Landscape evolution of the Black Forest: From the Variscan orogeny to the modern era

Felix Martin Hofmann

Institute of Earth and Environmental Sciences, University of Freiburg, Freiburg, Germany

e-mail: fmhofmann9892@gmail.com

This manuscript has been submitted for consideration for publication as chapter in the book “Landscapes and landforms of Germany” (publisher: Springer) which is part of the book series “World Geomorphological Landscapes”

Peer review status: This is a non-peer-reviewed preprint submitted to EarthArXiv.

4.3 Landscape evolution of the Black Forest: From the Variscan orogeny to the modern era

Felix Martin Hofmann

Institute of Earth and Environmental Sciences, University of Freiburg, Freiburg, Germany

e-mail: fmhofmann9892@gmail.com

Abstract. With a maximum elevation of 1493 m above sea-level, the Black Forest (*Schwarzwald* in German) is the second highest mountain range in Germany. It is subdivided in three main natural regions, the northern, central, and southern Black Forest. The Variscan basement of the Black Forest consists of plutonic and metamorphic rocks. Sedimentary rocks formed during the Mesozoic under marine and terrestrial conditions. The evolution of the Upper Rhine Graben had a profound impact on relief of the Black Forest. Higher erosion rates in the western part of the Black Forest resulted in the formation of deep and steep valleys (Rhenanian relief type), and in the removal of Mesozoic rocks. The relief of these Rhenanian valleys contrasts with the rather subdued relief in the eastern part of the Black Forest (Danubian relief type). Glacial deposits and landforms in the northern, central and southern Black Forest bear witness to Quaternary glaciations. Periglacial processes overprinted non-glaciated and deglaciated areas and gave rise to the development of slope deposits (cover beds). With the onset of the Holocene and rising temperatures, the Black Forest became almost entirely covered by forests, thus resulting in a period of geomorphological stability. Human activity caused processes, such as colluviation or soil erosion, and became an increasingly important factor in terms of geomorphological processes.

4.3.1 Introduction

The Black Forest (German: *Schwarzwald*) is the highest mountain range of Variscan mountains and uplands in Germany, and the highest region of Germany outside the Alps. It attains a maximum elevation of 1493 m above sea-level (m a.s.l.). The roughly N-S trending mountains lie in the south-westernmost part of Germany (Fig. 1.2), belong to the state of Baden-Württemberg, and represent a significant topographic boundary (Fig. 4.3.1). The Upper Rhine Graben delimits the Black Forest and its foothills to the west, while the High Rhine, i.e., the part of the Rhine between Lake Constance and the city of Basel, bounds the mountains to the south.

According to the Handbook of the Natural Region Divisions of Germany (Bundesanstalt für Landeskunde und Raumforschung 1953-1962), the Black Forest comprises the following natural regions: Black Forest Foothills (150), Black Forest Grinden and Enz Hills (151), Northern Black Forest Valleys (152), Central Black Forest (153), South-eastern Black Forest (154), and High Black Forest (155). The northern Black Forest attains a maximum elevation of 1164 m a.s.l. and comprises the Black Forest Foothills, the Black Forest Grinden and Enz Hills and the Northern Black Forest Valleys. The South-eastern Black Forest and the High Black Forest are subsumed under the southern Black Forest. As it will be discussed below, the northern, central, and southern Black Forest represent three distinct regions in terms of elevation, bedrock types, climate and the nature of geomorphological processes.

The four highest summits of the Black Forest, Feldberg (1493 m a.s.l.; Fig. 4.3.2a), Seebuck (1449 m a.s.l.; Fig. 4.3.2a), Herzogenhorn (1415 m a.s.l.), and Belchen (1414 m a.s.l.) lie in the southern Black Forest. The highest summit of the northern Black Forest is Hornisgrinde (Fig. 2b). Main rivers in the Black Forest include the Murg, the Enz, the Kinzig, the Danube and its headstreams, the Breg and the Brigach, the Wutach, and the Wiese (Fig. 4.3.1). The main water divide between the Rhine and Danube systems runs through the Black Forest.

A temperate climate prevails in most regions of the Black Forest (Cfb climate according to the Köppen-Geiger climate classification system; Glaser et al. 2013). The advection of humid air masses from the Atlantic Ocean leads to high annual precipitation when compared to other regions in Germany. The climate on the highest summits is described as subarctic (Dfc climate). According to data of the German Weather Service (DWD), annual precipitation and the mean annual temperature at the weather station on Feldberg amounted to 1909 mm a^{-1} and 3.3 °C in the 1961-1990 CE period, respectively. In the area around Hornisgrinde, annual average annual precipitation amounts to 2200 mm a^{-1}. Generally, annual precipitation is somewhat lower in the southern part of the Black Forest. The Vosges represent a topographic barrier and reduce the amount of annual precipitation in this region. Snow cover during winter is important and lasts, on average, for 157 days per year on Feldberg (Matzarakis 2012).

