re-examined by Thew, including numerous previously unidentified shells and frags. Partially published in Schlüchter 1976

Note 2 Unsieved sediment could be examined to look for granules, plant maroremains etc

Note 3 80 grammes of unprocessed sediment could be sieved to recover more shell material

Note 4 An *Alnus* stump growing at the surface of the sandy-silts has a C14 date of 3376-2873 cal BC (94.0%) Subboreal

Note 5 Sample 14 at the base of this profile has a C14 date on wood of 6779-6335 cal BC (91.3%) Older Atlantic

Note 6 *Abies, Alnus, Fagus, Fraxinus* and *Quercus*

Note 7 *3 Rubus* sp., 1 *Sambucus*, 2 *Potamogeton* sp.

Note 8 in the peaty sediments: frequent wood from deciduous trees, *Corylus* nuts, *Fagus* nuts, *Picea* cones

Note 9 50 grammes of unprocessed sediment was sieved to recover more shell material

Note 10 *Fagus, Picea, Rubus* + unident

Key

- 🟥 Pioneer species that disappeared from the Swiss Plateau + lower slopes of the Alps by c.6000 BC, during the Older Atlantic
- 🟨 Forest species that arrived and became widely present between the late Boreal/Older Atlantic and the Younger Atlantic in central CH
- 🟩 Species that arrived during the earlier part of the Subboreal after c.3300 BC
- 🟦 Species that arrived during the later part of the Subboreal after c.1200 BC

Fagus became well-established across the Swiss Pleateau at the end of the Older Atlantic/start of the Younger Atlantic

Picea became well-established across the Swiss Pleateau from the start of the Subboreal

Table 45 : The Molluscan Faunas from Bavois-en-Raillon, VD

Sampled : Louis Chaix + excavators 1977-8
Analysed : Louis Chaix 1978, published 1984
Reanalysed : Nigel Thew 2000

>		**Bavois-en-Raillon, VD** (2533 800-890/1170 880-905; 500-511 m asl)																												
Sample Column / Section (*profiles also studied for sedimentology)		**3* (S18)** (upper-eastern part of gully)		**20* (S5)**	**17 (S5)**			**16 (S5)**			**26 (S37)**		**25* (S36)**						**18 (S11-12)**							**19* (S11-12)**		**12 (S27)** (lower-western part of gully)	**Modern** 1977	
Altitude at surface (m asl) / **Sample position relative to gully** centre = C, more to the side = S		511 m / C		509 m / S	508.5 m / C			508.5 m / C			507.5 m / S		506.5 m / C						505.5 m / C							505 m / C		503 m / S		
Sample		B	C	P-Q-R									A	B	C	D	E	F	A	C	E-F	G-H	I-J	M	O-P	below A?	G			**28 samples**
Sample Weight (kg - if known)					8.23									5.27	4.61	3.5	7.42	7.48												
Sediment description		light brownish-grey sandy-silt with clay	light brownish-grey sandy-silt with clay	orangey brownish-yellow very sandy-silt	pale reddish yellowish-brown very sandy fine gravel with some medium	pale yellowish sand with some silt	light grey silty-sand with some clay	pale brown sandy-silt with clay	palish brown sandy-silt with clay	brown sandy silt with clay	light yellowish-brown sand with some silt	orangey brownish-yellow very sandy silt	pale yellow sand with a little fine gravel	pale yellow sandy fine gravel	light brownish-grey very sandy fine gravel with some silt	grey very silty sand	light grey silty-sand	grey very sandy silt with some clay	light grey sand with silt	light olive grey silty-sand with clay	light brownish-grey silty-sand with some clay	light brownish-grey silty sand with some clay	pale brown very sandy silt with clay	light yellowish-brown very sandy-silt with clay	brown very sandy silt with a little fine gravel + clay	pale yellowish-grey sand with some silt	pale brown sandy-silt with clay	light yellowish-brown very sandy silt with clay	modern humus	
Archaeological Period + 14C Dates			Early Bronze Age 3560 ± 100BP				Early Bronze Age 3560 ± 100BP	Late Bronze Age	LBA	LBA						Bell Beaker 3836 ± 60BP	Early Bronze Age 3560 ± 100BP	Early Bronze Age 3630 ± 60BP		Bell Beaker 3836 ± 60 BP	Early Bronze Age 3560 ± 100 BP	Early Bronze Age 3630 ± 60 BP	Late Bronze Age	LBA 2960 ± 70 BP	LBA		LBA 3230 ± 60 BP		modern 1977	
Probable Layer (based on the molluscs and stratigraphy)		15b	11	14b	17	15c	11 (mixed with some 15b)	6	5a	4	15	14b	16	15a	12b=13	12a	11	9	13	12a	11	9	6	5a	4	15c + some 13	5b	13		
Attributed Layer				14b	17	15	6	6	5a	4	15	14b	16	15	12b	12a	11	9	13	12a	11	9	6	5a	4	11	5b	13		
Malacozone		**Bav-3**	**Bav-6a**	**-**	**Bav-1**	**Bav-2**	**Bav-6a**	**Bav-7**	**-**	**-**	**-**	**-**	**?** not decalcified	**Bav-4**	**Bav-5a**	**Bav-5b**	**Bav-6a**	**Bav-6b**	**Bav-5a**	**Bav-5b**	**Bav-6a**	**Bav-6b**	**Bav-7**	**-**	**-**	**Bav-2 + Bav-5a**	**-**	**Bav-5?**	**Bav-8**	
Regional Biozone (radiocarbon, archaeological material, molluscs)		**early to mid Boreal**	**Subboreal**	**Older/ Younger Atlantic?**	**Younger Dryas**	**early to mid Preboreal**	**Subboreal**	**Subboreal**			**Boreal?**	**Older/ Younger Atlantic?**	**Preboreal?**	**late Boreal/ early Older Atlantic**	**Subboreal**				**Subboreal**							**early to mid Preboreal + Subboreal**	**Sub-boreal**	**Subboreal**	**Modern**	
Ecological Groups	**Species**																													
1	*Clausilia cruciata*	11	22				2							1	2	1	6	2	2	3	1	2								
	Ena montana	5	6				3							2	1			3		3	4	1								
	Isognomostoma isognomostomos		4				2	1							1		1		4	3	2	2	2			1				
	Macrogastra attenuata	16	27				3							2	4	2	5	4	8	4	5	3				2				
	Macrogastra ventricosa	10	18				7							2	7	5	16	8	121	19	22	3				2		1		
	% group 1	*6.5*	*3.7*		*0.0*	*0.0*	*2.3*	*4.2*						*11.5*	*7.2*	*2.7*	*4.4*	*6.5*	*20.3*	*3.5*	*2.1*	*12.8*	*14.3*			*0.2*		*8.3*	*0.0*	
2	*Vertigo alpestris*																									1				
	Vertigo pusilla					8	1										1		1	1	2					4				
	% group 2	*0.0*	*0.0*		*0.0*	*0.3*	*0.1*	*0.0*						*0.0*	*0.0*	*0.0*	*0.2*	*0.0*	*0.2*	*0.1*	*0.1*	*0.0*	*0.0*			*0.2*		*0.0*	*0.0*	
3	*Acanthinula aculeata*	7	53			10	11							1	3	4	16	3	15	12	40	2				16				
	Acicula lineata		5				1										3		2	4	2	1								
	Aegopinella pura	20	38				12							2	3	1	3	2	18	27	51	1				2				
	Cepaea silvatica				1	2	1																			1				
	Clausilia dubia	4	2											1	1	1	1	1	3	2	1									
	Cochlodina laminata	10	10				1	1						1	5	2	3			7	3	1								
	Euomphalia strigella		2				2																							
	Helicigona lapicida		2											2	1															
	Helicodonta obvoluta		14				4	2						2	5	1	2	2	1	12	2	1	3							
	Macrogastra plicatula	13	6				5							2	3	5	8	4	10	12	10	7	1			2		1	1	
	Merdigera obscura	1	2				1							1				1			1									
	Monachoides incarnatus		13				5	1							2	1	5	3	3	6	3	1	1						1	
	Platyla polita		2													1	4		1	10	33					1				
	Sphyradium doliolum	4	27				1							1	1		1	1	4		4									
	% group 3	*9.1*	*8.6*		*5.3*	*0.4*	*5.8*	*16.7*						*21.3*	*11.5*	*5.3*	*7.3*	*6.5*	*8.6*	*10.2*	*9.3*	*16.3*	*35.7*			*1.0*		*8.3*	*1.6*	
4	*Aegopinella nitens*	95	196			2	42	3						9	14	7	18	6	36	115	86	7	1			16		1		
	Clausilia rugosa parvula	3	3			1	5								1			1	2	1	3					3				
	Cochlostoma septemspirale							1																						
	Discus rotundatus	235	319			5	96	2						8	29	37	77	29	47	204	122	9	2			19		1	1	
	Discus ruderatus				1	49								1		1*			2*							15				
	Helix pomatia																												2	
	Milax sp.																		1											
	Nesovitrea petronella					59	5*							1			1*									94				
	Oxychilus cellarius	7	6			1	6								1		1	2	3	6	10									
	% group 4	*52.3*	*25.5*		*5.3*	*4.2*	*19.8*	*25.0*						*31.1*	*21.5*	*14.6*	*15.2*	*14.4*	*13.4*	*36.0*	*13.7*	*18.6*	*21.4*			*6.4*		*16.7*	*2.5*	
6	*Arianta arbustorum*		3		2	6	3							3	4	2	1		2	3	1					3		3		
	Carychium tridentatum	3	857			85	281	2						2	50	144	230	92	228	325	787	32				213		1		
	Cochlicopa lubrica	10	6		1	64	7							3			9	5	5	6	23					35		1		
	Columella columella					218	1*								1*		2*				1*					14				
	Columella edentula					1															1					4				
	Fruticola fruticum		4				3	1						1	1	1	1	1	4	1	2	1							1	
	Punctum pygmaeum					60	1								1				1	1	1					189				
	Trochulus sericeus	6	8		4	15	17	4						3	3	3	13	6	3	20	56	3	3			8			2	
	Vertigo substriata					115	1									1	4				4					175				
	Vitrea crystallina	96	101			7	13							1	2		9	9	22	6	17					16				
	% group 6	*17.7*	*47.6*		*36.8*	*20.5*	*43.3*	*29.2*						*21.3*	*29.2*	*50.2*	*42.3*	*43.0*	*39.8*	*40.0*	*55.4*	*41.9*	*21.4*			*28.5*		*41.7*	*2.5*	
7	*Cepaea hortensis*	1	11			2	7	1						3	6	2	5	1	11	2	3	2	1			7		1		
	Cepaea nemoralis																												1	
	Euconulus fulvus					97											1									22				
	Limax/Deroceras sp.	1	7		1	59	25	1						1	29	12	5	6	18	5	12	1				76		1	12	
	Nesovitrea hammonis	31	6			60	13	2						1	1	5	6	3	6	11	8					65				
	Vitrea contracta	1														1										1				
	% group 7	*5.2*	*1.2*		*5.3*	*7.8*	*6.0*	*16.7*						*8.2*	*17.2*	*6.6*	*2.7*	*3.8*	*5.3*	*2.0*	*1.4*	*3.5*	*7.1*			*7.4*		*16.7*	*10.7*	
8	*Abida secale*		1																											
	Cochlicopa lubricella	14	13			27	2							1			5			1	7					13				
	% group 8	*2.2*	*0.7*		*0.0*	*1.0*	*0.3*	*0.0*						*1.6*	*0.0*	*0.0*	*0.8*	*0.0*	*0.0*	*0.1*	*0.4*	*0.0*	*0.0*			*0.6*		*0.0*	*0.0*	
9	*Pupilla muscorum*				2	195	1										1		1							30			1	
	Vallonia costata	43	199		1	468	110	1						1	20	20	61	22	56	20	147	3				514			21	
	Vallonia excentrica		6				2										2	1			3								12	
	Vallonia pulchella	2	3		2	865	18								4	3	8	6	6	3	9	1				393		1	61	
	Vertigo pygmaea					3	2													1	6									
	% group 9	*6.9*	*10.1*		*26.3*	*55.1*	*17.7*	*4.2*						*1.6*	*11.5*	*7.6*	*11.4*	*11.0*	*9.5*	*2.7*	*10.3*	*4.7*	*0.0*			*40.6*		*8.3*	*77.9*	
10	*Chondrula tridens*							1																						
	Pupilla sterri					1																								
	Pupilla triplicata																									1				
	% group 10	*0.0*	*0.0*		*0.0*	*0.0*	*0.0*	*4.2*						*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*			*0.0*		*0.0*	*0.0*	
11	*Carychium minimum*	1	47			103	17								1	24	40	18	11	37	95	1				219				
	Succinea putris						1									7	31			1	1									
	Vertigo antivertigo					4											1									8				
	Zonitoides nitidus													1		2					4					1				
	% group 11	*0.2*	*2.3*		*0.0*	*3.8*	*2.4*	*0.0*						*1.6*	*0.5*	*11.0*	*11.4*	*6.8*	*1.7*	*4.2*	*6.2*	*1.2*	*0.0*			*9.9*		*0.0*	*0.0*	
12	*Euconulus alderi*					10																				2				
	Galba truncatula		9		4	152	17								3	6	26	21	7	11	13	1				103				
	Oxyloma elegans					1								1							1					4				
	Succinella oblonga					18																				5			6	
	Vertigo angustior					3	1										1		3		1					2				
	Vertigo geyeri					5																				6				
	% group 12	*0.0*	*0.4*		*21.1*	*6.8*	*2.4*	*0.0*						*1.6*	*1.4*	*2.0*	*4.3*	*8.0*	*1.5*	*1.2*	*0.9*	*1.2*	*0.0*			*5.3*		*0.0*	*4.9*	**Totals**
Total Terrestrial Molluscs (not including redeposited shells)		**650**	**2058**	**sterile**	**19**	**2781**	**753**	**24**	**sterile**	**sterile**	**sterile**	**sterile**	**sterile**	**61**	**209**	**301**	**631**	**263**	**666**	**905**	**1609**	**86**	**14**	**sterile**	**sterile**	**2308**	**sterile**	**12**	**122**	**13472**
Number of Terrestrial Species (not including redeposited shells)		**27**	**38**	**sterile**	**10**	**36**	**42**	**15**	**sterile**	**sterile**	**sterile**	**sterile**	**sterile**	**30**	**30**	**27**	**38**	**28**	**35**	**36**	**44**	**23**	**8**	**sterile**	**sterile**	**43**	**sterile**	**10**	**13**	**66**
13	*Anisus leucostoma*																			1										
14	*Pisidium casertanum*		3		1	3	17							1	3	**27**	**103**	**42**	**5**	**20**	36	1	1			**37**				
	Pisidium personatum		5			4	**7**									**38**	**78**	**23**	**18**	**11**	**36**					9				
	Radix labiata		1				1										12	5	2	6						1				**Totals**
15	*Pisidium amnicum*		2				15								2	**65**	**76**	**32**	1	2	**24**	2				3				
Total Aquatic Molluscs		**0**	**11**	**sterile**	**1**	**7**	**40**	**0**	**sterile**	**sterile**	**sterile**	**sterile**	**sterile**	**1**	**5**	**130**	**269**	**102**	**26**	**40**	**96**	**3**	**1**	**sterile**	**sterile**	**50**	**sterile**	**0**	**0**	**782**
Number of Aquatic Species		**0**	**4**	**sterile**	**1**	**2**	**4**	**0**	**sterile**	**sterile**	**sterile**	**sterile**	**sterile**	**1**	**2**	**3**	**4**	**4**	**4**	**5**	**3**	**2**	**1**	**sterile**	**sterile**	**4**	**sterile**	**0**	**0**	**5**
Aquatic Molluscs as a proportion of Total Molluscs (%)		**0.0**	**0.5**	**-**	**5.0**	**0.3**	**5.0**	**0.0**	**-**	**-**	**-**	**-**	**-**	**1.6**	**2.3**	**30.2**	**29.9**	**27.9**	**3.8**	**4.2**	**5.6**	**3.4**	**6.7**	**-**	**-**	**2.1**	**-**	**0.0**	**0.0**	
Total Molluscs (not including redeposited shells)		**650**	**2069**	**sterile**	**20**	**2788**	**793**	**24**	**sterile**	**sterile**	**sterile**	**sterile**	**sterile**	**62**	**214**	**431**	**900**	**365**	**692**	**945**	**1705**	**89**	**15**	**sterile**	**sterile**	**2358**	**sterile**	**12**	**122**	**14254**
16	*Cecilioides acicula*																												11	
7	earthworm granules		5											1			1	5	1	11	14					8		3		
	small vertebrates - bones																						1 tooth			2 teeth				

For a description of the ecological groups see Figure 2

🟥 Pioneer species that disappeared from the Swiss Plateau + lower slopes of the Jura by ca. 6000 BC, during the Older Atlantic
🟨 Forest species that arrived and became widely present between the late Boreal and the end of the Older Atlantic in western CH
🟩 Species that arrived or became common between the Younger Atlantic and the Subboreal
🟦 Species that arrived during the later part of the Subboreal after c.1200 BC
🟪 Pioneer species typical of colder periods
🟧 Pioneer species typical of both colder periods + the start of warmer periods

Note 1: 🟩 * these shells have been redeposited from older layers

⬜ shells from Layer 13

Appendix 2. Additional photographs for the most important Molluscan species from the Hasli Formation of the Irchel Plateau and from later sites

The Hasli Formation of the Irchel Plateau

Figure 1 *Cochlostoma salomoni*, Amselboden

Figure 2 *Acicula parcelineata*, Hochwacht (note scale = 2 mm)

Figure 3 *Azeca goodali*, Hochwacht + sub-fossil Holocene - SE England (note scale = 2 mm)

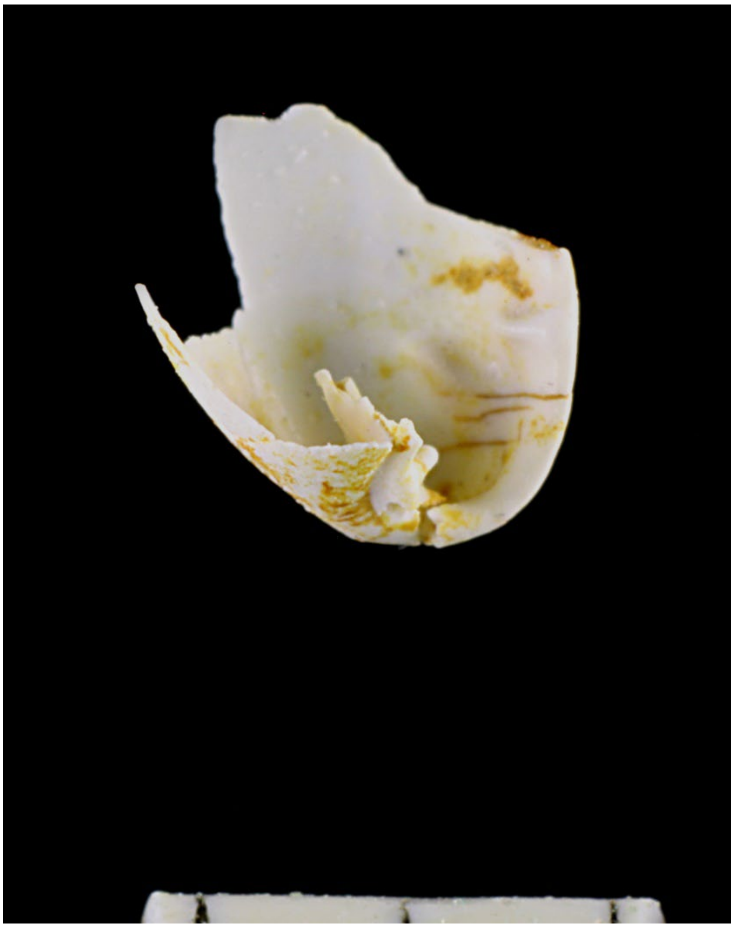


Figure 4 *Spermodea lamellata*, sub-fossil Holocene - southeastern England

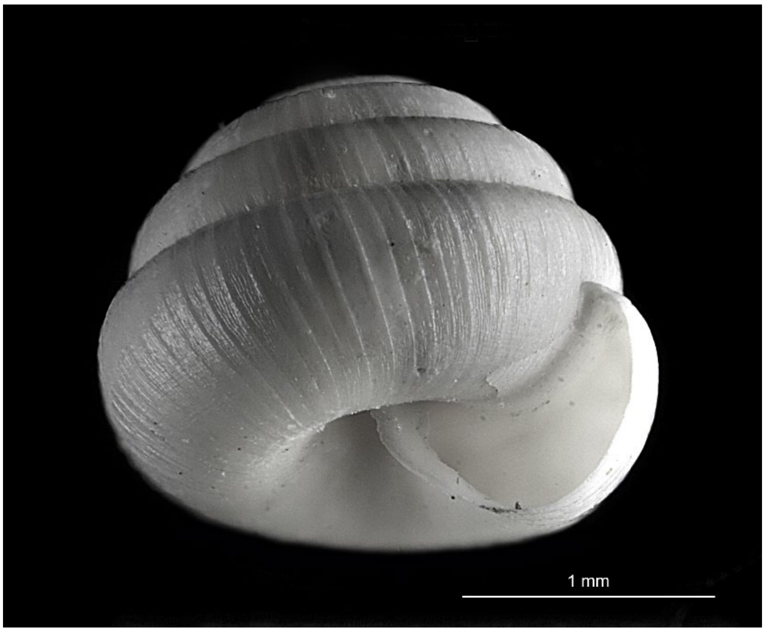
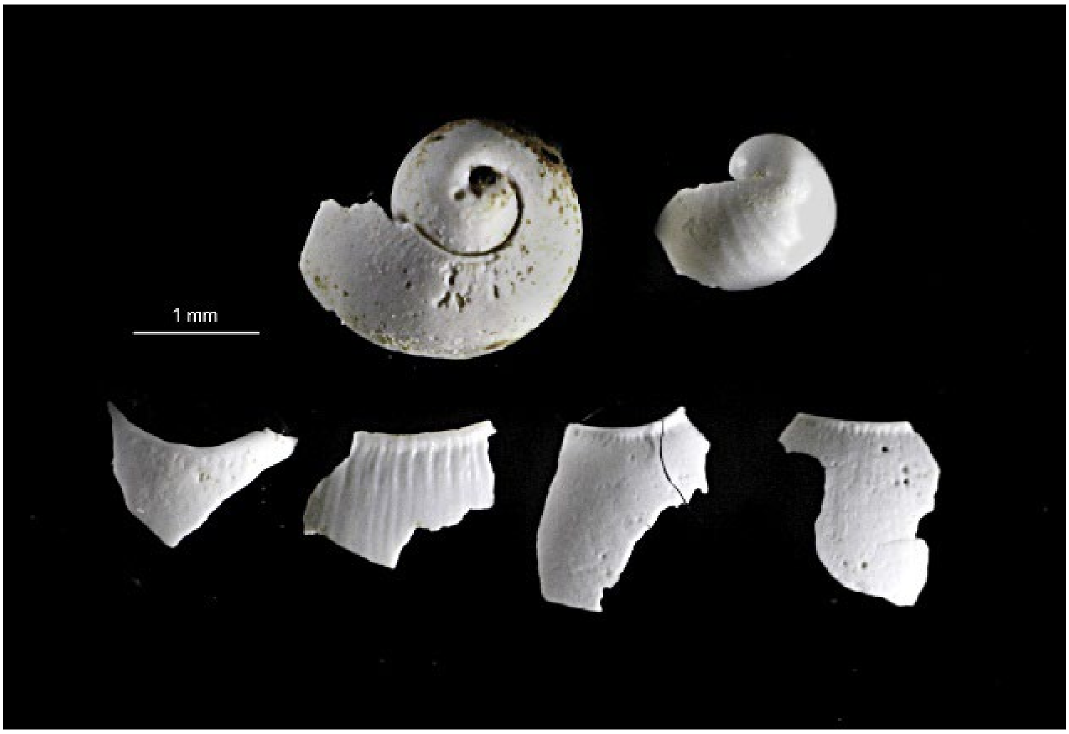


Figure 4 continued *Spermodea lamellata*, Hasli + Hochwacht

Figure 5 *Poiretia dilatata dilatata*, Hochwacht + Wilemerirchel



(note scale = 2 mm)

Figure 5 continued *Poiretia dilatata dilatata*, modern - Calabria southern Italy

1 mm

Figure 5 continued *Poiretia dilatata dilatata*, modern - Calabria southern Italy

…..

Figure 6 *Columella columella*, Hochwacht

Figure 7 *Discus perspectivus*, Hochwacht (note scale = 2 mm)

Figure 8 *Archaegopis acutus*, Hochwacht

Figure 8 continued *Archaegopis acutus*, Hochwacht; detail

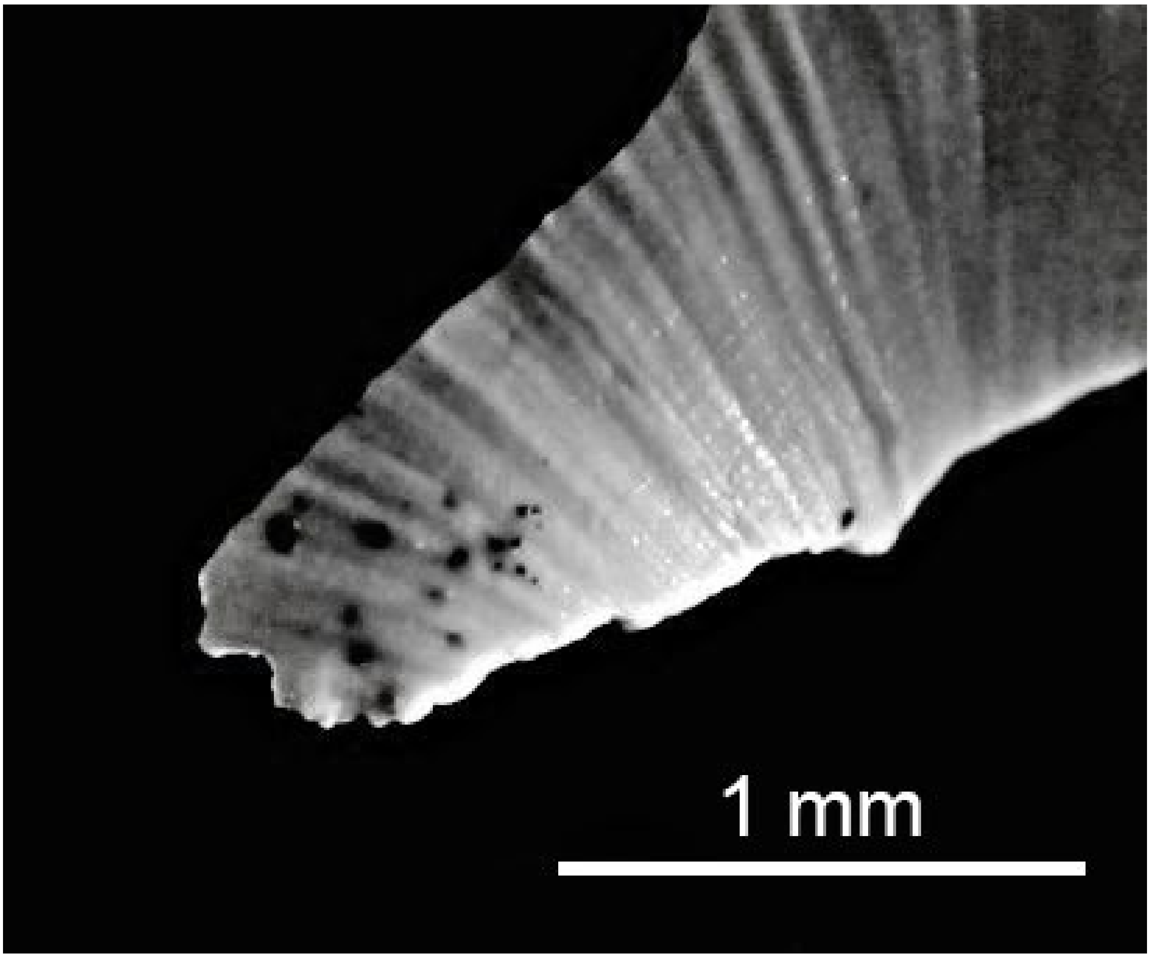


Figure 9 *Aegopis* sp., Hochwacht Upper level (note scale = 2 mm)

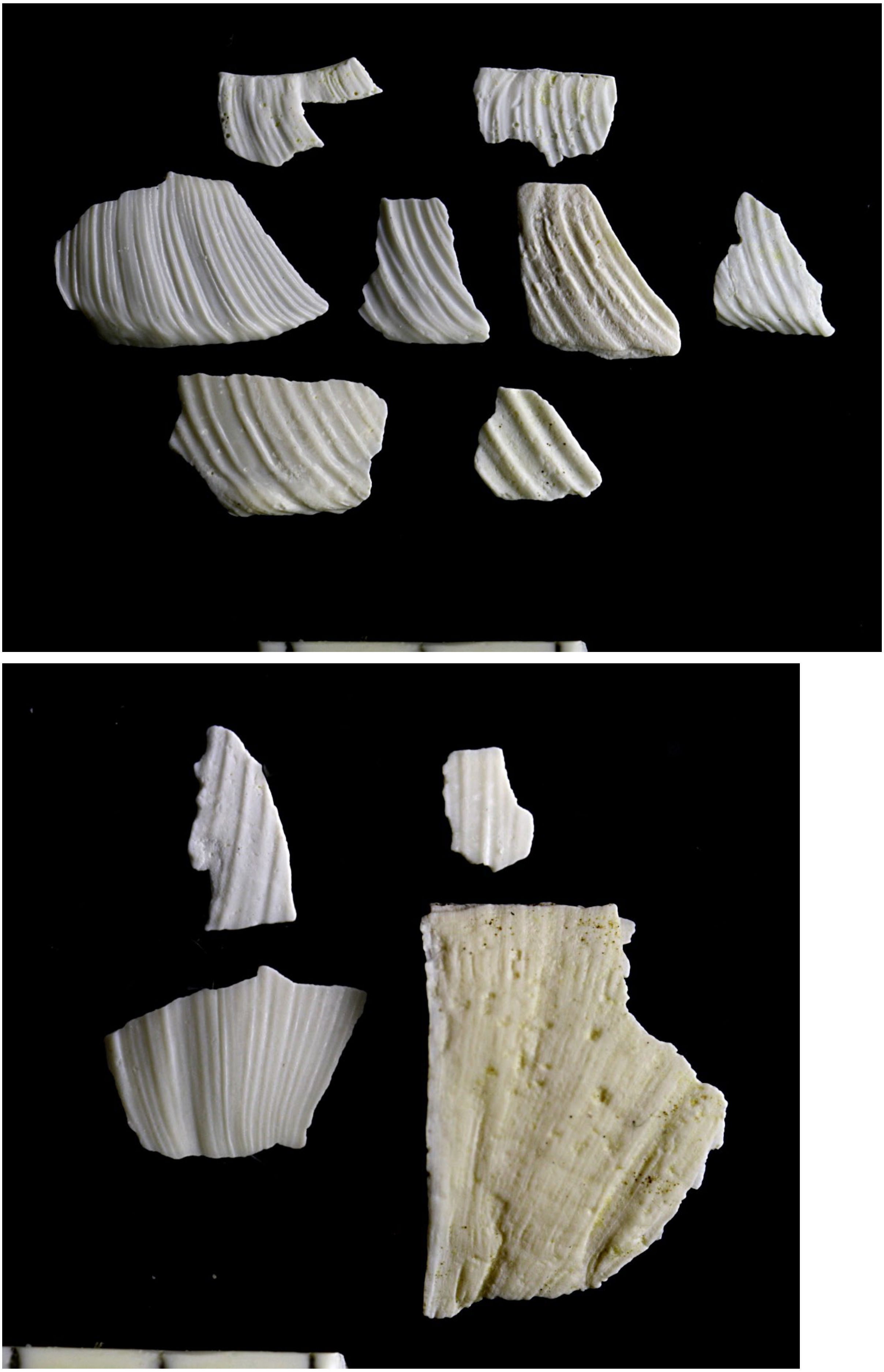


Figure 10 *Retinella elephantium*, Hochwacht

The scale is exactly twice that of the photo above.

Figure 11 *Aegopinella ressmanni*, Hasli (note scale = 2 mm)

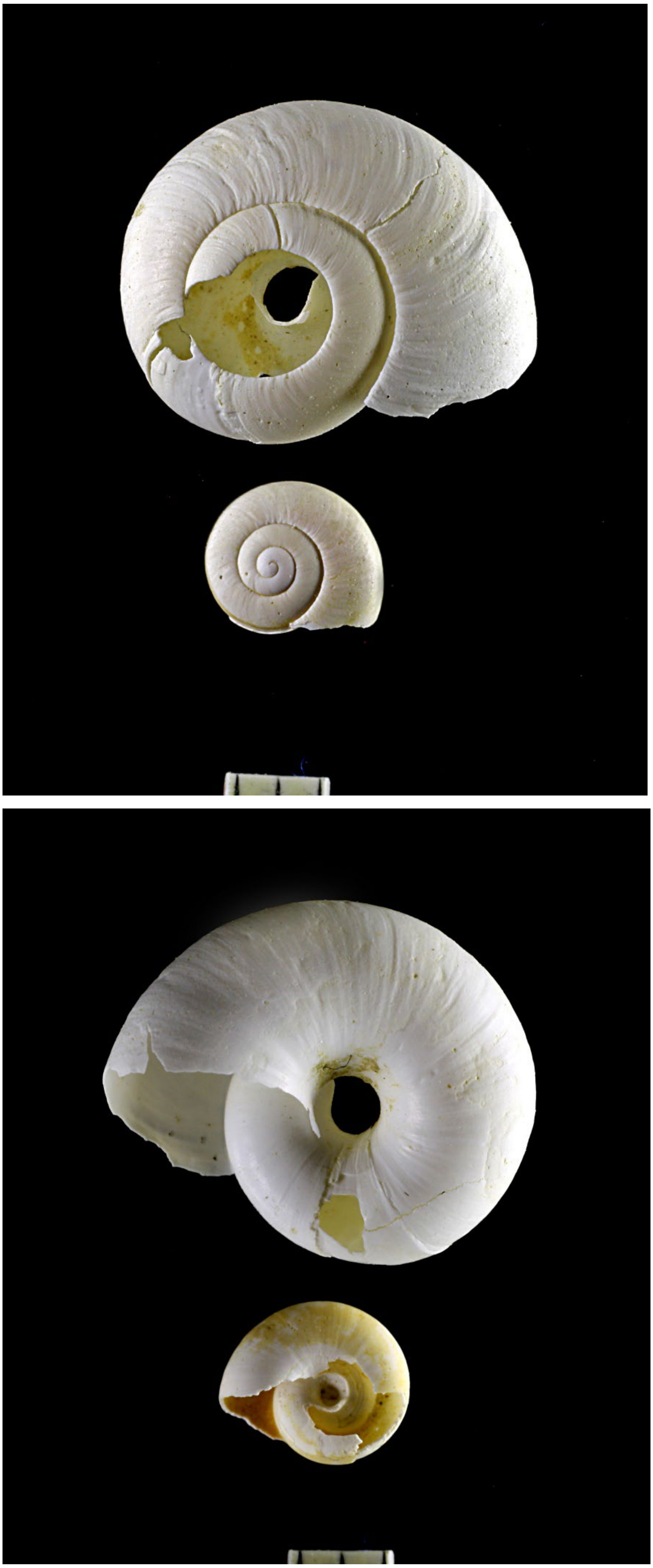


Figure 12 *Oxychilus clarus*, Hochwacht (note scale = 2 mm)

Figure 13 *Vitrinobrachium breve,* Hasli (note scale = 2 mm)