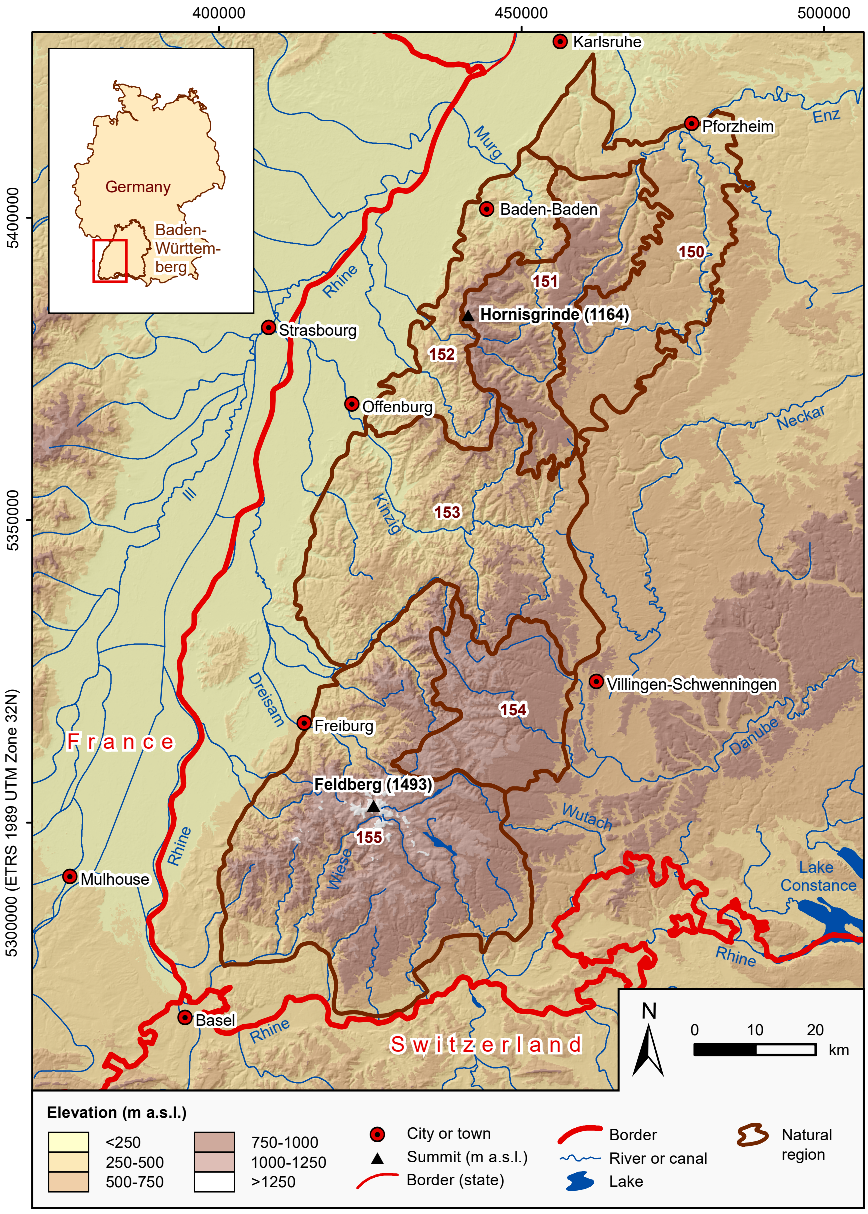

Figure 4.3.1 Topographical map of the Black Forest and natural regions according to Handbook of the Natural Region Divisions of Germany (Bundesanstalt für Landeskunde und Raumforschung 1953-1962): Black Forest Foothills (150), Black Forest Grinden and Enz Hills (151), Northern Black Forest Valleys (152), Central Black Forest (153), Southeastern Black Forest (154), and High Black Forest (155). The digital elevation model (DEM) in the background originates from data acquired during the shuttle radar topography mission (SRTM; Jarvis et al. 2008). It is superimposed on a hillshade derived from the same DEM. © EuroGeographics for administrative boundaries. © GeoBasis-DE / BKG (2022) for rivers

The Black Forest belongs to the Variscan orogenic belt. Igneous and metamorphic rocks outcrop in a vast area of the Black Forest (Fig. 4.3.3). Mesozoic sedimentary rock, mainly Buntsandstein, covers a significant portion of the northern Black Forest, particularly the eastern part. Mesozoic sedimentary rock also occurs in the western part of the central Black Forest between the cities of Freiburg and Offenburg, whereas metamorphic and plutonic rocks of the Variscan basement dominate the region further east. The southern Black Forest is largely composed of metamorphic and plutonic rocks of the Variscan basement.

A geologically interesting zone is situated south of Feldberg. The 40 km long and 3 to 4 km wide Badenweiler Lenzkirch zone, named after the villages at its western and eastern ends (Badenweiler and Lenzkirch, respectively), consists of non-metamorphic greywackes, claystones, volcanic rocks, granites, and metamorphic schists. It is nowadays considered a part of a Variscan suture zone (Huth and Zedler 2019). A fault separates the Badenweiler Lenzkirch zone from the southern Black Forest gneiss complex further south. Granites and gneisses dominate this region (Korn and Montenari 2021).