Figure 14 *Monachoides vicinus*, Hochwacht

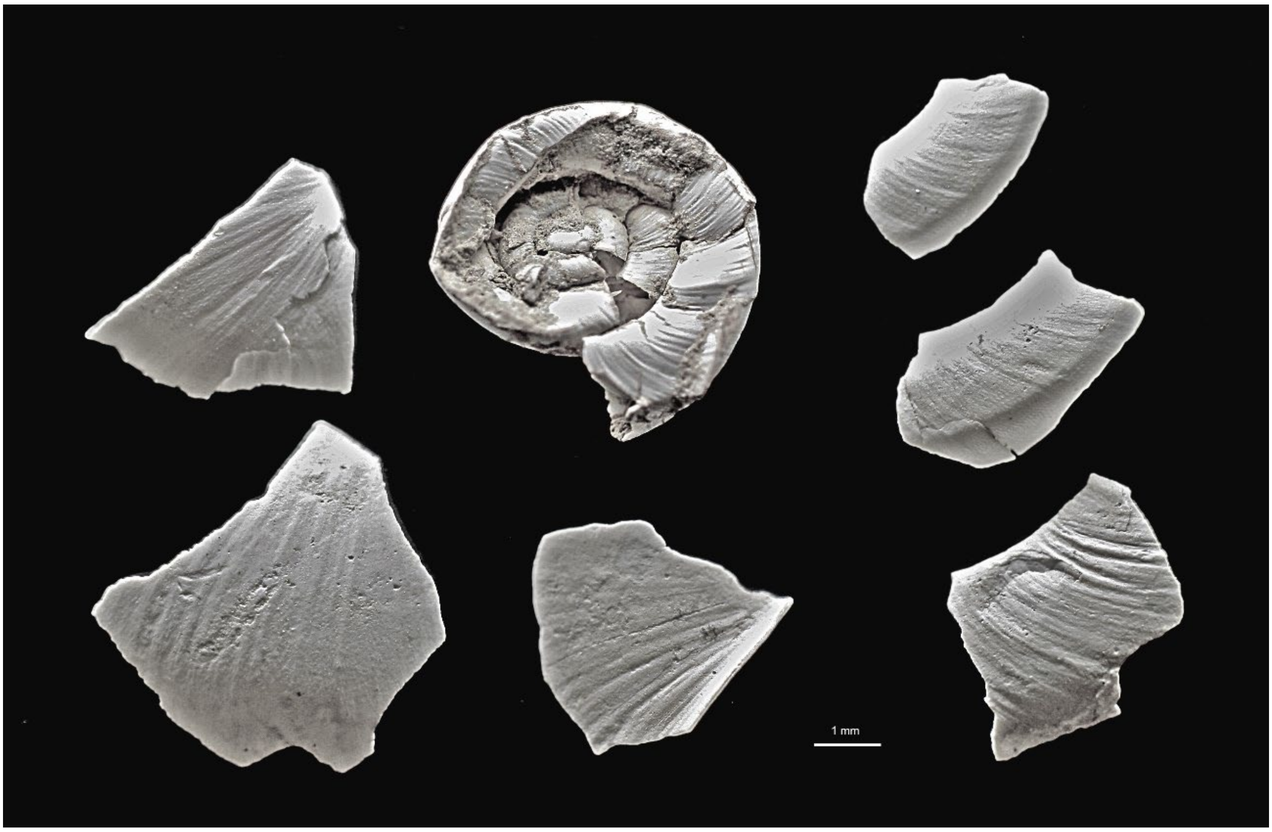


Figure 14 continued *Monachoides vicinus*, Hochwacht, detail

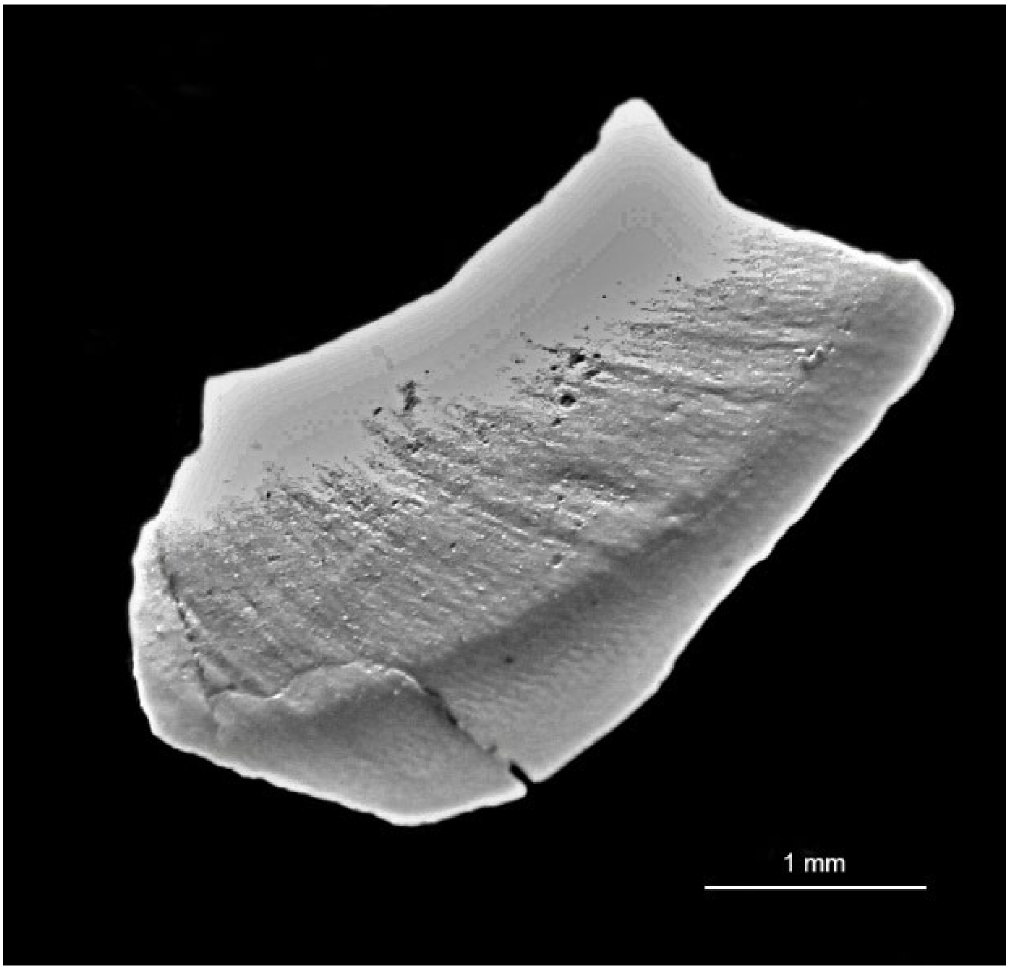


Figure 14 continued *Monachoides vicinus*, modern - eastern Czech Republic

Figure 15 *Monachoides incarnatus*, modern - western Switzerland (note scale = 2 mm)

Figure 16 *Causa holosericea*, Hochwacht Upper level (note scale = 2 mm)

Figure 16 continued *Causa holosericea*, modern- south-eastern Switzerland (note scale = 2 mm)

Figure 18 *Ciliella ciliata*, Hochwacht Upper level (note scale = 2 mm)

Figure 18 continued *Ciliella ciliata*, modern – south-eastern Switzerland (note scale = 2 mm)

Figure 19 *Trochulus filicinus*, Hasli (Bräm) + Hochwacht (note scale = 2 mm)

Figure 19 continued *Trochulus filicinus*, Hasli (Bräm; note scale = 2 mm)

Figure 20 continued *Trochulus filicinus*, Hasli (Bräm; note scale = 2 mm)

Figure 20 continued *Trochulus filicinus*, modern – south-central Austria (note scale = 2 mm)

Figure 21 continued *Trochulus filicinus*, modern – south-central Austria (note scale = 2 mm)

Figure 22 *Trochulus leucozonus*, Hasli (Bräm; note scale = 2 mm)

Figure 22 *Trochulus leucozonus*, continued – modern - southeastern Austria (note scale = 2 mm)

Figure 23 *Urticicola umbrosus*, Hasli (note scale = 2 mm)

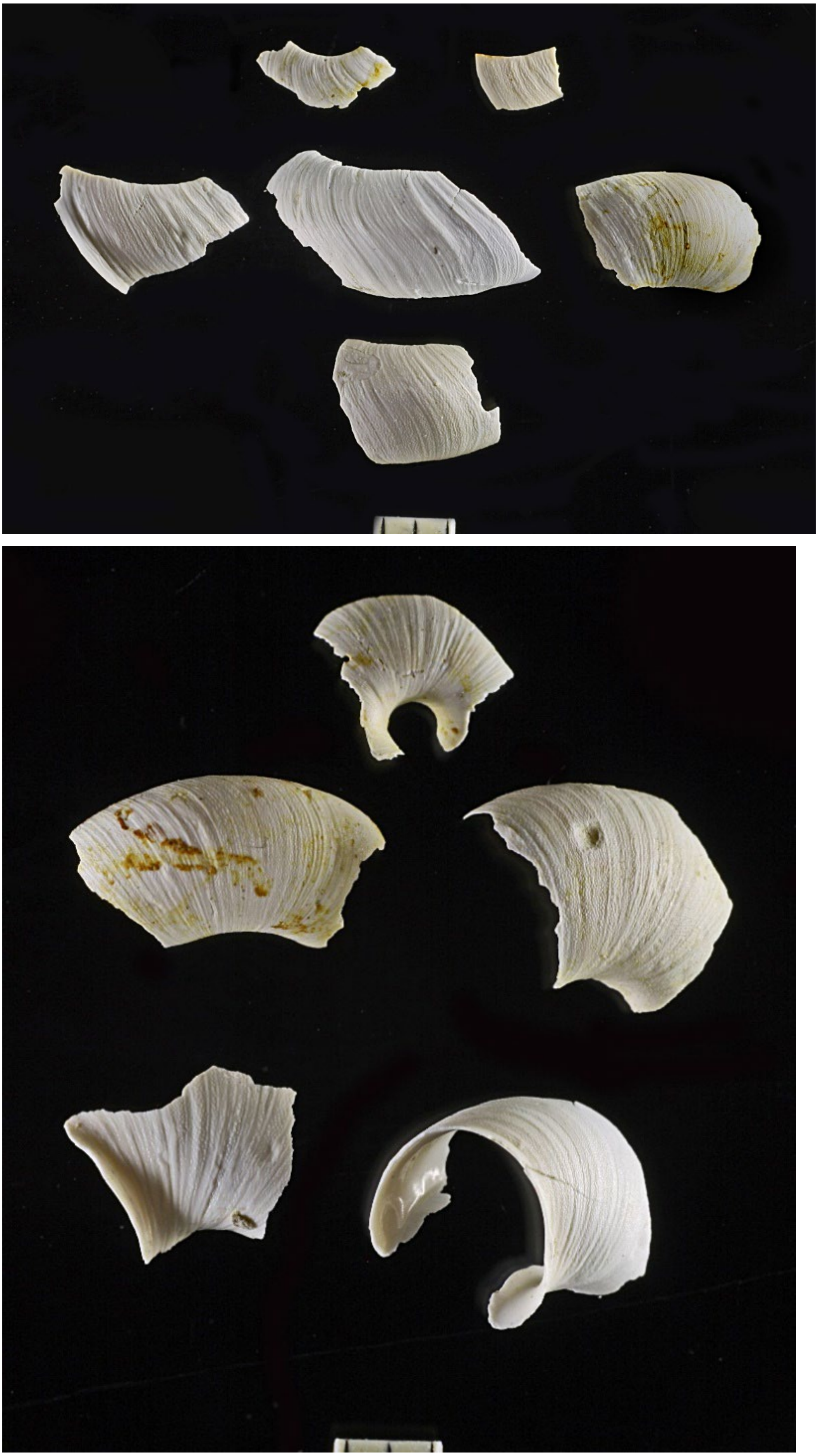


Figure 23 continued *Urticicola umbrosus*, Hasli

Figure 24 *Clausilia stranzendorfensis*, Hochwacht

Figure 24 continued *Clausilia stranzendorfensis*, Hochwacht

Figure 24 *Clausilia stranzendorfensis*, Wilemerirchel

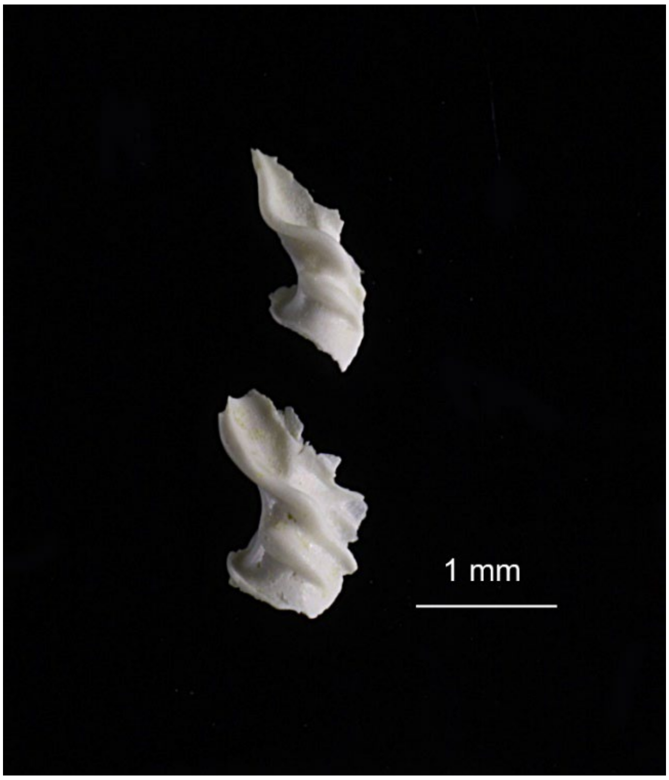


Fig. 25 *Clausilia parvula antiquatis*, Hochwacht Upper level ® + Hungerbol (note scale = 2 mm)

Figure 26 *Clausilia cruciata*, modern - western Switzerland (note scale = 2 mm)

Figure 27 *Macrogastra sessenheimensis*, Hasli (including Bräm material)

Figure 28 *Serrulella* sp., Wilemerirchel

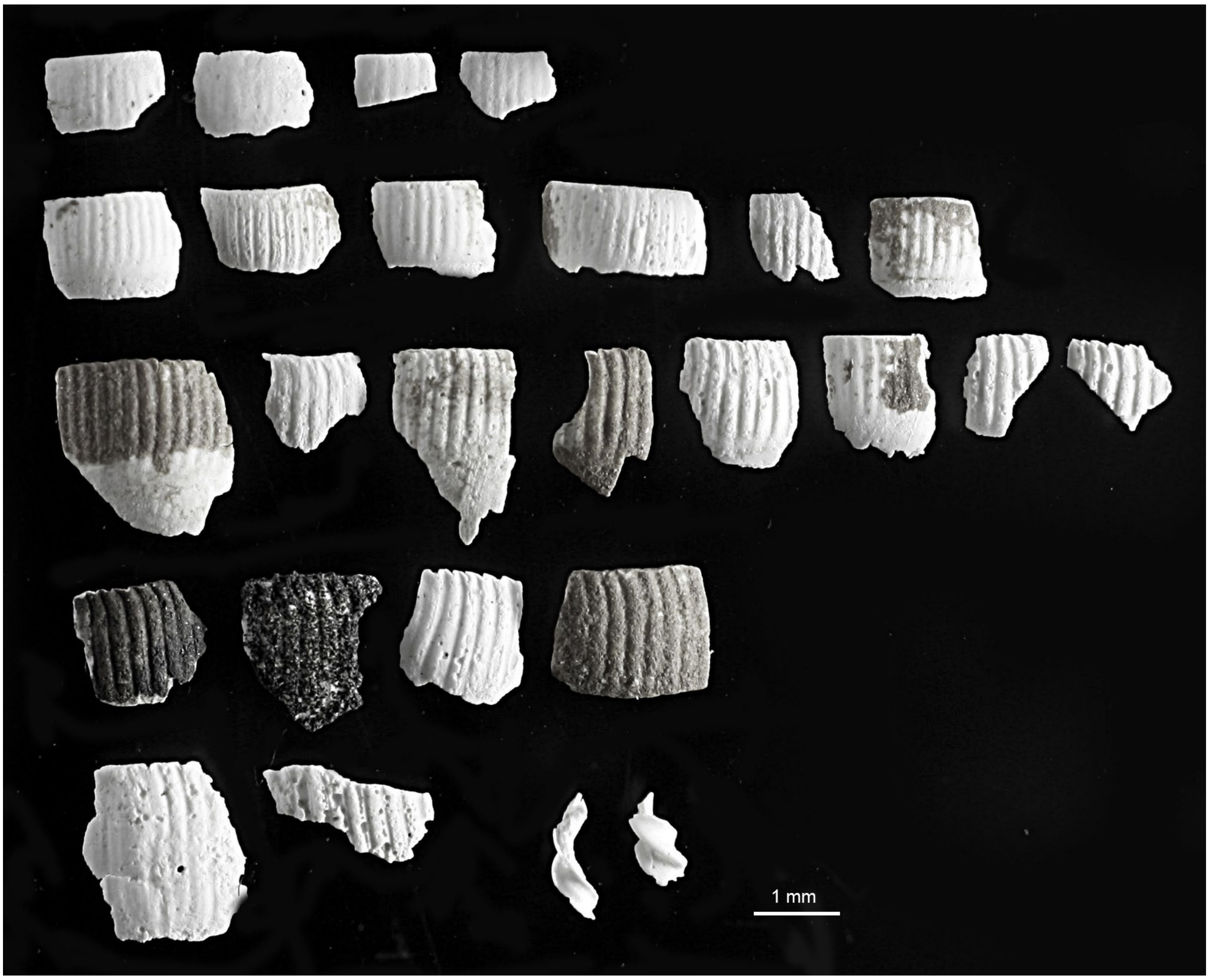


Figure 29 *Triptychia* new sp., Wilemerirchel

Figure 29 continued *Triptychia* new sp., Wilemerirchel. Decollate apices

Figure 29 continued *Triptychia* new sp., Wilemerirchel

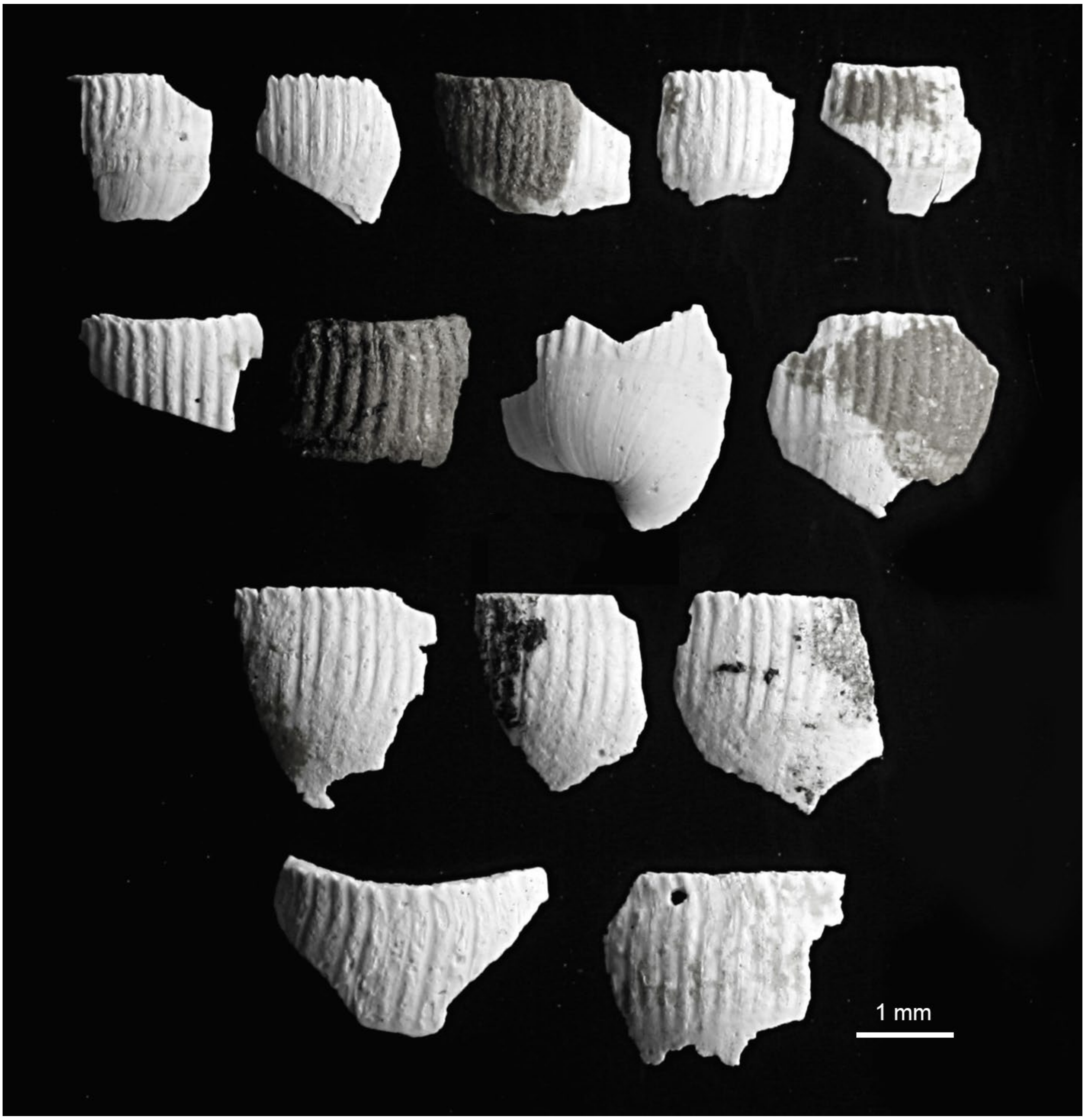


Figure 29 continued *Triptychia* new sp., Wilemerirchel

Figure 29 continued *Triptychia* new sp., Wilemerirchel

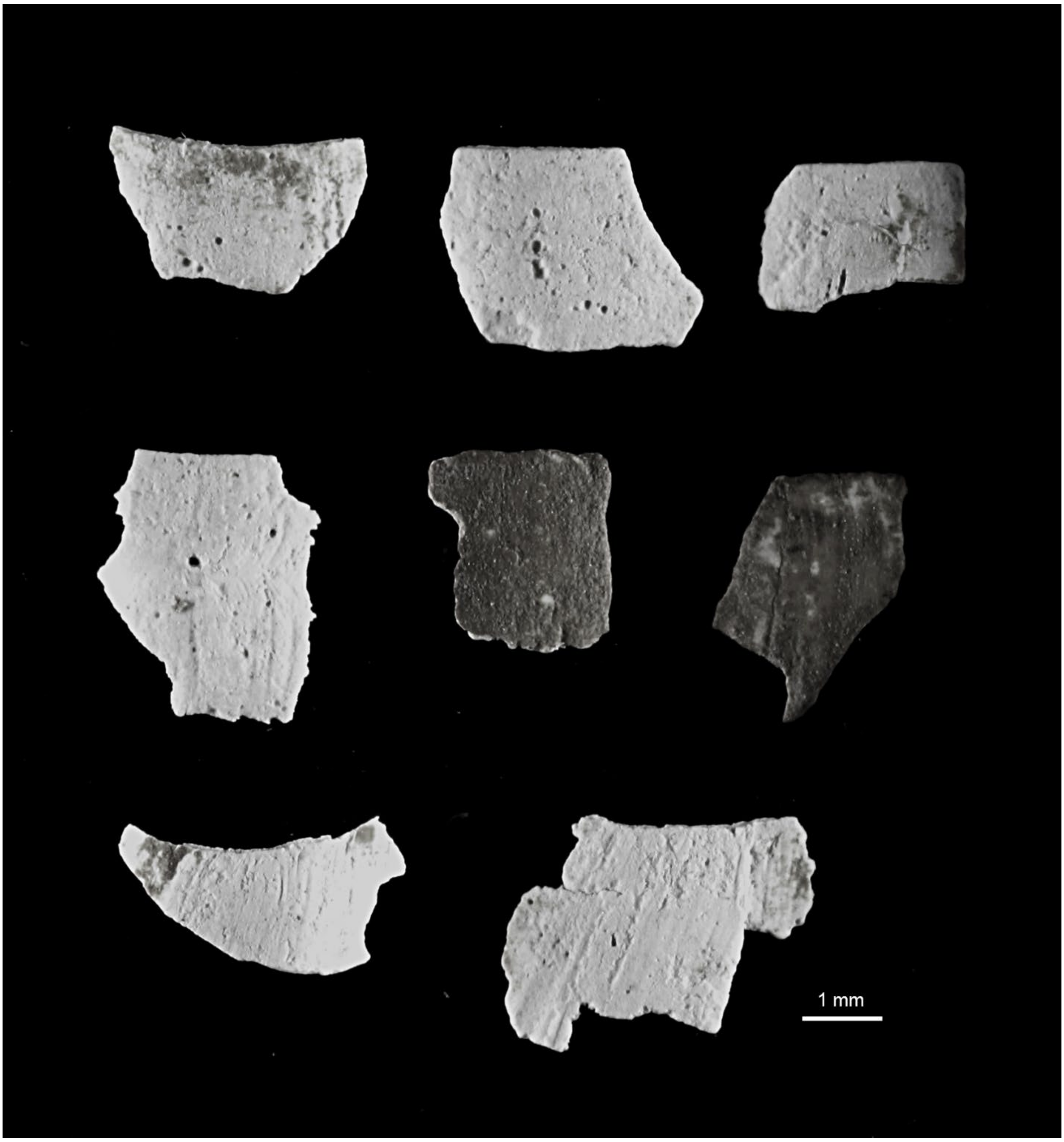


Figure 29 continued *Triptychia* new sp., Wilemerirchel

Figure 29 continued *Triptychia* new sp., Wilemerirchel

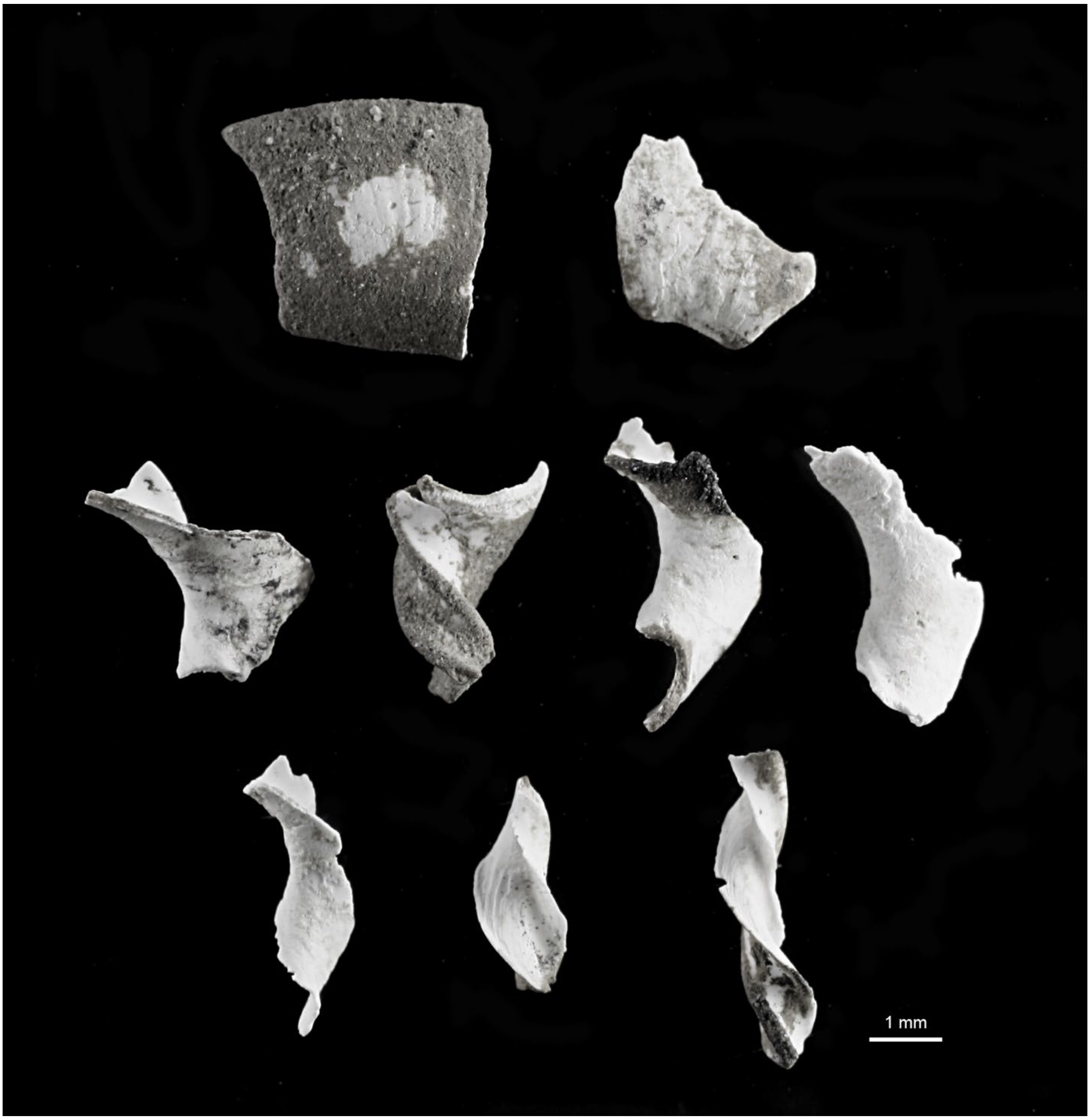


Figure 30 *Hauffenia*/*Islamia* sp., Hochwacht Upper level (note scale = 2 mm)

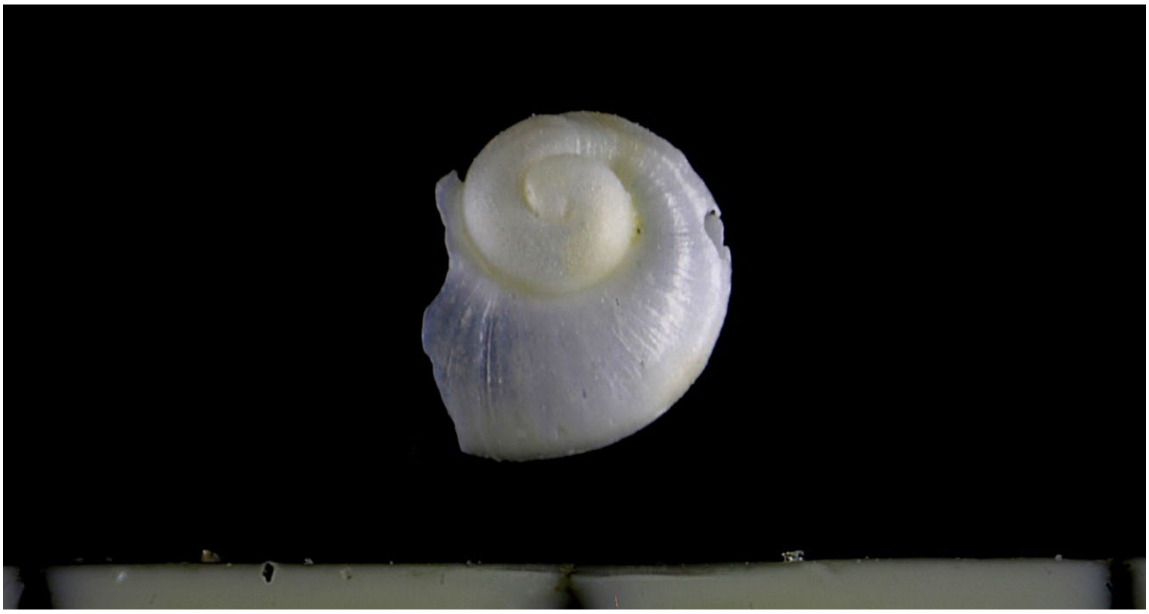


Figure 31 *Bythiospeum rhenanum*, Hochwacht (note scale = 2 mm)

Figure 32 Unidentified Moitessieriid/Hydrobiid sp., Hochwacht (note scale = 2 mm)

Figure 32 continued Unidentified Moitessieriid/Hydrobiid sp., Hochwacht (note scale = 2 mm)

A key molluscan species from Ecoteaux, VD

Figure 33 *Pisidium clessini* (fragments from several individuals; note scale = 2 mm)

Key molluscan species from Sous-Terre, Geneva, GE

Figure 34 *Aegopis klemmi* (note scale = 17 mm)

Figure 34 *Aegopis klemmi* continued (note scale = 17 mm)

(note scale = 2 mm)

Figure 34 *Aegopis klemmi* continued (note scale = 2 mm)

(note scale = 17 mm)

Figure 34 *Aegopis klemmi* continued (note scale = 17 mm)

Figure 35 *Zonitoides sepultus* (note scale = 2 mm)

Figure 36 *Clausilia pumila* (note scale = 2 mm)

A key molluscan species from Zell, LU compared to similar species from Switzerland

Figure 37 *Acicula parcelineata*, Hochwacht, *Acicula lineata*, modern - western Switzerland, *Acicula lineolata*, Zell, LU (note scale = 2 mm)

Appendix 3: The sites with molluscan faunas referred to in Sections 5.5 and 5.6

Please note: **sites in bold** have independent palaeomagnetic or radiometric/analytical dating.

Austria

A comprehensive overview by Frank (2006) covers most sites with molluscan data in Austria, three-quarters of which are located in the east of the country, one quarter in the centre and just a single site in the western part of the country. Much of the data is taken from detailed studies for most key sites of both molluscs (Frank) and small mammals (Rabeder), published in Döppes and Rabeder 1997. Important early work at a number of sites, including Stranzendorf and Deutsch-Altenburg, was undertaken by Binder (1977). An important review of Clausiliid identifications from Early and early Middle Pleistocene sites was undertaken by Nordsieck (2007, 2021).

The key sites are:

Neudegg: end of the Late Pliocene (MN16b); small mammals; Frank and Rabeder 1997b

Stranzendorf: end of the Late Pliocene (MN16b) to EP1 (MN17); palaeomagnetic dating, small mammals; Bucha et al. 1975, Fink 1979, Kovanda et al. 1995, Frank and Rabeder 1997c

Krems (Schieβstätte): late EP1(no/few molluscs) -EP2-EP3 to start of the early Middle Pleistocene; palaeomagnetic dating, small mammals; Bucha et al. 1975, Fink 1979, Kovanda et al. 1995, Frank and Rabeder 1997a

Deutsch-Altenburg: EP1 (few molluscs), EP2, EP3 to start of the early Middle Pleistocene; dated by small mammals (EP1 sediments are associated with *Mimomys pliocaenicus* and *Borsodia hungarica*, EP2 with *Allophaiomys pliocaenicus*, late EP2 contexts with *Microtus praehintoni* and EP3 strata with *M. hintoni*); Frank and Rabeder 1997d

Radlbrunn: EP2; small mammals; Frank and Rabeder in Doppes and Rabeder 1997

Hundsheim: early Middle Pleistocene; small mammals; Frank and Rabeder 1997e

Kovanda et al. 1995 undertook new analyses of molluscan faunas (Kovanda) and soils at Stranzendorf and Krems, but the identifications for the Clausiliidae may not be fully reliable.

The following later sites are also dated:

Vienna Basin; MIS 11, MIS 9, MIS 5e and Early to Late Würm; OSL and palaeomagnetic dating; Salcher et al. 2017

Stratzing; later Middle Pleistocene; MIS 11 or MIS 9; OSL; Terhorst et al. 2011

Aigen-Hollweg (Göttweig-Aigen); MIS 5e; OSL; Terhorst et al. 2011

Paudorf; MIS 5e; OSL; Terhorst et al. 2011

Czech Republic and Slovakia

A comprehensive overview by Ložek (1964) covers most sites with molluscan data in these two countries up until that time, while key sites studied up until the mid-eighties are listed in Horáček and Ložek 1988, with updates in Ložek 1972a, 2000, 2001.

The following key sites having dating evidence:

Červený kopec (CR); EP3 to early Middle Pleistocene; palaeomagnetic dating; Bucha et al. 1975

Chlum (CR); EP2-EP3; small mammals

Ctiněves-Hýkovina (CR); EP1; small mammals

Dolni Věstonice (CR); early Middle Pleistocene; stratigraphy; seeds from *Celtis* sp.; Ložek 2008

Gombasek-Steinbasek (S); EP2/EP3; small mammals

Hradište (S); early Middle Pleistocene; small mammals

Plešivec-Csepkö (S) and Slovenská skala, Plešivec-Csepkö; there are EP1 + EP3 sites dated by small mammals; but the most important molluscs come from EP3

Přezletice (CR); early Middle Pleistocene; small mammals; palaeomagnetic dating; Bucha et al. 1975

Stránská skála I (CR); EP3; small mammals; palaeomagnetic dating; Bucha et al. 1975

Stránská skála II (CR); EP3; small mammals

Únětice-Holý vrch (CR); EP3 to early Middle Pleistocene; small mammals; palaeomagnetic dating; Bucha et al. 1975

Zlatý Kůň-C718 and Zlatý Kůň-Höhle, Koněprusy (CR); early Middle Pleistocene; small mammals

Stránská skála I and Únětice-Holý vrch both date from EP3 as they have reversed polarity corresponding to the last part of the Matuyama Chron, while the latter site also has early Middle Pleistocene sediments with normal polarity. At Červený kopec the lowest layers with normal polarity corresponding to the Jaramillo sub-chron from EP3, are followed by deposits with reversed polarity, then by early Middle Pleistocene upper levels with normal polarity (Bucha et al. 1975).

At Hlubná, a probable EP3 fauna is mixed with MN16 small mammals.

Hungary

General overviews of Hungarian malacostratigraphy: Krolopp 1995, 2003, 2014, Sümegi 1995

Bükk Mountains; NE Hungary; EP3, Middle Pleistocene to Late Pleistocene; Krolopp 1992

Poland

Przymiłowice 3, Olsztyn, central southern Poland; EP1; small mammals; Stworzewicz 1994

Kielniki, Częstochowa, central southern Poland; EP2; small mammals; Stworzewicz 1981 Nordsieck 2007, 2021

Kozi Grzbiet, Kielce, central southern Poland; MIS 19/17; Fluorine-Chlorine-Apatite Dating of bones; small mammals; Stworzewicz 1981, Nordsieck 2007, 2021

Szymanowo, eastern Poland; MIS 11; molluscan biostratigraphy, pollen; Szymanek 2014.

A review of molluscs found at Eemian (MIS 5e) sites in Poland is given by Alexandrowicz and Alexandrowicz 2010.

Ukraine

Kolodiiv, eastern Ukraine; MIS 5e; Alexandrowicz and Dmytruk 2007

Belgium

Herzeele Formation; one site in NW France and five sites in SW Belgium; MIS 11; AAR dating; Meijer 1988b, Meijer and Preece 1995, Meijer and Cleveringa 2009

Zelzate, Vlaamse Valley; MIS 5e; AAR dating; Meijer 1969, 1988b, Meijer and Cleveringa 2009

France

Cessey-sur-Tille, Côte-d'Or; Late Pliocene (MN16b); small mammals, molluscan biostratigraphy, stratigraphy; Nordsieck 1972, 2007 (Clausiliidae), Schlickum 1975, Puisségur 1976, 1984

Cuisery, Saône et Loire; Late Pliocene (MN16b); molluscan biostratigraphy, stratigraphy; Schlickum and Puissegur 1978

Montagny-les-Beaune, Côte-d'Or; Late Pliocene (MN16b); molluscan biostratigraphy, stratigraphy; Schlickum and Puissegur 1978

Saint Bernard, Côte-d'Or; Late Pliocene (MN16b); molluscan biostratigraphy, stratigraphy; Schlickum and Puissegur 1977

Sessenheim, Alsace; Late Pliocene (MN16b); molluscan biostratigraphy, stratigraphy; Geissert 1967, Nordsieck 1974, 1976, 1981, 2007 (Clausiliidae), Schlickum and Geissert 1980

Sondage de l'Hôpital Civil, Strasbourg (at 65-65.5 m depth, core Upper Rhine Graben), Alsace; Late Pliocene (MN16b) and early Middle Pleistocene; molluscan biostratigraphy, stratigraphy; Nordsieck 1974 p.36, Geissert et al. 1976

Agencourt/Nuits-Saint-Georges, Côte-d'Or; EP1; small mammals, molluscan biostratigraphy; Puisségur 1976, 1984

Binges 5, Côte-d'Or; EP1; molluscan biostratigraphy, stratigraphy; Puisségur 1984

Gamsheim, Alsace; EP1; mammals, stratigraphy; Geissert 1985; in early gravels from the Rhine

La Wantzenau, Alsace; EP1; mammals, stratigraphy; Geissert 1969, 1970, 1985; in early gravels from the Rhine

Sondage des 'Dernières Nouvelles,' Strasbourg (core Upper Rhine Graben), Alsace; EP2/EP3; stratigraphy; Geissert et al. 1976

Grâce-Autoroute, Somme; later/final EP3 (MIS 21); ESR dating and ESR-U/Th dating; palaeomagnetic dating; fluvial terrace stratigraphy; Antoine et al. 2020; the faunal remains are said to date from MIS 21, but based on the dates alone they may date from MIS 25.