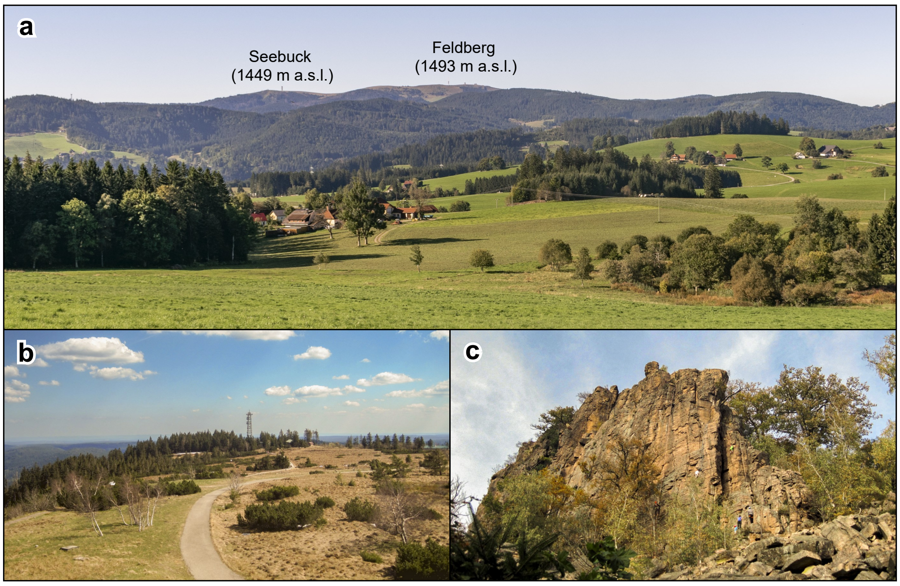

Figure 4.3.2 Landscapes and landforms of Black Forest. **a** Feldberg and Seebuck seen from the area north of Feldberg. **b** A peat bog covers the summit area of Hornisgrinde, the highest summit of the northern Black Forest **c** The Battert is situated close to the city of Baden-Baden and consists of sedimentary rock of the Rotliegend (Lower Permian). All photos: FM Hofmann

According to the State Geological Survey of Baden-Württemberg (LGRB), glacial deposits, such as till, cover the formerly glaciated areas in the Black Forest (LGRB 2013). Loess occurs below ~400 m a.s.l., whereas areas at higher elevations are dominated by periglacial cover beds. See Lehmkuhl et al. (2016, 2018) for further details.

4.3.2 Landscape evolution

4.3.2.1 Formation of the Variscan orogenic belt

The Variscan orogeny (at around 380–290 Ma; Geyer et al. 2011), resulted in metamorphism and the formation of rocks of intrusive origin. The Black Forest pertained to the Moldanubian zone, delimited to the north by the Baden-Baden fault (Figs. 1.3 & 4.3.4). Note that the rocks of the Variscan basement are commonly subsumed under *Grundgebirge*. The granites of the Variscan basement are slightly younger than the widespread gneisses (LGRB 2023a).

During the Carboniferous, the Variscan orogenic belt became affected by tectonic uplift and erosion, resulting in the formation of sedimentary rock. Note that sedimentary rocks on the Variscan basement are commonly subsumed under *Deckgebirge* in the German literature. The Lower Permian saw the formation of sedimentary rock in basins on the Variscan orogenic belt (Eberle et al. 2023).

Figure 4.3.3 reveals that the Lower Permian sedimentary rocks have been preserved in the northernmost, eastern, and south-westernmost part of the Black Forest. The morphologically prominent Battert rocks (natural reserve) on the southern flank of Battert (568 m a.s.l.; Fig. 4.3.2c) near the city of Baden-Baden (Fig. 4.3.3) consists of Lower Permian sedimentary rocks, i.e., reddish to grey conglomerates, breccias, and arkosic sandstones. At around 290–280 Ma, rivers and debris flows carried sediments to a sedimentary basin on the Variscan orogenic belt. As the sedimentary rocks were silicified during the Cenozoic, the rocks became relatively resistant to erosion. Erosion resulted in the formation of imposing rock towers and rock cliffs on the southern flank of Battert (4.3.2c; LGRB 2020).