In cores from the Upper Rhine Graben taken near Mannheim, Germany (see below), it appears that subsidence due to tectonic movement may have slowed significantly after MIS 11, between 0.4 and 0.35 My (after the Ludwigshafen Formation), allowing subsequent erosion during MIS 6 and MIS 4/2 to largely remove sediments linked with interglacials MIS 9 and MIS 7, while strata linked with MIS 5e (within the Mannheim Formation) are also poorly conserved (cf. Hahne et al. 2012, Gabriel et al. 2013, Menzies and Ellwanger 2012, 2015, Li et al. 2018). The degree of subsidence seems to be fairly constant between Strasbourg and the Mannheim area (Ellwanger et al. 2012). In the following core sequences, the shells in cores from Strasbourg, Ohnheim and Marckolsheim come from two levels of silty sediment that resemble those of the OZH unit in cores in the URG from the region between Philippsburg-Mannheim-Biebesheim, Germany. As the gravels between the two silty levels are fairly thin, rather fine and sandy, they are unlikely to represent MIS 12, so the silts from both levels are believed to correspond to MIS 15-13.

Sondage Dingsheim (core Upper Rhine Graben), Alsace; early Middle Pleistocene; stratigraphy; Geissert et al. 1976

Sondage Lampertheim (core Upper Rhine Graben), Alsace; early Middle to Late Pleistocene; stratigraphy; Geissert et al. 1976

Sondage Marckolsheim (core Upper Rhine Graben), Alsace; early Middle Pleistocene; stratigraphy; Geissert et al. 1976

Sondage Ohnheim-Fegersheim (core Upper Rhine Graben), Alsace; early Middle Pleistocene and Holocene; stratigraphy; Geissert et al. 1976

Sondage La Place des Halles, Strasbourg (core Upper Rhine Graben), Alsace; early Middle Pleistocene; stratigraphy; Geissert et al. 1976

Sondage Polygone, Strasbourg (core Upper Rhine Graben), Alsace; early Middle Pleistocene; stratigraphy; Geissert et al. 1976

In the Rhine Valley from south of Strasbourg to the north of Karlsruhe, shared by Alsace and SW Germany, are a series of quarries for gravel and ‘brick-earth.’ Overlying gravels with Early Pleistocene mammal remains (*Mammuthus meridionalis*) and molluscs (see above), are gravels with bones from mammal species that first appeared or became more widespread during the Middle Pleistocene (*Mammuthus trogontherii*, *Palaeoloxodon antiquus*, *Bos primigenius*, *Equus caballus germanicus, Megaloceros* sp.). At 5-10 m depth within these gravels are yellowish silts, sandy-marls and sandy-silts with molluscs and abundant plant remains that confirm their interglacial character, including deciduous trees and shrubs like *Acer*, *Alnus*, *Cornus*, *Corylus*, *Ilex*, *Prunus* and *Tilia*. As these gravels are covered by ‘Rhine Sands’ that began to be deposited during MIS 15 (see below), they seem to date from MIS 18 and MIS 16, while the silts correspond to MIS 17.

Three levels have been recognised within the ‘Rhine Sands’: 1. (base) Grey sands with interglacial molluscs, 2. Mixed grey and reddish sands with both warmer and cold-tolerant pioneer mollusc species and 3. (summit) ‘Voges Sands’ with no warm taxa. While level 3 seems to correspond to MIS 12, levels 1 to 2 correspond to MIS 15 to MIS 13, similar to the ‘Mosbach Sands’ (see below). The ‘Rhine Sands’ have mammal remains which confirm that they date from the early Middle Pleistocene (*Palaeoloxodon antiquus*, *Stephanorhinus* cf. *hundsheimensis*, *Ursus* cf. *deningeri, Hippopotamus amphibius*, *Equus mosbachensis*, *Cervalces latifrons*, *Sus scrofa mosbachensis*, *Castor* cf. *fiber*) and are contemporary with the ‘Mosbach Sands’ (see below; Geissert 1969, 1970).

The Rhine Sands are succeeded by loessic silts, which at their base have cold-climate faunas (MIS 12), but then become more organic and have an interglacial fauna corresponding to MIS 11. At key sites like Achenheim and the neighbouring Hangenbieten, these lower loessic deposits are no longer accessible. The dating of the loessic silts has been confirmed by TL and OSL (see Achenheim below).

The relevant references for all of the following Alsace sites are Geissert 1969, 1970.

Hanhoffen/Bischwiller, Alsace; MIS 17, MIS 15 to MIS 13, MIS 11; mammals, plant macroremains, stratigraphy

Eschau, Alsace; MIS 17; mammals, stratigraphy

La Wantzenau, Alsace; MIS 17; stratigraphy

Achenheim, Alsace; MIS 14 to MIS 12 (Rhine sand terrace), MIS 11 (basal loess); stratigraphy; Wernert 1957, Wernert and Geissert 1963, Nordsieck 2021

Hangenbieten, Alsace; MIS 14 to MIS 12 (Rhine sands), MIS 11 (basal loess); stratigraphy; Mazenot 1963, Wernert and Geissert 1963 (the assemblage from a late 19th century study by Andreae comes from both layers)

Mothern, Alsace; MIS 14 to MIS 12 (Rhine sands); stratigraphy

Achenheim, Alsace; MIS 11 to MIS 5e and Würm; OSL dating, TL dating; Wernert 1957, Mazenot 1963, Puisségur 1976, 1978a, Lautridou et al. 1985, Rousseau 1987, Rousseau and Puisségur 1990a, Rousseau et al. 1998

Arrest; MIS 11; Rousseau et al. 1992

Chelles; MIS 11; Breuil 1939

La Celle (-sous-Moret/-sur-Seine); MIS 11; U/Th dating; Limondin-Lozouet et al. 2006, 2010, 2015, 2020, Limondin-Lozouet 2017

Saint Acheul; MIS 11; ESR dating; Antoine and Limondin-Lozuet 2004, Limondin-Lozouet and Antoine 2006

Saint Pierre-les-Elbeuf; MIS 11; IRSL dating; Lautridou et al. 1974, Rousseau and Puisségur 1989, Rousseau and Puisségur 1990b, Rousseau et al. 1992, Limondin-Lozouet et al. 2006, Cliquet et al. 2009

Vernon; MIS 11; U/Th dating; Rousseau et al. 1992

Chaignay; MIS 9, MIS 7, MIS 5; and Würm; stratigraphy; Puisségur 1976

Piégu, Brittany; MIS 9, (MIS 7), MIS 6, (MIS 5e), MIS 5d-5a; ESR + ESR/U dating; Danukalova et al. 2015

Soucy; MIS 9; AAR dating, ESR dating; Chaussé et al. 2000, Limondin-Lozuet 2001

(Fontaine d'Ouche) Dijon; MIS 9, MIS 7, MIS 6, MIS 5e; stratigraphy; Puisségur 1976, 1978

Abîmes de la Fage (Aven 1), Noailles; (MIS 8), MIS 7; U/Th dating; small mammals; Vilain 1974, Mourer-Chauviré et al. 1975, 2003

Biache-Saint-Vaast; MIS 7; TL dating, ESR dating; Puisségur 1978b, Guipert et al. 2011

Menchecourt-Abbeville; MIS 7; ESR dating, U/Th dating; Bahain et al. 2019

Baume Moula-Guercy in the Ardèche; MIS 5e; Magnin in Slimak et al. 2010

Caours; MIS 5e; OSL dating, U/Th dating; Antoine et al. 2006, Limondin-Lozouet 2011

Chambolle; MIS 5e; stratigraphy; Puisségur 1976

Erquinghem; MIS 5e; pollen, terrace stratigraphy; Sommé et al. 1996

Grand Abri aux Puces-Vaison-la-Romaine, the Vaucluse SW France; MIS 5e; small mammals, archaeology; Slimak et al. 2010

Mens (Ruisseau de l'Amourette, S of Grenoble); MIS 5e; stratigraphy, pollen; Gremmen et al. 1984, Rousseau and Puisségur 1999

Resson; MIS 5e; plant impressions, travertine stratigraphy; Dabkowski et al. 2020

Saint-Pierre-de-Cherennes; MIS 5e; pollen; Puisségur 1976

Schiltigheim, Alsace; MIS 5e; terrace stratigraphy; Puisségur 1965, 1976

Vanvey; MIS 5e; stratigraphy; Puisségur 1976

Germany

Cores in the Upper Rhine Graben: the deeper cores include Early to Late Pleistocene molluscs, while the shallower ones have Middle to Late Pleistocene faunas. OSL and palaeomagnetic dating in two deep cores has allowed strata in other cores to be dated by correlation, notably the OZH level that corresponds to MIS 15/13 and MIS 11, although the main shell-bearing layers date from MIS 11. This level can also be correlated with the help of pollen (Hahne et al. 2012) and molluscan biostratigraphic markers like the freshwater prosobranch *Parafossarulus* (*Bithynia*) *crassitesta*, which seems to have become extinct after MIS 11, in keeping with evidence from the Netherlands (Meijer 1989, Tesakov et al. 2020).

Progressing from south to north:

Elchesheim-Illingen, SW Germany (core Elchesheim S2, shells at 59.2-60.0 and 58.5-59.2 m depth); Late Pliocene (MN 16b); molluscan biostratigraphy; Nordsieck 1976 p.77, Münzing 1981

Near Philippsburg, SW Germany; EP1-EP3 to Middle Pleistocene; stratigraphy; Münzing 1973, Engesser and Münzing 1991

Mannheim/Lindenhof, SW Germany; MIS 11; stratigraphy, molluscan biostratigraphy; Rähle 2005

Near **Heidelberg**, **Ludwigshafen and Viernheim**, SW Germany; EP1-EP3 to Late Pleistocene; OSL dating, palaeomagnetic dating, stratigraphy, molluscan biostratigraphy, small mammals, palynostratigraphy (some pollen types disappear after EP1, others after EP3); Wedel 2008, Hahne et al. 2008, 2012, Lauer et al. 2010, 2011, Ellwanger and Wielandt-Schuster 2012, Gabriel et al. 2013, Scheidt et al. 2015, 2020, Li et al. 2018

Mannheim to Ladenburg and Viernheim/Weinheim, SW Germany; EP1-EP3 to Middle Pleistocene; stratigraphy, molluscan biostratigraphy; Engesser and Münzing 1991

Biblis, west central Germany; EP2/EP3; stratigraphy, small mammals; Wedel 1999

Groβ-Rohrheim, west central Germany; EP3 to Late Pleistocene; stratigraphy; Neubert and Kinzelbach, 1988, Wedel 1996

Biebesheim, west central Germany; EP3 to Late Pleistocene; stratigraphy; Wedel 1996

Wolfskehlen, west central Germany; Late Pleistocene; stratigraphy; Neubert and Kinzelbach 1988

Bären- und KarlsHöhle, Erpfingen SW Germany; Late Pliocene (MN16b), the molluscs come from the base of the cave sequence, while the mammals come from two levels (MN16b + MN17); a

U/Th date (MIS 13) from a flowstone caps the sequence after a hiatus, small mammals; Abel et al. 2006

Fortuna-Garsdorf, west central Germany; Late Pliocene (MN16b); molluscan biostratigraphy, regional stratigraphy; Nordsieck 1972, 2007 (Clausiliidae), Schlickum and Strauch 1979

Frechen, west central Germany; Late Pliocene (MN16b); molluscan biostratigraphy, small mammals, regional stratigraphy; Nordsieck 1972, Schlickum and Strauch 1979, van Kolfschoten et al. 1998

Hambach, west central Germany; Late Pliocene (MN16a); small mammals, pollen, regional stratigraphy; Mors et al. 1998, Heumann and Litt 2002

Frechen, west central Germany; EP1 (Early Tiglian); molluscan biostratigraphy, regional stratigraphy; Ložek 1972b (in Boenigk et al. 1972); the shells have recently been revised by Meijer (in preparation).

Rottenburg, SW Germany; EP1; molluscan biostratigraphy, terrace stratigraphy; Rähle and Bibus 1992, Bibus and Rähle 2005, Ufrecht 2022

The following EP1 sites are all from the Zusamplatte of the Iller-Lech-Platte, central southern Germany, and are dated by both their faunas and palaeomagnetic dating at **Uhlenberg**; Doppler and Jerz 1995, Strattner and Rolf 1995

Buch, Illertissen; EP1; Geyer 1914, Schröder and Dehm 1951, Münzing 1974, Rähle and Bibus 1992

Fischach; EP1; Schröder and Dehm 1951, Rähle and Bibus 1992

Fürbach; EP1; Münzing 1974

Hörlis, Kirchhaslach; EP1; Münzing 1974, Rähle and Bibus 1992

Uhlenberg, Dinkelscherben; late EP1; palaeomagnetic dating, molluscan biostratigraphy, small mammals (MN17), pollen; Dehm 1979, Ellwanger et al. 1994, Rähle 1995, Strattner and Rolf 1995

The following EP3 sites are from the lower part of the same Zusamplatte of the Iller-Lech-Platte, central southern Germany, and have palaeomagnetic dating at **Lauterbrunn** and **Roßhaupten**; Bucha et al. 1975, Tillmanns et al. 1986, Doppler and Jerz 1995, Strattner and Rolf 1995

Brennberg; EP3; Löscher et al. 1978

Fuchsberg, Wollbach; EP3; Münzing and Aktas 1987

Kirchberg; EP3; Löscher et al. 1978

Lauterbrunn; EP3; palaeomagnetic dating; Rähle 1995

Osterbuch; EP3; Münzing and Aktas 1987, Rähle and Bibus 1992

Welden; EP3; Münzing and Aktas 1987

Untermassfeld, C Germany; EP3; palaeomagnetic dating, mammals, river terrace stratigraphy; Krolopp 1997, Ellenberg et al. 1997, Wiegank 1997 and other articles in Kahlke 1997

The following sites in terrace deposits from the valleys of the River Helme and River Unstrut in central Germany have deposits of similar ages, with the extinct freshwater marker species *Esperiana* (*Fagotia) wuesti* (Meijer and Preece 1996, Kovanda 2006, Maul et al. 2013). The Helm flows into the Unstrut, a tributary of the River Saale, which feeds into the River Elbe.

Bottendorf; EP3; molluscan biostratigraphy, terrace stratigraphy; Zeissler 1971

Edersleben/Voigtstedt; EP3 (lower level), MIS 19/17 (upper level); palaeomagnetic dating, AAR dating, molluscan biostratigraphy, small mammals, pollen, terrace stratigraphy; Zeissler 1965, 1971, Mania 1973, Meijer and Preece 1996, Maul et al. 2013

Kalbsreith; EP3; molluscan biostratigraphy, terrace stratigraphy; Zeissler 1968, 1971, Mania 1973, Meijer and Preece 1996

Rossleben;

Wendelstein; EP3; molluscan biostratigraphy, terrace stratigraphy; Mania 1973

Zeuchfeld; EP3; molluscan biostratigraphy, terrace stratigraphy; Zeissler 1971, Mania 1973

Kärlich, west central Germany; EP3, MIS 18 to 8, molluscs from MIS 18, 17, 16, 14, 12, 11 and 10; palaeomagnetic dating, ^{40}Ar/^{39}Ar dating, Tephrochronology, small and large mammals, pollen, terrace stratigraphy; Brunnacker et al. 1971, Brunnacker and Boenigk 1976, Bogaard et al. 1989, Bogaard and Schmincke 1990, van Kolfschoten et al. 1990, Bittmann 1992, Bosinski 1995, Roth 1995, van Kolfschoten and Turner 1996, Gaudzinski et al. 1996, Gaudzinski 1997, 1998, Boenigk and Frechen 1998, Gallant et al. 2014

Miesenheim I, west central Germany; MIS 15; Tephrochronology, ^{40}Ar/^{39}Ar dating, small and large mammals, pollen; van Kolfschoten and Turner 1996, Turner 2000

Diersheim, SW Germany; MIS 17; mammals, stratigraphy, Rhine gravels (see text above for Alsace); Geissert 1969, 1970

‘Mosbach Sands’ of the Rhine, Wiesbaden, west central Germany; MIS 15 to 12; terrace stratigraphy; Geissert 1970, Bohatý 2018

The remains from many large and small mammals found within these sands confirm that they date from the early Middle Pleistocene (Keller 1994, Keller 1999, Glienke 2014, Bohatý 2018). Beneath the sands lie a mix of sand and gravels that date from the last part of the Early Pleistocene and the start of the early Middle Pleistocene, like the Rhine terrace deposits in Alsace. Similarly, down-stream at Kärlich and Ariendorf the major sedimentary change from gravels and sands to more silty layers took place near the end of MIS 16, with MIS 17 being represented by finer sediments (Bogaard and Schmincke 1990, Gaudzinski 1997, Boenigk and Frechen 1998). It seems that the Lower and Middle levels of 3the ‘Mosbach Sands’ correspond to MIS 15, while after a phase of colder conditions (MIS 14), the Upper level of the sands equates to MIS 13, before colder conditions at the summit of the sands represent the start of MIS 12. Similar ‘Rhine Sands’ are found upstream in the Rhine Valley in Alsace and SW Germany, including those at Herxheim, with mammal remains that confirm they are contemporary with the ‘Mosbach Sands’ (see above).

Dyckerhoff Pit/Wiesbaden-Biebrich, west central Germany; part of the ‘Mosbach Sands,’ MIS 13; terrace stratigraphy; Meijer and Preece 2002, Nordsieck 2007, 2021

Elisabethen-Höhe/Wiesbaden, west central Germany; part of the ‘Mosbach Sands,’ MIS 13; terrace stratigraphy; Meijer and Preece 2002

Herxheim, SW Germany; MIS 13; stratigraphy, ‘Rhine Sands’ (see text above for Alsace); Geissert 1969, 1970

The following group of sites are dated to MIS 13 on the basis of a stratigraphic and faunal analysis for Bietigheim-Bissingen by Bibus and Rähle in 2003, with which these sites have been correlated due to their faunal similarities (presence of *Aegopis klemmi*, *Cochlostoma scalarinum saueri*, *Fusulus interruptus*, *Macrogastra densestriata*, *Platyla similis*, *Theodoxus danubialis*, *Zonitoides sepultus*). Meng 2007 disagrees with the date for the Bietigheim-Bissingen terrace deposit, however, believing it to be MIS 11, which might also mean that some of these other sites are MIS 11. Doubt has also come from separate sources for the Bilzingsleben sites (see below). An additional argument for these sites belonging to MIS 11 is that the great westwards expansion of *Theodoxus danubialis* and *Zonitoides sepultus* occurred during MIS 11 in France and southern England rather than MIS 13.

Adlerberg-Nördlingen, central southern Germany; MIS 13; Dehm 1969, Bibus and Rähle 2003

Bietigheim-Bissingen, SW Germany; MIS 13; terrace stratigraphy; Geyer 1914, Bibus and Rähle 2003, Ufrecht 2022

Bilzingsleben I, central Germany; MIS 13; travertine and terrace stratigraphy; Mania 1983, 1995, 2002, 2006

Breitenberghöhle, Gößweinstein, SE Germany; MIS 13; cave deposit; Hässlein 1957, 1958, Dehm 1969, Bibus and Rähle 2003

Bruheim-Gotha, central Germany; MIS 13; Mania 1973, Bibus and Rähle 2003

Schmiechen-Blaubeuren, SW Germany; MIS 13; stratigraphy; Dehm 1951, 1969, Bibus and Rähle 2003

Weißenburg 7, central southern Germany; MIS 13; Dehm 1969, 1971, Bibus and Rähle 2003, Nordsieck 2007, 2021

Roßbach, central Germany; early MIS 12; Mania 1973

Süßenborn; central Germany; early MIS 12; Mania 1973

Uichteritz, central Germany; early MIS 12; OSL dating, terrace stratigraphy; Meng and Wansa 2005, Lauer et al. 2020

Berlin, NE Germany; MIS 11; terrace stratigraphy; Schmierer 1923, Meijer 1988b, Meijer and Preece 1996

Bilzingsleben II, central Germany; MIS 11; U/Th dating, ESR dating, travertine and terrace stratigraphy; Mania 1983, Schwarcz et al. 1988, Mania 1995, 2002, 2006, Mallick and Frank 2002 (despite the radiometric dates there is still some dispute whether Bilz II might be MIS 9, in which case Bilz I would be MIS 11 and Bilz III MIS 7; cf. van Kolfschoten 2014)

Heilbronn, SW Germany; MIS 11; terrace stratigraphy; Münzing 1968

Hundersingen, SW Germany; MIS 11; terrace stratigraphy; Münzing 1966a

Leilenkopf-Vulkans, Osteifel, west central Germany; MIS 11; tephrochronology; Puisségur and Windheuser 1979

Salzmünde, central Germany; MIS 11; molluscan biostratigraphy, terrace stratigraphy; Mania 1973

Seebach, central Germany; MIS 11; molluscan biostratigraphy, travertine and terrace stratigraphy; Mania 1973

Steinheim an der Murr, SW Germany; MIS 11; terrace stratigraphy; Falkner 1984

Bad-Cannstatt/Stuttgart (Haas, Lauster and Schauffele Quarries), SW Germany; MIS 9; U/Th dating, terrace stratigraphy; Münzing 1966b, 1973, Dehm 1969, Rähle 1986, Geyh et al. 1999, Ufrecht 2022; there are probable MIS 11 travertines at the base of the Terrasse 9 tufa sequence

Bilzingsleben III, central Germany; MIS 9; U/Th dating, travertine and terrace stratigraphy; Mania 1983, 1995, 2002, 2006

Lengefeld-Bad Kösen, central Germany; (MIS 11-*Corbicula* Schotter), MIS 9, (MIS 8); terrace stratigraphy; Mania and Mai 1969, Mania 1973, 2006

Neumark-Sud, central Germany; (MIS 11-*Corbicula* Schotter), (MIS 10), MIS 9, (MIS 8); terrace stratigraphy; Mania and Mai 1969, Mania 1973, 1995, 2006, Nordsieck 2007

Schöningen 12, central Germany; [Schöningen 13 = (MIS 11) + MIS 9], (MIS 10), MIS 9, (MIS 8), (MIS 7); U/Th dating, TL dating, pollen, small/large mammals, stratigraphy; Thieme et al. 1993, Mania 2006, 2007, van Kolfschoten 2014, Serangeli et al. 2015, Stahlschmidt et al. 2015, plus several articles in Behre 2012

Bilzingsleben IV, central Germany; MIS 7; U/Th dating, travertine and terrace stratigraphy; Mania 1983, 1995, 2002, 2006

Höchstadt, SE Germany; MIS 7; OSL dating, ESR dating, terrace stratigraphy; Schellmann et al. 2019; note the presence of *Esperiana (Fagotia) daudebartii acicularis* as the samples were taken from the *Dillinger Hochterrasse* at the north bank of the River Danube

Rain, central southern Germany; MIS 7; ESR dating, terrace stratigraphy; Tilmanns et al. 1982, Schellmann et al. 2019; redeposited interglacial shells in soft clasts

Weimar-Ehringsdorf, central Germany; MIS 8, **MIS 7**, early MIS 6, MIS 5e; U/Th dating, small/large mammals, travertine stratigraphy; Mania 1973, 1993, 2006, Mallick and Frank 2002

Mainz-Weisenau, west central Germany; MIS 6 and MIS 5d-5a; loess stratigraphy; Bibus et al. 1996a, 2002

Zeuchfeld, central Germany; MIS 6 (plus redeposited MIS 11 and MIS 7 shells); OSL dating; terrace stratigraphy; Meng and Wansa 2008, Kreutzer et al. 2014

SW of Moosburg between the River Amper and the River Isar in SE Germany, there are two gravel terrace units, an *Altere* (older) and a *Jungere* (younger) *Moosburger Hochterrassen*. The lower, younger terrace with *Esperiana* (*Fagotia) daudebartii acicularis*, is dated by ESR at Moosham to MIS 5e, while the other sites come from the same terrace (Kovanda 2006, Schellmann et al. 2019). There are no faunas documented from the higher terrace, which seems to be of MIS 6 age. The Amper flows into the Isar, which is a tributary of the River Danube.

Moosham, SE Germany; MIS 5e; OSL dating, ESR dating, terrace stratigraphy; Schellmann et al. 2019

Niederhummel, SE Germany; MIS 5e; molluscan biostratigraphy, terrace stratigraphy; Brunnacker and Brunnacker 1962, Kovanda 2006

Thonstetten-Moosham, SE Germany; MIS 5e; molluscan biostratigraphy, terrace stratigraphy; Brunnacker and Brunnacker 1962, Kovanda 2006

Weigl hinterm Holz, SW of Bonau, SE Germany; MIS 5e; molluscan biostratigraphy, terrace stratigraphy; Kovanda 2006

Bilzingsleben V, central Germany; MIS 5e; travertine stratigraphy and terrace; Mania 1983, 1995, 2002, 2006

Bötzingen, SW Germany; MIS 5e; loess stratigraphy; Münzing 1969

Burgtonna, central Germany; MIS 5e +5c; U/Th dating, small and large mammals, travertine stratigraphy; Mania 1973, 1978, Mallick and Frank 2002, Meyrick and Maul 2002, Nordsieck 2007

Dieβen, SW Germany; MIS 5e; travertine stratigraphy; Mägdefrau and Maeck 1965

Eichenreid, NE of Münich, SE Germany; MIS 5e; terrace stratigraphy; Brunnacker and Brunnacker 1962

Eicherloh, NE of Münich, SE Germany; MIS 5e; terrace stratigraphy; Brunnacker and Brunnacker 1962

Hausen, SW Germany; MIS 5e; terrace stratigraphy; Münzing 1970

Heilbronn-Böckingen, SW Germany; MIS 5e; terrace stratigraphy; Bibus and Rähle 1986, 2003, Ufrecht 2022

Hurlach, central southern Germany; MIS 5e; travertine stratigraphy; Kovanda 1989

Königsaue, Ascherslebener See, central Germany; MIS 5e (Würm to Holocene); molluscan biostratigraphy, stratigraphy; Mania 1973

Neumark-Nord, central Germany; MIS 5e; AAR dating, TL dating, palaeomagnetic dating, pollen, palaeo-lake stratigraphy; Mania 2006, Mania et al. 2010, Strahl et al. 2010, Sier et al. 2011, Richter and Krbetschek 2014

Oberheisesheim, SW Germany; MIS 5e; terrace stratigraphy; Bibus and Rähle 2003, Ufrecht 2022

Rottenburg, SW Germany; MIS 5e; terrace stratigraphy; Bibus and Rähle 1986, Ufrecht 2022

Schöningen, central Germany; MIS 5e; stratigraphy, pollen; Urban et al. 1991

Sesselfelsgrotte, Essing (near the Altmühl River a tributary of the Danube, explaining shells of *Esperiana daudebartii acicularis*), SE Germany; MIS 5e, MIS 5d-5a; U/Th dating, radiocarbon dating, molluscan biostratigraphy; Reisch 1985, Richter et al. 2000, Richter 2002, Rähle 2017

Tönchesberg, west central Germany; (MIS 6), MIS 5e, Würm; tephrochronology, loess stratigraphy; van Kolfschoten and Roth 1995

Wallertheim, west central Germany; MIS 5e, Würm; terrace stratigraphy, loess stratigraphy; Remy 1969, Conard et al. 1995, Mania unpublished

Parkhöhle, Weimar, central Germany; MIS 5e; cave stratigraphy; Zeissler 1967

Bad-Cannstatt/Stuttgart (Deckerstrasse Quarry), SW Germany; MIS 5c; U/Th dating, terrace stratigraphy; Münzing 1973, Frank et al. 2000, Ufrecht 2022

Wiesbaden, west central Germany; Würm; loess stratigraphy; Remy 1969

Rheinfelden, SW Germany near Basel; probably early-mid MIS 3; Brunnacker and Brunnacker in Graul 1962

Denmark

Copenhagen; MIS 7; AAR dating, OSL dating, molluscan biostratigraphy, pollen, stratigraphy; Bennike et al. 2018

Italy

General reviews of molluscs and small mammal faunas are given in Esu and Girotti 1991 (Late Pliocene to Late Pleistocene), Esu et al. 1993 (Late Pliocene to Early Pleistocene), Gliozzi et al. 1997 (Late Pliocene to Late Pleistocene), plus Esu and Ciangherotti 2004 (Late Pliocene to Early Pleistocene). The stratigraphic correlations for several of the earlier sites mentioned below are simplified by their being linked with transitions from marine to terrestrial/freshwater sediments.

The following are all sites from the Piemonte region of NE Italy:

Ceresole d'Alba, Cuneo; Late Pliocene; molluscan stratigraphy, plants, regional stratigraphy; Esu and Ciangherotti 2004, Ciangherotti et al. 2007, Nordsieck 2013a

Dusino, Asti; Late Pliocene; molluscan stratigraphy, regional stratigraphy; Esu and Ciangherotti 2004

Fossano, Cuneo; Late Pliocene; molluscan stratigraphy, regional stratigraphy; Esu and Ciangherotti 2004

Madonna di Casale, Asti; Late Pliocene; molluscan stratigraphy, regional stratigraphy; Ciangherotti 1997, Esu and Ciangherotti 2004

Molinetta, Asti; Late Pliocene; molluscan stratigraphy, regional stratigraphy; Ciangherotti 1997, Esu and Ciangherotti 2004

San Giacomo, near Ovada, Alessandria; Late Pliocene; molluscan stratigraphy, regional stratigraphy; Schnabel 2006

San Paolo, Asti; Late Pliocene; molluscan stratigraphy, regional stratigraphy; Schnabel 2006

Tassarolo, Alessandria; Late Pliocene; molluscan stratigraphy, regional stratigraphy; Esu and Ciangherotti 2004

RDB Quarry/Villafranca d'Asti, Asti; Late Pliocene; molluscan stratigraphy, regional stratigraphy; Ciangherotti 1997, Esu and Ciangherotti 2004

Cerbaie Hills (including Monte Serampoli), Lower Valdarno Unit, Toscana; Late Pliocene; regional stratigraphy; Zanchetta 1995, Sart et al. 2008, Nordsieck 2013b

Dunarobba, Terni, Umbria; Late Pliocene + EP1; stratigraphy, pollen and wood, molluscan biostratigraphy; Ambrosetti et al. 1995

Castelnuovo Berardenga, Siena, Toscana; EP1, palaeomagnetic dating, Argon/Argon dating of an ash bed; Ghinassi et al. 2004, Aldinucci et al. 2007

(Balze di Caspreno) Pianella, Castelnuovo Berardenga, Siena, Toscana; probable EP1 (or possibly EP2, by correlation with neighbouring basins); regional stratigraphy; De Stefani 1880

Leffe Basin, Bergamo, Lombardy; EP2; regional stratigraphy; Esu and Gianolla 2009

Mugello Basin, Toscana; EP2; palaeomagnetic dating, small mammals, stratigraphy; Benvenuti et al. 1998

Steggio Basin, Veneto; EP2; regional stratigraphy; Ciangherotti et al. 2000

Tiberino Basin, Umbria; EP2-EP3; palaeomagnetic dating, pollen, plant remains, stratigraphy; Bizzari et al. 2018

The following sites from river valleys are all underlain by the South Po Basin (Cau et al. 2020)

Castell'Arquato, Arda River Valley, Emilia-Romagna; EP3; palaeomagnetic dating, regional stratigraphy, large mammals; Bona and Sala 2016, Monesi et al. 2016, Crippa et al. 2016, 2018, 2019, Nordsieck 2021 (the record of *Serrulella ultima*).

Crostolo River Valley, Emilia-Romagna; EP3; regional stratigraphy, correlated with a palaeomagnetically dated sequence in the neighbouring Enza River Valley; Esu and Girotti 1991, Crispino and Esu 1995, Monesi et al. 2016

Enza River Valley, Piacenza region, Emilia-Romagna; EP3; palaeomagnetic dating, regional stratigraphy, small and large mammals; Gunderson et al. 2014, Bona and Sala 2016, Monesi et al. 2016

Stirone River Valley, Piacenza region, Emilia-Romagna; EP3; stratigraphic correlation with a palaeomagnetically dated sequence in the neighbouring Arda River Valley; Esu and Girotti 1991, Ciangherotti et al. 1997, Monesi et al. 2016

Campani Quarry, Pontedera, Toscana; MIS 16 to MIS 13; Fission-track dating, small mammals; Zanchetta et al. 1998, Marcolini et al. 2003

Sulmona Basin, Aquila, Abruzzo; MIS 14; Ar/Ar dating; Zanchetta et al. 2017

Valle Giumentina, Abruzzo; MIS 14, MIS 13, MIS 12; ^{40}Ar/^{39}Ar dating, tephrachronology, small mammals, pollen; Villa et al. 2016, Limondin-Lozuet et al. 2017,

Monrupino, near Trieste, Friuli-Venezia-Giulia; MIS 11; molluscan biostratigraphy, regional stratigraphy; Esu and Kotsakis 1987

Aurelian Formation, Rome, Lazio; MIS 9, ^{40}Ar/^{39}Ar and Fission-track dating; Esu and Girotti 1991, Marra et al. 2018

Liri Basin, Lazio; Middle Pleistocene; regional stratigraphy; Esu et al. 1989, Esu and Girotti 1991

Poggetti Vecchi, Grosseto, Toscana; late MIS 7-MIS 6; U/Th and ESR dating; Benvenuti et al. 2017

Boccabianca, Cupra Marittima, Marche; MIS 5e; terrace stratigraphy, archaeology; Silvestrini et al. 2000-2001

Salviano-Livorno, Toscana; MIS 5e; correlation with dated stratigraphy; Bossio et al. 2008

Villa San Giorgio-Livorno, Toscana; MIS 5e; correlation with dated stratigraphy; Zanchetta et al. 2004

Livorno town, Toscana; MIS 5e; small mammals, pollen, correlation with dated stratigraphy; Zanchetta et al. 2006

Rocca del Campione, Cherasco, Cuneo; MIS 5e; regional stratigraphy; Gianolla et al. 2015

Moncucco Torinese, Piemonte; Early Würm; radiocarbon dating (>38 k BP, >45k BP) small mammals, pollen, plant remains; Alessio et al. 1982

The Netherlands

AAR dating for The Netherlands in Meijer and Cleveringa 2009

Dordrecht; EP1 (Middle Tiglian); Meijer 1988b

Maalbeek Pit; EP1 (Middle to Late Tiglian); small mammals, pollen, regional stratigraphy; Westerhoff et al. 1998, Meijer 2009, Meijer unpublished

Russel-Tiglia-Egypte Pit; EP1 (Middle to Late Tiglian); small mammals, pollen, regional stratigraphy; Meijer 1976, 2009, Freudenthal et al. 1976, Tesakov 1998, Westerhoff et al. 1998, Meijer unpublished

Core Zuurland-2/Brielle; EP1 (Middle to Late Tiglian), EP2 (Waalian), and EP3 (Bavelian), MIS 7, MIS 5e, Holocene; AAR dating, small mammals, molluscan biostratigraphy, regional stratigraphy; Meijer 1987, 1988a, Meijer 1989, Preece et al. 2020, Meijer unpublished

Bavel; EP3; Spaink 1968

Core Hendrik Ido, Ambacht; EP3 (Leerdam); Meijer 1987, Meijer unpublished

Core 38H/148, Leerdam; EP3; Meijer 1987, Meijer and Preece 1996, Meijer unpublished

Core 40/351, Velp; EP3 (Leerdam); Meijer and Preece 1996

Bélvèdere Pit, Maastricht; MIS 9; AAR, pollen, regional stratigraphy; Meijer 1985

Wageningen; MIS 9; AAR dating, regional stratigraphy; Meijer 1991b

Borehole Noorderhoeve-19E117; MIS 7 + MIS 5e; AAR dating; Meijer 2003

Bakkersdam; MIS 5e; Meijer 1988b

Bergen-Pompstation P.W.N.; MIS 5e; Meijer 2010

Opgespoten terrein ‘t-Kalf’-Oostenpolder; MIS 5e; Meijer 2010

Zaanstreek; MIS 5e; regional stratigraphy; Meijer 1991b

England, UK

Background data on available AAR dates up until 2012 is given in Penkman et al. 2008, 2011, 2013

Sidestrand; EP1 and MIS 13; AAR dating, large and small mammals, pollen, stratigraphy; Preece 2001, Maher and Hallam 2005, Preece et al. 2009, Preece et al. 2020

Kessingland/Pakefield; MIS 19/17 and MIS 15; AAR dating, small mammals, stratigraphy; Preece 2001, Reece and Parfitt 2012

Little Oakley; MIS 15; AAR dating, large and small mammals, pollen; Preece 1990, 2001, Preece and Parfitt 2012

Sugworth; MIS 15; AAR dating, small mammals, pollen, stratigraphy; Gilbertson 1980, Shotton et al. 1980, Bowen et al. 1989, Preece 1989, 2001, Preece and Parfitt 2012

West Runton; MIS 15; AAR dating, EST Dating, pollen, stratigraphy; Sparks 1963, Preece 1990, 2001, 2010, Penkman et al. 2010, Preece and Parfitt 2012, Preece et al. 2020

Sun Hole/Cheddar; MIS 15/13; Ellis 1983, Parfitt and Preece 2022

Boxgrove; MIS 13; AAR dating, U/Th dating, ESR dating, TL dating, OSL dating, palaeomagnetic dating, small/large mammals, pollen, stratigraphy; Preece and Bates 1999 (see dating chapters in Roberts and Parfitt 1999)

Ostend; MIS 13; AAR dating, pollen, Preece 2001, Reece and Parfitt 2012

Valdoe Quarry (5 km from Boxgrove); MIS 13; small mammals, stratigraphy; Preece and Parfitt 2022

Waverley Wood; MIS 13; AAR dating, large and small mammals; Shotton et al. 1993, Preece 2001, Reece and Parfitt 2012

Bradwell Hall, Tillingham; MIS 11; AAR dating, stratigraphy; Briant et al. 2012

East Farm, Barnham; MIS 11; AAR dating, small mammals, pollen; Seddon 1998, Preece and Penkman 2005 (plus other chapters in Ashton et al. 1998)

Beeches Pit/West Stow (= Icklingham); MIS 11; AAR dating, U/Th dating, TL dating, OSL dating, stratigraphy; MIS 11; Kerney 1976, Holyoak et al. 1983, Rousseau et al. 1992, Preece et al. 2007

Clacton-on-Sea; MIS 11; AAR dating; Warren 1955, Turner and Kerney 1971, Bridgeland et al. 1999, Meijer and Preece 2002

East Hyde, Tillingham; MIS 11; AAR dating, OSL dating, stratigraphy; Roe 2001, Briant et al. 2012

Elveden; MIS 11; AAR dating, pollen, stratigraphy; Ashton et al. 2005

Hoxne; MIS 11; AAR dating, pollen, stratigraphy; Sparks 1956, Bowen et al. 1989, Ashton et al. 2008

Hitchin; MIS 11; molluscan biostratigraphy; Kerney 1959, Holyoak et al. 1983, Sherriff et al. 2021

Barnfield Pit/Swanscombe; MIS 11; pollen, stratigraphy; Kerney 1971, Meijer and Preece 1995, 1996, Preece 1995

Dierden's Pit/Swanscombe; MIS 11; AAR dating, pollen, stratigraphy; Preece 1995, Roe and Preece 1995, White et al. 2013b

Southfleet Road/Swanscombe; MIS 11; AAR dating, OSL dating, large/small mammals; pollen, stratigraphy; Wenban-Smith et al. 2006, White et al. 2013a, various articles in Wenban-Smith 2013

Woodston; MIS 11; AAR dating, pollen, plant macroremains, stratigraphy; Bowen 1992, Horton et al. 1992

Red Barns, Portchester; MIS 10/MIS 8; AAR dating, stratigraphy; Wenban-Smith et al. 2000; the fragments of *Pomatias elegans* may possibly have been redeposited from earlier interglacial deposits.