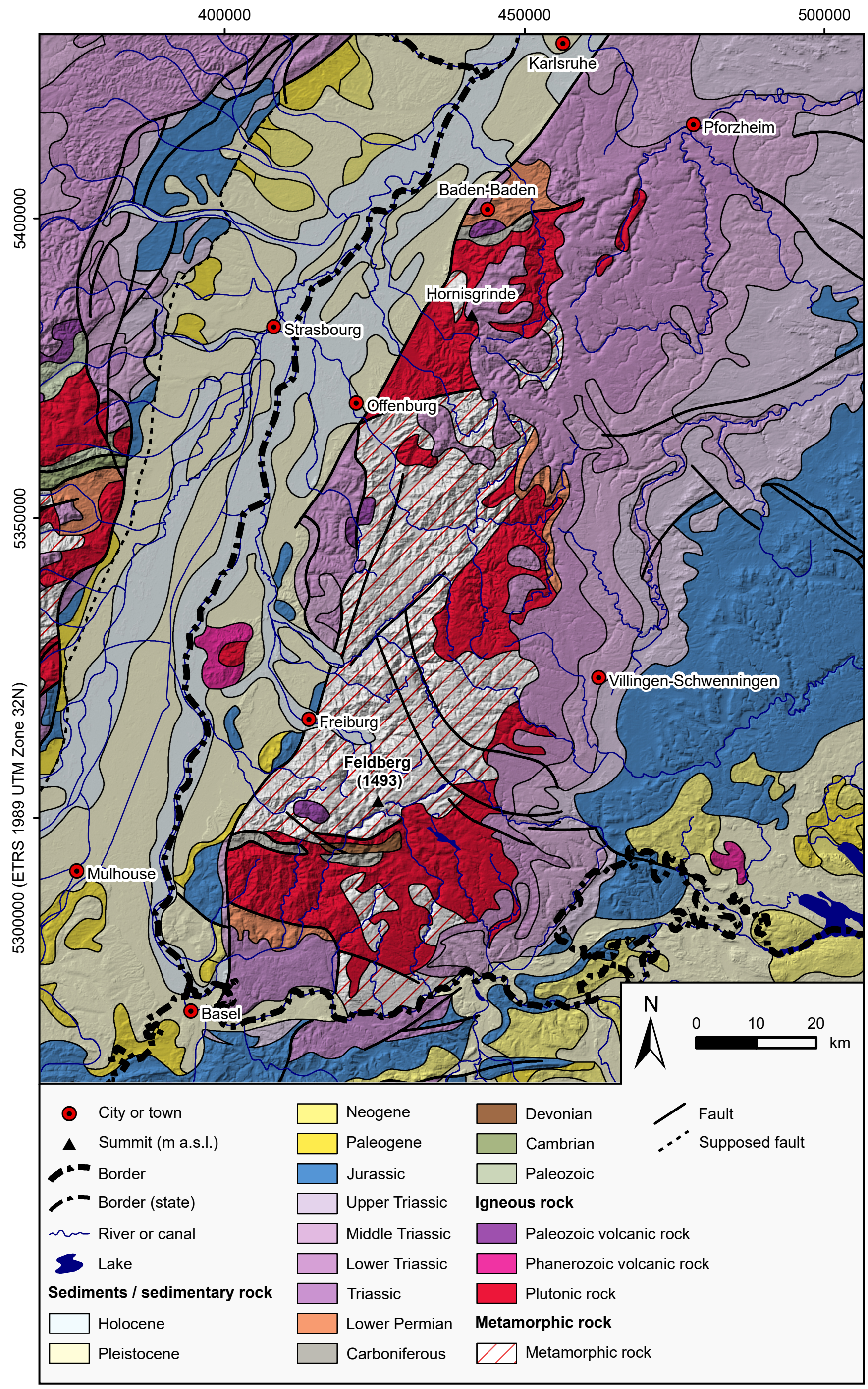

Figure 4.3.3 Geological map of the southern Black Forest and the surrounding region (Lahner and Toloczyki 2004) superimposed on a hillshade derived from elevation data of the SRTM (see Fig. 4.3.1 for the data source). © EuroGeographics for administrative boundaries. © GeoBasis-DE / BKG (2022) for rivers

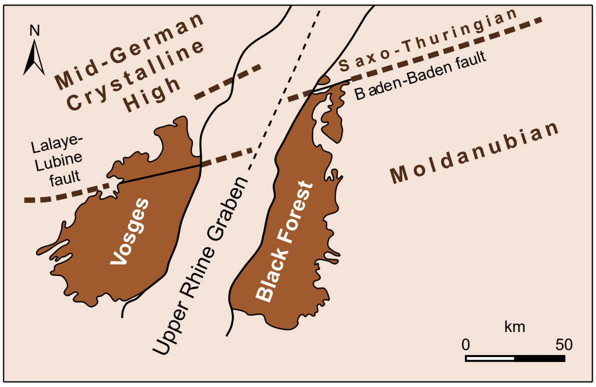

Figure 4.3.4 Paleogeographic reconstruction showing the Variscan basement of the Black Forest and the Vosges (brown area) as well as faults and tectonic zones during the Variscan orogeny. Redrawn from Franke et al. (2017)

4.3.2.2 Landscape evolution during the Mesozoic

The Mesozoic rocks imply that both marine and terrestrial conditions prevailed during this period (Fig. 4.3.5; Geyer et al. 2011; Eberle et al. 2023). One noteworthy example is the Triassic Bundsandstein, which today occurs particularly in the central and northern Black Forest (Figs. 1.7 & 4.3.3).