Barling; MIS 9; AAR dating, stratigraphy; Bridgeland et al. 2001

Cudmore Grove; MIS 9 AAR Dating, terrace stratigraphy; Roe et al. 2009

Frog Hall Pit, Stretton-on-Dunsmore; MIS 9; AAR dating, pollen; Keen et al. 1997

Hackney, London; MIS 9; AAR dating, molluscan biostratigraphy, pollen, terrace stratigraphy; Green et al. 2006

Purfleet; MIS 9; AAR dating, terrace stratigraphy; Preece 1995, Schreve et al. 2002, Bridgeland et al. 2013

Crayford; MIS 7; AAR dating, terrace stratigraphy; Kennard 1944, Preece 1999, Penkman et al. 2008, 2013

Histon Road, Cambridge; MIS 7; AAR dating; Sparks and West 1959

Ilford; MIS 7; AAR dating, terrace stratigraphy; Kennard and Woodward 1900, West et al. 1964, Penkman et al. 2008, 2013

Marsworth; MIS 7; AAR dating, OSL dating, stratigraphy; Murton et al. 2001, 2015

Stoke Goldington; MIS 7; AAR dating, U/Th dating, stratigraphy; Green et al. 1996

Stutton; MIS 7; AAR dating; Sparks and West 1963, Miller et al. 1979

Sutton Cross; MIS 7; AAR dating; Langford et al. 2020

Tattershall Thorpe, Quarry D; MIS 7; AAR dating; Holyoak and Preece 1985

West Thurrock; MIS 7; AAR dating; Shreve et al. 2006

Whittlesey; MIS 7; AAR dating; Langford et al. 2014

Wretton; MIS 7; molluscan biostratigraphy, stratigraphy; Sparks and West 1970

Bobbitshole/Ipswich; MIS 5e; AAR dating, pollen, stratigraphy; MIS 5e; Davis 1954, Sparks 1957, Penkman et al. 2013

Deeping St James; MIS 5e; AAR dating, TL dating, pollen; Keen et al. 1999

Folkestone; MIS 5e; AAR dating; Bridgeland et al. 1995

Tattershall Castle; MIS 5e; AAR dating, U/Th dating, TL dating, radiocarbon dating, pollen; Holyoak and Preece 1985

Tattershall Thorpe, Quarry A; MIS 5e; AAR dating, radiocarbon dating, pollen; Holyoak and Preece 1985

Trafalgar Square/London; MIS 5e; AAR dating; Preece 1999

Woolpack Farm/Fenstanton; MIS 5e; AAR dating; Gao et al. 2000

Appendix 4: The stratigraphy for the site at Nuolen/Buechberg, Wangen, SZ

The following site sequence is compiled from notes and information given by Thomas Bolliger in 2018, together with NT's study of photographic documentation provided by TB. TB says that he visited Nuolen three times in 1989. Doubts about possible earlier visits arise due to notes from the *Palaeontological Museum of the University of Zürich* attached to the material from the '*Chara*-Mergel', which are marked "Fund T. Bolliger 1984" and "Fund T. Bolliger 1985", but these could be in error.

<u>The profile sequences are as follows, allowing for significant lateral changes in the sediments:</u>

Eastern Gravel Pit – visited 9th April 1989 (est.2710 370/1228 440 to 2710 420/1228 440)

TOP	***Surface from 480 to 485 m asl***
>1 m	gravelly moraine with cobbles up to 30 cm. Surface already removed (pic 04-24)
1-4 m	gently dipping deltaic sands with bands of gravel/pebbles; the upper 1+ m and lower 2-3 m are mostly sand with some silt and scattered stones and rare cobbles up to 20 cm, the basal sand is coarser; there are several erosion surfaces; (pics 04-24)

Erosion surface with heterochronous lateral on-lap (pic 04-24)

4-7 m	complex of ~horizontally-bedded fluvioglacial fine to coarse sandy gravels with sandy layers and rare cobbles up to 50 cm; very sandy in the upper 1 m (pic 04-24)
	The total thickness for the two gravel units is c.8 m

Erosion surface

0.3 m	(**middle lignite**) grey-black bedded silty lignite with a few stones
0.8-1.3 m	inter-banded darkish blue-grey marly-silts with *Chara* + abundant **molluscs**, sandy-silts and silty-sands with some fine gravel; lacustrine (pics 04-25, 26)
0.3 m	gravelly sand with some silt
1.8-2 m	inter-banded darkish blue-grey marly-silts with Chara + abundant molluscs, sandy-silts and silty-sands with some fine gravel; lacustrine (pics 04-25, 26)
	The above sequence is 3.4-3.7 m thick
>2 m	~horizontally-bedded deltaic gravel complex: fine to coarse gravels, either clast supported with a sandy matrix or supported by a silty-sand matrix; sub-rounded to angular clasts, which in the sandy layers have a mostly ~horizontal orientation, as well as imbricated, but which in the silty layers have a vertical to horizontal orientation, with some thin sandy lenses; deposited by fluvial activity and/or slope wash and debris flows (silty layers) (pic 04-26)

Base of sequence = 'Baggersee' (quarry lake), c.468 m asl

A little to the east in the same gravel pit:

Surface deposits already removed

~6 m	~horizontally-bedded to gently dipping fine to coarse sandy gravels (pics 04-24, 26)

Erosion surface

0.3 m	marly-silts
~1 cm	thin lignite-layer
0.4 m	marly-silts
~1 cm	thin lignite-layer

0.35-0.4 m	marly-silts
0.35-0.4 m	marly-silts
0.05 m	organic-silt
0.3 m	darkish grey marly-silts with *Chara* + abundant **molluscs** (**Sample Nuolen 4**, incl. *Bithynia*), seeds, beetle frags
0.05 m	organic-silt
0.8-1.3 m	marly-silts with some sand and gravel OVER bedded sandy fine to medium gravels
0.3 m	(**middle lignite**) grey-black bedded silty lignite (*Schieferkohle*) with vertical tree trunks and tree roots (pics 06-31, 32)
0.5 m	silty-marls; fairly organic in upper part; with bands of sand and gravel, esp. in the basal part
0.5-0.6 m	top: band/lens of lignite with some sand and fine gravel OVER: 0.1 m of fine to medium gravel OVER a band/lens of marly-silt bottom 0.4 m coarse sand with fine to medium gravel
~1.0 m	marly-silts

The above sequence is 5.0-5.6 m thick; based on Bolliger notebook entry for 09.04.89

>2 m	~ horizontally-bedded deltaic gravel complex

All of the above sequence is affected by a fault line dipping steeply towards the SW, with a displacement of c.0.3 m

Base of sequence = 'Baggersee' (quarry lake), c.468 m asl

Western Gravel Pit – visited 13th July +August 1989 (est.2710 100/1228 620)

TOP	***Surface from c.485 to 488 m asl***
2 m	grey-brown gravelly moraine, matrix supported, massively bedded, with boulders up to 40 cm, sub-rounded to sub-angular, no clear clast orientation (pic 08-02b)
1 m	grey basal till with frequent boulders up to 50 cm at base

Erosion surface

0.3-0.4 m	grey marly silt
0.4 m	(**upper lignite**, not sampled) grey-black bedded silty lignite with a few stones
0.5 m	dark olive-grey marly silts, becoming olive-grey and sandier at summit
~8 m	horizontally-bedded fine to coarse sandy gravels, with some larger boulders up to 30 cm at base; most clasts in basal part have a horizontal orientation, although some are vertical, whereas in the upper part clasts have no clear orientation (pics 08-02b, 08)

Erosion surface

The best developed sequence is in pic 08-08:

0.5 m	gently-dipping olive-grey silt with moderate fine to medium stones up to 5 cm
0.8-1.1 m	darkish greenish-grey marly-silt with some fine gravel in upper 0.4 m, with **molluscs** (**Samples Nuolen 2** and **Nuolen 3**; including *Cepaea*),
0.8-1.1 m	gently dipping olive-grey fine to medium gravel in a silty-sand matrix, mostly matrix supported, clasts up to 8 cm
0.5 m	(**middle lignite**) grey-black bedded silty lignite with a few stones

1.7 m	alternating layers of olive-grey/grey fine silty-sand and silty-marl (**Sample Nuolen 1**), with some fine gravel in basal 0.6 m
	The above sequence is 4.5-4.6 m thick
>0.3 m	horizontally-bedded grey fine to medium gravel sandy gravel
	<u>Nearby in (pics 08-06b, 06c, 07)</u>
0.4 m	grey to greenish-grey interbanded silt and silty-sand with some fine gravel
0.6 m	olive-grey fine-medium sandy gravel to 4 cm
0.7 m	darkish-grey fine-medium gravel to 4 cm in a silty-sand matrix
2.2-2.5 m	alternating horizontally bedded 5 layers of 0.1-0.4 thick grey/olive-grey/darkish grey silts, marly-silt and sandy-silt, with at least 5 thin layers of grey-black lignite, and layers 0.05-0.4 m thick of olive-grey fine sandy gravel to 3 cm
	The above sequence is 3.9-4.2 m thick
Erosion surface	
0.8-1.2 ->1.5 m	horizontal to gently dipping to trough-cross bedded fine to medium sandy gravels with sandy bands which then become steeply bedded deltaic fine to medium gravels with sandy and some silty bands (pics 08-06b, 06c)
Erosion surface	
>3.5 m	gently then steeply dipping finely bedded fine + some medium (to 4 cm, occasionally to 8 cm) sandy gravel interrupted by thin sandy bands, alternating with layers of grey/brownish-grey sand; more gravelly at summit, then more sandy and then more gravelly in basal part lenses (pics 08-05a, 05b, 06a, 06b, 06c)
Erosion surface	
c.5 m	deltaic sandy complex: gently to steeply dipping olive-grey/grey sands and silty-sands with thin silty bands, including many erosion surfaces (08-1a, 1b, 2a, 2b, 2c)
Erosion surface	
>5 m	darkish grey horizontally-bedded inter-layered sands, silty-sands, silts and organic silts, with a few gravelly bands (fine-medium) and at least three thin layers of grey-black lignite (**lower lignite**, not sampled; pics 08-1a, 1b)

The lower 10 m of the sequence is cut by a sharp near vertical fault line with little apparent displacement (c.0.10 m; pics 08-01a, 01b**)**

Base of sequence = c.455 m asl

The above sequence is based on photographic slides and the Bolliger notebook entry for 13.07.89

Appendix 5: Visit to Vienna to re-examine Early Pleistocene molluscan material held in the Natural History Museum Vienna and the Institute of Palaeontology University of Vienna, May 30th - June 3rd 2022

Part 1: Clarifying the criteria for identifying *Clausilia stranzendorfensis*, defining its chronostratigraphic limits in north-eastern Austria and verifying its presence in the Hasli Formation of the Irchel Plateau (Zürich, Switzerland)

Introduction

During the present study of Early Pleistocene molluscan material from the Hasli Formation of the Irchel Plateau, ZH, shells and fragments from several extinct (*Archaegopis acutus* and *Oxychilus steiningeri*) and living (*Acicula parcelineata* and *Monachoides vicinus*) species were encountered that published literature showed to be known from Early Pleistocene sites and modern locations in eastern Austria or further east (notably Frank 2006 and Welter-Schulthes 2012). A number of shells of an unknown *Clausilia* species were also encountered that seemed to correspond to specimens of the extinct taxon *Clausilia stranzendorfensis*, from the Late Pliocene levels A and C at Stranzendorf, which are illustrated in Frank 2006 (Plate XXXI, figs.7-10). The *Clausilia* from Irchel closely resemble these shells in their ribbing, the shape of the mouth, the pronounced depth and narrowness of the basal groove, the sharpness of the palatal fold and the form of the inferior lamella (columellaris). Until now this species has only been found in Late Pliocene and older Early Pleistocene levels at sites in north-eastern Austria.

During her study of the molluscs from a series of key sites from north-eastern Austria that span from the Late Pliocene until the early Middle Pleistocene, C. Frank (2006) maintained that *Clausilia stranzendorfensis* was present in both the Late Pliocene levels at Neudegg and Stranzendorf (A to C), and the older Early Pleistocene levels (D to M) at Stranzendorf and Unterparschenbrunn, but was absent from middle to late Early Pleistocene contexts at Krems, Deutsch-Altenburg and Radlbrunn. Indeed, at Deutsch-Altenburg it may been replaced by the rather similar species *Clausilia cruciata* (see below). This would imply both that *Clausilia stranzendorfensis* disappeared after the end of the Tiglian, around 1.8 My, and could be considered to be a biostratigraphic marker for the Late Pliocene and the older Early Pleistocene, and that *Clausilia cruciata* first appeared after the Tiglian. If the *Clausilia* species identified from the deposits at Irchel is indeed *C. stranzendorfensis*, this would therefore have important dating implications for the Hasli Formation.

A problem with this model, however, is that although H. Nordsieck (1990) has assigned certain *Clausilia* shells from the Late Pliocene levels at Neudegg and Stranzendorf (A to C) to *C. stranzendorfensis*, he has contradicted Frank by attributing similar shells from the older Early Pleistocene levels at Stranzendorf to *C. cruciata* (Nordsieck 2007 and 2021): "the hypothesis of Frank (in Döppes and Rabeder 1997, p.132, 136) concerning the continued occurrence of these Pliocene *Clausilia* species (*C. strauchiana*, *C. stranzendorfensis*) in Early Pleistocene layers of Stranzendorf, which later on (2006, p.366) was repeated, is based on confusion with similar *Clausilia* species (*C. pumila*, *C. cruciata*; ibid 2021)." He has so far failed, however, to give precise conchological arguments for this assertion, mentioning only that *C. cruciata* has a lower fold from the columellar lamellae that is "more s-like ascending, with more distinct folds in front" and a rib density of 7-8 ribs per mm on the penultimate whorl. Instead, his main reasoning for refuting the Frank hypothesis for a continuation of *C. stranzendorfensis* across the Pliocene/Pleistocene boundary (c.2.6 My) at Stranzendorf, appears to be linked to the significant number of molluscan and mammal extinctions that occurred at that time, such as the disappearance of *Triptychia* spp, which were linked to a well-documented deterioration in the climate (cf. Lisiecki and Raymo 2005, Petronio et al. 2011).

In view of this contradiction, and the potential importance of these *Clausilia* shells from the Irchel sites for the dating of the Hasli Formation, it was decided that it would be best to re-examine the Clausiliid material from the key Early Pleistocene sites mentioned above that is held in the Natural History Museum Vienna and the Institute of Palaeontology University of Vienna.

Questions to be answered

The re-examination of the Clausiliid material aimed to answer the following basic questions:

1) Can reliable criteria be established for identifying *C. stranzendorfensis* and for separating it from similar contemporary Late Pliocene (*C. strauchiana*) and older Early Pleistocene taxa (*C. strauchiana* and *C. pumila*)?

2) Can reliable criteria be established for separating *C. stranzendorfensis* from *C. cruciata*?

3) Is it possible to say with confidence whether certain *Clausilia* shells from the older Early Pleistocene levels at Stranzendorf belong to the same species, *C. stranzendorfensis*, as the shells from the Late Pliocene levels at Neudegg and Stranzendorf (A to C), as Frank maintained, or are they from a different species, *C. cruciata*, as believed by Nordsieck?

4) If Frank is right, can shells of *C. stranzendorfensis* still be found among the faunas from the middle to late Early Pleistocene sites at Deutsch-Altenburg, Krems and Radlbrunn, or had it truly become extinct after the Tiglian? Or are there shells of the similar species *C. cruciata* at these sites?

4) If Nordsieck is right, are there shells of *C. cruciata* among the Late Pliocene and older Early Pleistocene faunas from Neudegg and Stranzendorf? Or does *C cruciata* first appear after the Tiglian?

5) Finally, do certain *Clausilia* shells from the Hasli Formation correspond to *C. stranzendorfensis* or do they belong to some other species?

Criteria for identifying *C. stranzendorfensis* and separating it from other species

The precise original description of *C. stranzendorfensis* is given in Nordsieck 1990.

The most important characteristics noted from the Vienna material are: fairly sharp moderately spaced ribs (8-9 per mm on penultimate whorl), the whorls have a gently curved profile and moderately indented sutures, the mouth is notably elongated and narrow (2.3-2.4 x 1.2-1.3 mm), the basal groove is both narrow and deep, the palatal fold is pronounced and rather sharp, the subcolumellar lamella is also fairly pronounced and rather sharp, there are 1 or sometimes 2 interlamellar folds - some of which may extend backwards until the columellar (inferior) lamella, and the palatal callus is very pronounced and sometimes fairly pointed. The clausilium plate has an outer corner that is bent upwards, although this is impossible to see in most specimens.

The columellar (inferior) lamellar (columellaris) bifurcates to produce two parallel folds separated by a clear gap. Nordsieck based his species description on the most common form present during the Late Pliocene where both these folds are poorly developed, but this is not always the case. Many of the specimens from Neudegg and Stranzendorf levels A and C do indeed have poorly developed folds, including the Holotype and Paratype from Stranzendorf level A (Nordsieck 1990, figs. 9-10) and one from level C (Frank 2006, pl. XXXI,10), and these shells can be classed as '***Type A***'. In other specimens the folds are partially developed, and these can be called '***Type A/B***', while a minority have well-developed folds that continue until the edge of the mouth, including examples from both Neudegg ($ new photo $) and from Stranzendorf levels A and C (cf. Frank 2006, pl. XXXI,7-9), and these can be labelled '***Type B***'.[1] Despite these differences, however, in almost all cases there is a clear gap between these parallel folds. By contrast, in the older Early Pleistocene levels at Stranzendorf, of the 21 *Clausilia* shells that possess the characteristics mentioned above, most have folds that correspond to Type B, while a few (2 from level G) have Type A/B. These 21 shells include 1 from level D (apex), 2 from F, 10 from G, 4 from K, 2 from K/L and 2 from L. Nordsieck identified these shells as being *C. cruciata*, but this is incorrect as they all possess the characteristics typical of *C. stranzendorfensis* mentioned above, including the clearly separated parallel folds from the columellar lamellar, while missing several features typical of *C. cruciata* (see below). It appears that Frank was right in believing that *C. stranzendorfensis* continued into the older Early Pleistocene. Variation within *Clausilia* species is not unusual, and this often involves the columellar lamellar. During this re-examination of the Late Pliocene and Early Pleistocene material from Austria, for example, specimens of *C. dubia* could be observed with well-developed folds extending from the columellar lamellar, although they are usually absent, while there are rare examples of *C. strauchiana* and *C. pumila* with poorly developed folds from the columellar lamellar, although they are normally prominent. Variation in the folds of the columellar lamellar is therefore insufficient reason for not considering certain shells from the older Early Pleistocene levels from Stranzendorf to be *C. stranzendorfensis*, when they possess all of the diagnostic characteristics of this species. It therefore seems appropriate to refer to *C. stranzendorfensis* 'Types' for the material from Neudegg and Stranzendorf, as shells that have columellar lamellar with both poorly-developed and well-developed folds can be observed from both sites, in deposits that span from the Late Pliocene to the older Early Pleistocene.

The Late Pliocene species *C. strauchiana* is very similar to *C. stranzendorfensis*, but can be distinguished from it by the notably broader and blunter more widely spaced ribbing (7-8 per mm on penultimate whorl), the broader and blunter palatal fold and subcolumellar lamella, the much less pronounced palatal callus, and the noticeably wider gap between the palatal fold and the palatal callus. Despite the claim by Nordsieck that *C. strauchiana* is completely replaced by *C. pumila* at the start of the older Early Pleistocene, specimens of *C. strauchiana* may still be present in Stranzendorf levels D, F, G, I, J and K, while *C. pumila* seems to be present from level F and largely replaces *C. strauchiana* from K/L upwards.[2] Both *C. strauchiana* and *C. pumila* have whorls that have a rather flat profile and a shallow suture, while *C. stranzendorfensis* has whorls with a gently curved profile and somewhat deeper sutures. *C. pumila* has similar ribbing to *C. strauchiana* and a comparable palatal fold, subcolumellar lamella and palatal callus, with the major differences being the slightly larger shells, the somewhat wider spacing of the ribbing (6-7 per mm on penultimate whorl) and the notably wider mouth. The gap between the palatal fold and the palatal callus is also wider in *C.*

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[1] An example of 'Type B' from Stranzendorf level C bares a hand-written label from Nordsieck identifying it as *C. stranzendorfensis*.

[2] As the transition from *C. strauchiana* to *C pumila*, was not the main focus of this re-examination, there was no systematic effort made to separate these two very similar species, so only rather typical specimens were noted but not examined more closely, the most obvious difference being the width and shape of the mouth.

pumila, with a shell profile that is fairly horizontal, while in *C. stranzendorfensis* the gap is noticeably narrower and the shell profile slopes upwards fairly steeply.

When *C. cruciata* is compared to *C. stranzendorfensis*, it has more widely spaced ribbing (6-7 ribs per mm on penultimate whorl), the mouth is elongated but notably wider (2.3-2.4 x 1.5 to 1.8 mm), the basal groove is significantly less deep, the palatal fold and subcolumellar lamella are somewhat broader and less pronounced, there are 1, sometimes 2 and rarely 0 or 3 interlamellar folds, the palatal callus is much less pronounced and never pointed, and the gap between the palatal fold and the palatal callus is greater. The most important difference lies with the columellar lamella, which in *C. cruciata* often bifurcates internally, something that is never seen in *C. stranzendorfensis*. The columellar lamella also bifurcates towards the lip of the mouth, with both folds being normally fairly well developed, but unlike *C. stranzendorfensis* the two folds are not parallel but bifurcate with an angle of 20-30° between them, with the lower fold being continuous and step-like (or s-like) so there is no gap between the folds (cf. Welter-Schulthes 2012, p.296). Although *C. cruciata bonellii* from central Italy, *C. cruciata pedemontana* from NW Italy (Nordsieck 1990, pl. 2,17), and similar varieties from SE France, have more closely spaced ribbing, they have a wider mouth, a less deep basal groove, a less pronounced palatal callus and a form of columellar lamella that is characteristic for *C. cruciata*.

To summarise: *C. stranzendorfensis* can be reliably separated from *C. strauchiana*, *C. pumila* and *C. cruciata*, although this can be rather time-consuming. At Stranzendorf, *C. stranzendorfensis* is present in both the Late Pliocene and older Early Pleistocene levels, from A up to L, so the shells in the older Early Pleistocene levels identified by Nordsieck as *C. cruciata* instead belong to *C. stranzendorfensis* as Frank believed, although this re-examination has identified 5 more levels where this species is present. The majority of shells from the Late Pliocene levels at Neudegg and Stranzendorf have folds extending from the columellar lamella that are poorly developed (‘Type A’), although a few shells have well-developed parallel folds (‘Type B’). By contrast, in the older Early Pleistocene levels at Stranzendorf ‘Type B’ shells are more common and ‘Type A’ are fairly rare.

The chronostratigraphic limits of *Clausilia stranzendorfensis* and *C. cruciata* in the Late Pliocene and Early Pleistocene deposits of north-eastern Austria

A re-examination of the shell material from the sites of Neudegg, Stranzendorf, Deutsch-Altenburg, Krems and Radlbrunn has shown that specimens of *C. stranzendorfensis* are only present in the Late Pliocene and older Early Pleistocene levels at Neudegg and Stranzendorf. The shells from Unterparschenbrunn could not be located, but it is reasonable to assume that Frank was correct in her analysis given that her identifications from Neudegg and Stranzendorf have been largely supported by this re-examination. There are no shells from *C. stranzendorfensis* in the middle to late Early Pleistocene deposits at Deutsch-Altenburg, Krems and Radlbrunn, confirming that this species probably became extinct at the end of the Tiglian and can be considered to be a biostratigraphic marker for the later Late Pliocene and the older Early Pleistocene, from c.3.2 until c.1.8 My, that corresponds to the European small mammal zones MN16b to MN17. At Stranzendorf the youngest context with a definite specimen of *C. stranzendorfensis* is level L, which immediately predates the Olduvai Subchron.

No specimens of *C. cruciata* could be found among the abundant shell material from Neudegg and Stranzendorf. Specimens were however found at Deutsch-Altenburg in contexts 30A, 2C1, 22A and

4B, which date from the middle Early Pleistocene,[3] as well as in Krems level 7/2, which dates from the later Early Pleistocene (fig. $$$). There are no shells from this species at Radlbrunn. All shells have a bifurcating columellar lamella typical of *C. cruciata*. Although the penultimate whorls were not conserved, it appears that the ribbing is denser that in typical modern specimens, being similar to *C. cruciata bonellii* but not as dense as *C. cruciata pedemontana*. These records indicate that *C. cruciata* probably first appeared after the Tiglian, during the middle Early Pleistocene and may have been the successor to *C. stranzendorfensis*, as Nordsieck believes (1990, fig. 6).

The *Clausilia* shells from the Hasli Formation of the Irchel Plateau

Like the shells from Neudegg and Stranzendorf, most of the shells from the Hasli Formation of the Irchel Plateau are rather broken. This is especially true of shells from the Clausiliid species, which due to their elongated shape and high number of whorls (often 10 or more) are easily crushed and fragmented. In one exceptional layer (Irchel Hochwacht west, Layer 7), however, a number of *Clausilia* shells resembling *C. stranzendorfensis* have been found that are almost complete, although some of these have cemented sediment blocking the all-important mouths of the shells.

These well-preserved shells have 10, sometimes 11 whorls and vary from 9.3-10.7 mm in height, with a mean of 9.9 mm (18 shells), and 2.6-2.8 mm in diameter, with a mean of 2.7 mm (32 shells). They have fairly sharp, moderately spaced ribs (8-9 per mm on penultimate whorl; often with somewhat whitened crests on the middle whorls), the whorls have a gently curved profile and moderately indented sutures, the mouth is elongated and narrow (2.2-2.4, mean 2.3 mm high x 1.2-1.4, mean 1.3 mm wide), the basal groove is both narrow and deep, the palatal fold is pronounced and rather sharp, the subcolumellar lamella is also fairly pronounced and rather sharp, there are 1, sometimes 2 interlamellar folds, most of which are short and not well-pronounced, while the palatal callus is notably pronounced and rather pointed. The clausilium plate has an outer corner that is bent upwards. The columellar lamellar bifurcates to produce two parallel folds separated by a clear gap, confirming that these *Clausilia* shells correspond to *C. stranzendorfensis*. Of 55 specimens from Hochwacht Layer 7, 49 were ‘Type B’, with well-developed parallel folds, while 6 were ‘Type A/B’ with rather poorly developed folds. In specimens from various other layers from all the Irchel sites where the mouth elements were preserved, the majority were also ‘Type B,’ meaning that the specimens of *C. stranzendorfensis* from the Irchel sites resemble those from the older Early Pleistocene levels from Stranzendorf. The chronostratigraphical implication from these shells is that the Hasli Formation dates from before the end of the Tiglian, at c.1.8 My.

The species *C. cruciata* is entirely absent from the Hasli Formation, but has been found in the deposits of Hungerbol 2. This also indicates that the Hasli Formation predates the end of the Tiglian.

Clausilia shells from older Early Pleistocene sites in central southern Germany

Apart from the sites in north-eastern Austria and the Irchel Plateau in Switzerland, Nordsieck has also identified shells as being *C. cruciata* from older Early Pleistocene deposits at the sites of Buch and Uhlenberg from the Zusamplatte of the Iller-Lech-Platte in central southern Germany, which lies

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[3] Also listed for D-A 37 in Frank and Rabeder 1997d (p.265), but not in Nordsieck 2007 (p.140). Records for D-A 30A and 4B have been verified by Nordsieck (2021), and for D-A 30A, 2C1 and 22A by NT. The shell from Krems 7/2 has been identified by NT, but records from Krems levels -5 to -1 in Kovanda et al. 1995 have all been refused by Nordsieck (2005). Unfortunately, NT has not been able to check the Kovanda material (not in Vienna) or all of the shells from Deutsch-Altenburg, including D-A 37, or the material from Hundsheim.

between the two areas where *C. stranzendorfensis* has now been positively identified. The shells from Buch were first identified as *C. pumila* by Geyer (1914), then as *C. cruciata* by Schröder and Dehm (1951), again as *C. cruciata* by Münzing (1974), then as *C. pumila* by Rähle and Bibus (1992) and finally as *C. cruciata* by Nordsieck (2021). Those from Uhlenberg were identified as *C. cruciata* by Dehm (1979), then as *C. pumila* by Rähle (1995), and then again as *C. cruciata* by Nordsieck (2021). Other *Clausilia* shells from the contemporary older Early Pleistocene site at Fischach, which also lies within the Zusamplatte, were first identified as *C. cruciata* by Schröder and Dehm (1951), then as *C. pumila* by Rähle and Bibus (1992) and finally as *C. pumilla* by Nordsieck (2021). These uncertainties in shell identification stem from the similarities between certain species during the older Early Pleistocene and also possibly because these shells belong to *C. stranzendorfensis*, which in size and ribbing is rather similar to *C. cruciata*, but has a columellar lamellar that resembles that of *C. pumila*. It would be extremely useful to check the *Clausilia* shells from Buch and Uhlenberg to see whether they may correspond to 'Type B' *C. stranzendorfensis*.

Conclusions

The species *Clausilia stranzendorfensis* appears to be present in sites from north-eastern Austria from the later Late Pliocene until the older Early Pleistocene (Tiglian), after which it seems to become extinct. Although there was moderate morphological variation in the columellar lamellar, this followed a similar pattern throughout this period, indicating that it remained the same species and implying that there is no reason to create different subspecies.

Certain shells from the Hasli Formation, ZH, also appear to represent *C. stranzendorfensis*. The predominant form of their columellar lamellar is similar to that of the shells from the older Early Pleistocene levels at Stranzendorf. The presence of these shells in the Hasli Formation implies that it is likely to predate the end of the Tiglian.

The fairly similar species *C. cruciata* seems to appear after the Tiglian, as it is absent from older Early Pleistocene sites in north-eastern Austria but has been found at two middle to late Early Pleistocene sites. *C. cruciata* is entirely absent from the Hasli Formation but is present at Hungerbol 2.

Part 2: Data on other molluscan species gathered during the Vienna visit

In the following text Neud = Neudegg and Stranz = Stranzendorf

The Stranzendorf, Krems and Deutsch-Altenburg material includes numerous unidentified shell fragments, so there are many possibilities for new records for the various levels and contexts

Cochlostoma: the shells from later Late Pliocene deposits at the sites of Neudegg and Stranzendorf level C have been identified as being *C. salomoni* by Frank, as the mouth-edge of the shells from Neudegg is significantly thickened, fairly strongly reflected and has a protruding inner ring, unlike the mouth edge of *C. salomoni*, which is simple, only moderately thickened and only slightly reflected. Although the gently rounded whorls and rather regular, sharply defined fine ribs (with every 3rd, 4th or fifth rib being slightly more protruding), is similar to *C. salomoni*, these shells seem to belong to a different species. The specimens from Stranzendorf do not have a preserved mouth.

Ena montana: Stranz - new record level A

Cochlodina laminata: Neud - new record; Stranz - new record level K

Macrogastra densestriata: Stranz - record level F confirmed, incorrect records levels J, K/L, L and M; Krems - incorrect record level 11, new record level 7

Macrogastra plicatula: Stranz - new records levels L and L/M; Krems - new records levels 11 and 7, incorrect record level 8/2

Macrogastra sessenheimensis: Stranz - confirmed record from level F; no other specimens seen

Triptychia neudeggensis: Neudegg - Type site; Stranz- confirmed record level C (Frank 2006, p.389-391), new record level A, and redeposited fragments levels K/L and M. The records from A and C are important as this biostratigraphic marker genus seems to have disappeared from the region after the Late Pliocene, confirming the palaeomagnetic date for these levels.

Aegopinella ressmanni: Krems - records confirmed for levels 4/2 and 4/1

Aegopis sp.: (not *klemmi* or *verticillus* because no spiral microsculpture) Stranz - new records levels K, K/L and L, where 2 species may be present, one with a moderately shallow but wide umbilicus with a smooth shiny shell (K/L and L), and the other with a fairly deep umbilicus with rather pronounced growth ridges that disappear on the underside of the shell outside of the umbilicus (K, K/L and L); Deutsch-Altenburg - new record context 30A

Aegopis klemmi: Krems - new records levels 9 and 7, confirmed for level 8/2,

Aegopis verticillus: Stranz - incorrect records levels G and K/L; Krems - incorrect records levels 9 and 7, so the earliest levels are 4/2 and 4/1, from the early Middle Pleistocene. There thus seem to be no Early Pleistocene records for Austria.

Archaegopis (Retinella) acutus: Neud - record confirmed; Deutsch-Altenburg - records confirmed

Oxychilus sp.: Stranz - new record level C

Retinella (Lyrodiscus) sp.: Neud - the shells belong to *Retinella (Lyrodiscus) elephantium*

Causa holosericea: Neudegg - record confirmed; Stranz - records levels A and C incorrect, so this species is not present at Stranzendorf

Cepaea nemoralis: Krems - new record level 5

Euomphalia strigella: Stranz - present in most levels (new records from the unidentified fragments)

Helicigona čapeki: Stranz - new records levels D, G, K and L (from the unidentified fragments); Krems - new record level 5, incorrect record level 4/1; so this species seems not to have been present in Austria after the Early Pleistocene.

Helicodonta obvoluta: records in Frank for this species at Stranzendorf (levels C, K and L) and the Early Pleistocene levels at Krems (5) are incorrect; the earliest records for this species from Austria are therefore from the early Middle Pleistocene strata at Krems (levels 4/2 and 4/1).

Helicopsis striata: Stranz - present in most levels (new records from the unidentified fragments)

Isognomostoma isognomostomos: Stranz - new records levels A and L

Monachoides incarnatus: Stranz- new records levels D and F; Krems - incorrect records levels 11 and 8/2, confirmed for levels 7, 7/1, 4/2 and 4/1

Monachoides vicinus: Neud - new record; Stranz - new records levels D and L (present in most levels)

Perforatella bidentata: Stranz - new records levels A, C, F and J (present in most levels); Deutsch-Altenburg - new record context 30A

Serrulella sp.: Stranz - record for level C (same as Nordsieck 2021), new records for levels F and L

Trochulus filicinus: Stranz - new records levels C, F, K, L and L/M (confusion with *T. hispidus* by Frank + present among unidentified fragments); Krems - new record level 7/2; Radlbrunn - new record; Deutsch-Altenburg - new records contexts 30A, 2C1, 37, 4B and 4A

Trochulus leucozonus: Stranz - new records levels C, F, K and L; Krems - new records levels 9 and 7

Vallonia tenuilabris: Stranz – some levels include *Vallonia declivis*, which is a new record for the Early Pleistocene of Austria

Xerolenta *obvia*: Stranz - all records are modern shells that represent recent contamination

Urticicola umbrosus: Neud - record is incorrect; Stranz - new records levels C, J and K, record level G is incorrect; Deutsch-Altenburg - new record context 30A

Aquatic species

B. leachii: Stranz - level C, operculum, new record

Bithynia tentaculata: Stranz - level C, operculum incorrect record

Lymnaea stagnalis.: Stranz - level K/L, new record

Stagnicola sp.: Stranz - level K/L, incorrect record

Corbicula sp.: Stranz - new records levels H and J (although all records need to be checked in case of redeposited tertiary bivalves)