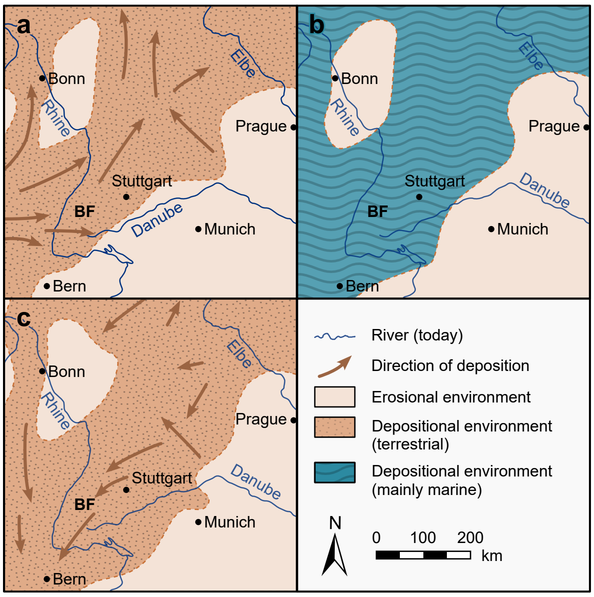

Figure 4.3.5 Erosional and depositional environments during the **a** Early, **b** Middle and **c** Late Triassic (modified from Eberle et al. 2017). **BF:** Black Forest

While the environmental conditions during the Triassic and Jurassic periods can be well reconstructed based on the nature of rocks, the scarcity of Cretaceous rocks and deposits (cf., LGRB 2023b) poses considerable difficulties for the reconstruction of landscape development during this final phase of the Mesozoic. Therefore, the environmental conditions during the Cretaceous remain poorly understood (cf., Eberle, chapter 4.4, this book; Geyer et al. 2011; Eberle et al. 2023).

4.3.2.3 Formation of the Upper Rhine graben and consequences for the landscape evolution of the Black Forest

The onset of the development of the Upper Rhine Graben marks an important point in the landscape evolution of southern Germany. This around 300 km long and 30-50 km wide graben (Fig. 4.3.6a) developed as part of the European Cenozoic rift system (see Fuchs, chapter 4.1; Ziegler 1992). Crustal extension, subsidence, and shearing began during the Eocene. The Variscan basement on either side of the Upper Rhine Graben became affected by uplift (Rotstein and Schaming 2011).

Crustal discontinuities that started developing during the Variscan orogeny played a key role during the development of the Upper Rhine Graben (Schumacher 2002). During the Eocene and the Oligocene, the graben became repeatedly inundated by the Tethys Ocean (Eberle et al. 2023). The difference in elevation between the graben and the Black Forest resulted in erosion of Mesozoic rocks that once covered the Variscan basement. In the southern Black Forest, Mesozoic sedimentary rock became completely eroded with only a few exceptions (Fig. 4.3.3). Rivers from the Black Forest carried boulders towards the Upper Rhine Graben and alluvial fans formed at the eastern margin of the graben (LGRB 2011). The resulting conglomerates (Fig. 4.3.6b) have been preserved on Schönberg (644 m a.s.l.), which belongs to the foothill zone of the Black Forest SW of the city of Freiburg (Fig. 4.3.6a).

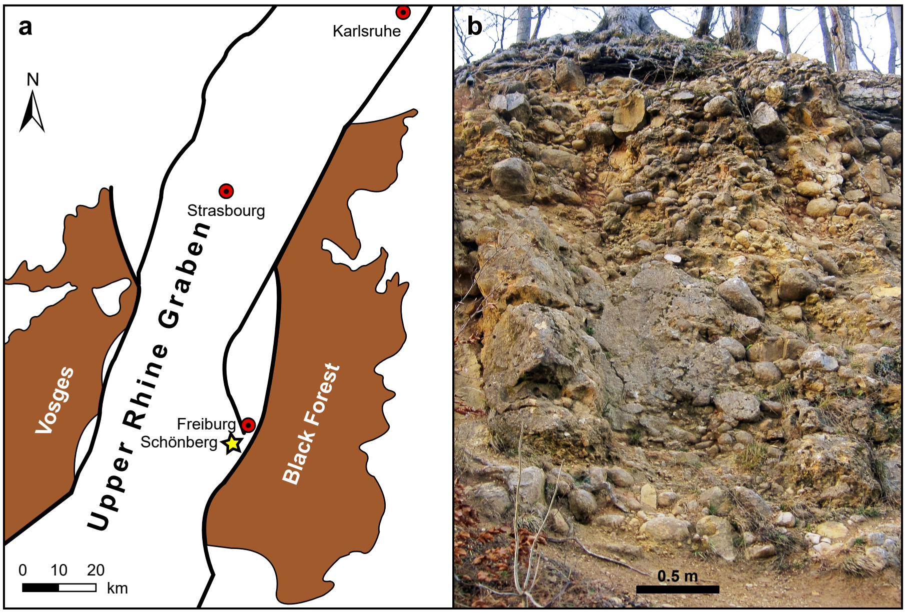

Figure 4.3.6 Development of the Upper Rhine Graben. **a** Map of the Vosges, the Upper Rhine Graben, and the Black Forest. The Variscan basement is shown in brown. Main faults are marked with solid lines (adapted from Eberle et al. 2017). **b** Conglomerates on Schönberg SW of the city of Freiburg are of Eocene to Oligocene age (Groschopf et al. 1996). Photo: FM Hofmann

The clasts were derived from sedimentary rocks of Middle Triassic to Upper Jurassic age. The conglomerates interfinger with sandstones and marls that have been deposited in lakes in the Upper Rhine Graben (Groschopf et al. 1996). The size of clasts in the conglomerates suggests that rivers with a steep longitudinal profile must have transported the boulders to alluvial fans at the eastern margin of the graben (Eberle et al. 2023).

During the Early Miocene, the Black Forest and the surrounding region were a rather low-relief landscape. Renewed tectonic activity during the Late Miocene and the Pliocene led to uplift of the Black Forest and subsidence of the Rhine plain (Eberle et al. 2017). Differences in elevation favoured erosion and resulted in the formation of two morphologically distinct landscapes. Strong erosion in the western part of the Black Forest led to the formation of deep and narrow valleys (Rhenanian relief type). Due to lower erosion rates, valleys with a rather flat longitudinal profile and gently sloping valley walls formed in the eastern part of the southern Black Forest (Danubian relief type; Metz and Saurer 2012; Coch 2014).

Due to stronger erosion in the Rhenanian valleys of the Northern Black Forest, the Mesozoic sedimentary cover on the Variscan basement became affected by erosion (Fig. 4.3.3). Stronger erosion in the Rhenanian valleys of the Southern Black Forest led to a progressive eastward shift of the western limit of the drainage basin of the Danube (Metz and Saurer 2012). Gently sloping areas at high elevations in the Rhine catchment are considered relicts of the Danubian relief type (Metz and Saurer 2012). The last major shift of the drainage divide occurred at the end of the last glacial cycle (presumably during marine isotopic stage 2) when the Wutach was redirected towards the Rhine (Hebestreit et al. 1993). This river capture resulted in enormous erosion of about 2 km^3 in the Wutach drainage basin (LGRB 2022).

4.3.2.4 Pleistocene environmental change

The northern, central, and southern Black Forest became temporarily glaciated during the Pleistocene. Previous reconstructions concluded that the penultimate glaciation (presumptive age: ≥ marine oxygen isotope stage (MIS) 6 (191-130 ka; Lisiecki and Raymo, 2005)) in these regions surpassed the last (Late Pleistocene) glaciation in ice extent (Fezer et al. 1961; Schreiner 1986, 1995; Schinke and Paul 1997; Schreiner and Groschopf 2002).

During the Late Pleistocene, an icefield and its up to five kilometres-long outlet glaciers temporarily covered the summit area of Hornisgrinde (1164 m a.s.l.) and the valleys east of the main ridge of the northern Black Forest, respectively (Fezer et al. 1961). The striking absence of glacial landforms west of the main ridge and the high abundance of ice-marginal moraines and cirques east of the main ridge point towards an asymmetric glaciation of the region around the Hornisgrinde. The numerous cirques in other parts of the northern Black Forest temporarily hosted smaller glaciers (Zienert and Fezer 1967). Figure 4.3.7 reveals that many cirques in the surroundings of Hornisgrinde have a north-easterly or easterly orientation. Periods of ice-marginal stability and/or re-advance phases punctuated glacier decay in the northern Black Forest. Zienert (1970) assigned moraines of this phase to three main ice-marginal positions. Lakes and peat bogs that formed in depression on cirque floors are key elements of today's landscape of the northern Black Forest (Schlund 2014). One easily accessible glacial lake is the Mummelsee on the southern flank of Hornisgrinde (Fig. 4.3.7).

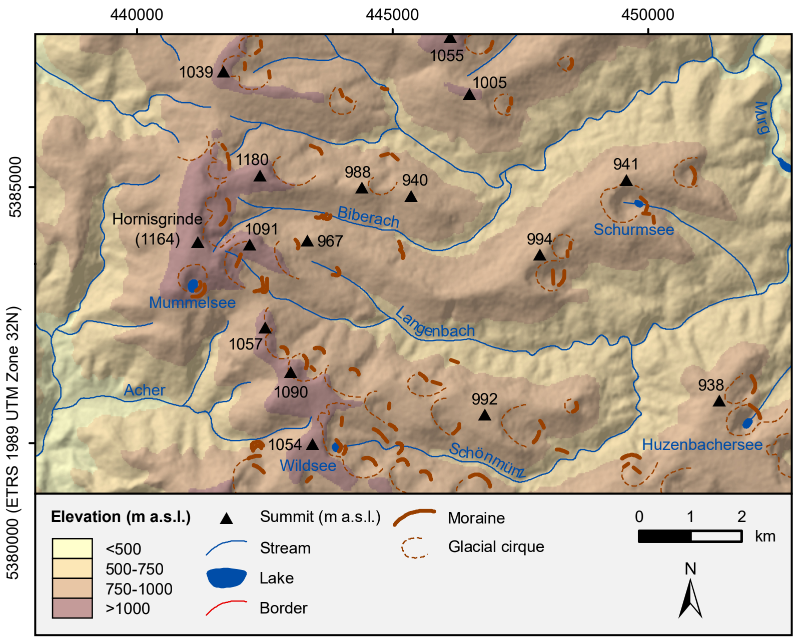

Figure 4.3.7 Glacial landforms in the region around Hornisgrinde (Fezer et al. 1961). Glacial landforms are superimposed on a hillshade, derived from elevation data of the SRTM (NASA Jet Propulsion Laboratory 2013)

Due to the lower elevation (Fig. 4.3.1), the ice masses in the central Black Forest did not reach the same dimensions as those in the northern Black Forest during the Late Pleistocene. Previous reconstructions point towards the temporary existence of cirque glaciers and small valley glaciers (e.g., Reichelt 1996, 1998; Leiber 2000). As pointed out by Reichelt (1996), gneisses in the central Black Forest were less favourable for cirque formation due to their lower erodability than the Triassic sandstone in the northern Black Forest. Due to the relatively limited glaciation, periglacial processes were dominant. Most of the glacial landforms, such as whalebacks, glacial cirques, trough valleys, meltwater channels and ice-marginal moraines, have been ascribed to glaciations prior to the Late Pleistocene (Schinke and Paul 1997).

Due to its elevation, the southern Black Forest was the most extensively glaciated region during the Late Pleistocene. Previous reconstructions conclude that four, probably interconnected ice caps with a surface of 1000 km^2 covered the region around Feldberg, Schauinsland, Belchen, and Köhlgarten (Fig. 4.3.8; Giermann 1964; Rahm 1987; Hofmann et al. 2020). The ice cap on Feldberg was, by far, the largest. With a length of about 25 km and a thickness of more than 400 m, the Alb outlet glacier was the longest and thickest glacier in the southern Black Forest (Hofmann et al. 2020 and references therein). During the Late Pleistocene, however, the glaciation was less extensive than during the penultimate (Middle Pleistocene) glaciation (Fig. 4.3.8; e.g., Schreiner 1986, 1995; Schreiner and Groschopf 2002). Glacial landforms, such as trough valleys, overdeepened valleys, whalebacks, glacial cirques, and ice-marginal meltwater channels, or moraines, are widespread elements of the landscape in the formerly glaciated region (Liehl 1982; Hemmerle et al. 2016; Hofmann et al. 2020).

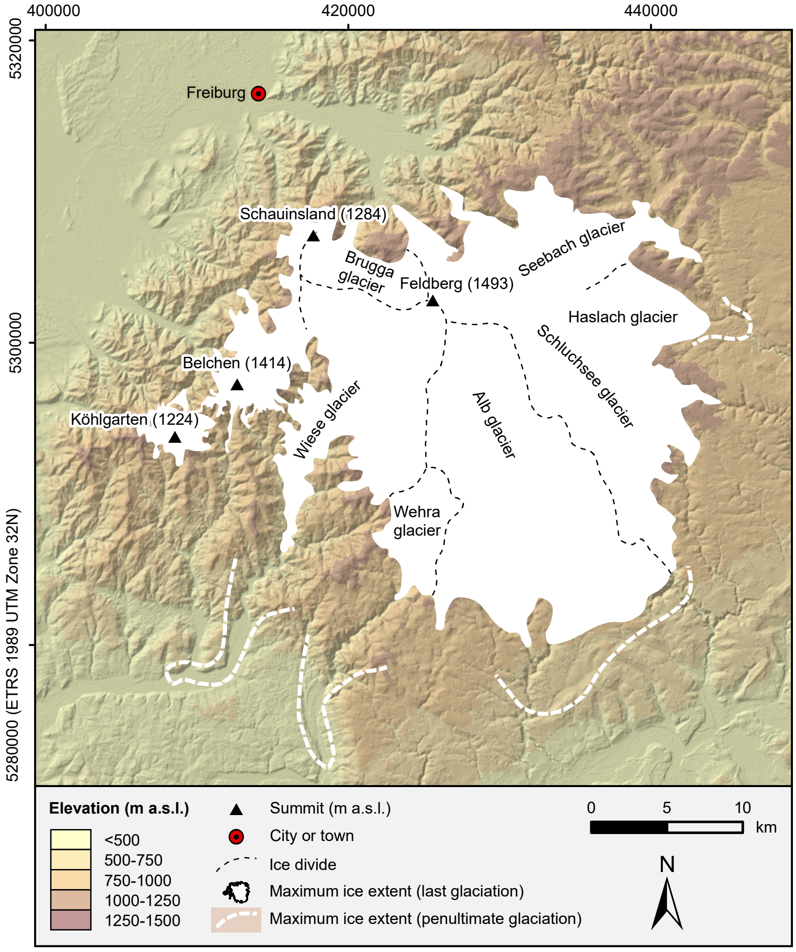

Figure 4.3.8 Maximum ice extent in the southern Black Forest during the last and the penultimate glaciation (Hemmerle et al. 2016, and references therein). The nomenclature of the outlet glaciers follows Hofmann et al. (2020). Elevation data in the background were acquired during the SRTM (NASA Jet Propulsion Laboratory 2013)

Preliminary ^{10}Be cosmic-ray exposure (CRE) ages of erratic boulders and moraine boulders at the last glaciation maximum position of the Haslach and Schluchsee glaciers indicate that the last deglaciation of the southern Black Forest began no later than ~21 ka (Hofmann 2023a, b). Multiple groups of younger moraines document repeated periods of ice-marginal stability and/or re-advance phases during the last deglaciation. The ice cap disintegrated into valley glaciers with independent accumulation areas. Beryllium-10 CRE dating of moraines in the region formerly covered by the Brugga outlet glacier and the westernmost branch of the Seebach glacier (Fig. 4.3.8) revealed a stepwise retreat of valley glaciers during the subsequent millennia, punctuated by phases of moraine formation (Hofmann et al. 2022, 2024a). These ice masses finally evolved into small cirque glaciers (Liehl 1982; Hemmerle et al. 2016; Hofmann et al. 2020). According to ^{10}Be CRE ages, final glacier retreat in most of the cirques began by 16–14 ka at the latest (Hofmann et al., 2022, 2024a, b). Chronological data imply that the deglaciation of the southern Black Forest was largely complete before the beginning of the Lateglacial, defined here as the period between the rapid rise in summer temperatures at around 14.7 ka and the beginning of the Holocene.

Three easily accessible glacial landscapes are the valley of Sankt Wilhelm (Fig. 4.3.9a), the Feldsee cirque east of Feldberg

(Fig. 4.3.9), and the Menzenschwander Albtal, a textbook example of a trough valley (Fig. 4.3.10) where the *Klusenmoränen*, a set of morphologically distinct ice-marginal moraines, has been preserved (Fig. 4.3.9c).

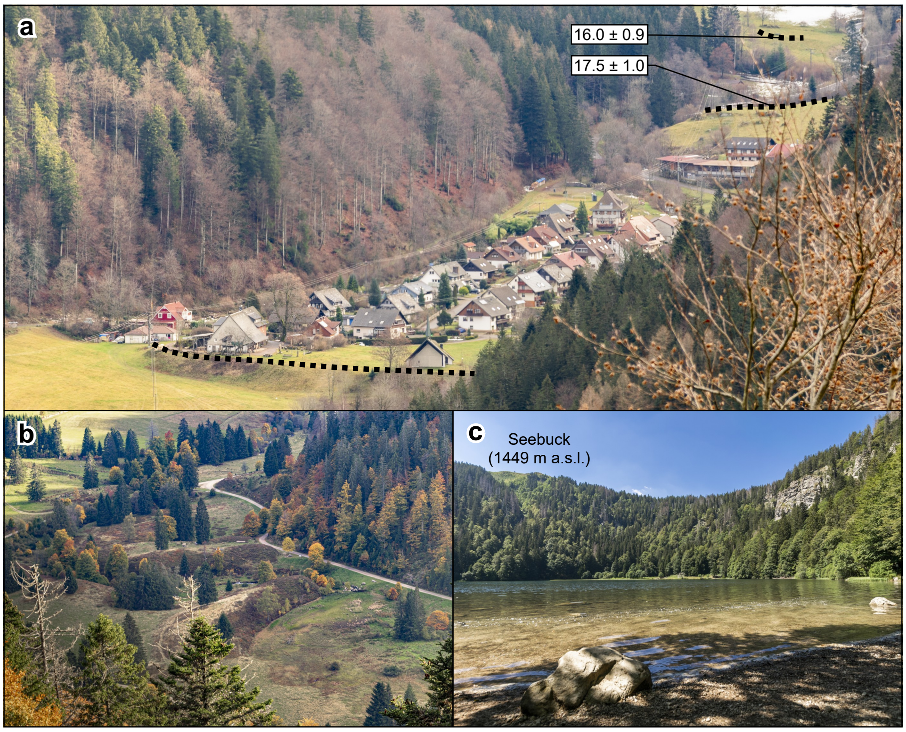

Figure 4.3.9 Glacial landforms in the southern Black Forest. **a** The glacial landscape around the village of Sankt Wilhelm NW of Feldberg. During the deglaciation of the valley of Sankt Wilhelm that once hosted the Brugga outlet glacier (Fig. 4.3.8), periods of moraine formation interrupted the trend towards ice-free conditions. Recently obtained ^{10}Be CRE ages (given in ka before 2010 CE) imply moraine formation prior to the onset of the Lateglacial (Hofmann et al. 2022). **b** The moraines in the upper part of the Menzenschwander Alb valley, the *Klusenmoränen*, are undoubtedly among the best-known and best-preserved moraines in the entire Black Forest. **c** Feldsee, a moraine-dammed lake up to about 33 m deep, is situated in the morphologically prominent Feldsee Cirque with an impressive headwall up to 300 m high. All photos: FM Hofmann

Figure 4.3.10 View from the NE valley wall of Menzenschwander Albtal towards the SE. Note the set of well-developed ice-marginal moraines of the last deglaciation, the *Klusenmoränen* (marked with dotted lines). Photo: FM Hofmann

Periglacial processes overprinted non-glaciated and deglaciated regions during the Pleistocene (Migoń and Waroszewski 2022). Processes, such as weathering and solifluction, resulted in the formation of periglacial layers (periglacial cover beds *sensu* Semmel and Terhorst 2010). The lack of vegetation in areas at high elevation favoured the development of these deposits. Solifluction in the active layer on the former permafrost table gave rise to the development of unconformities and, therefore, periglacial layers show a distinct stratification. Apart from the basal periglacial cover bed, all strata contain an admixture of loess (Semmel and Terhorst 2010; Kleber et al. 2013).

During the early Lateglacial, the dominant ecosystem at high elevations was a steppe-tundra. From 14 ka onwards, trees spread onto areas at higher elevations and the timberline rose to at least 1100 m a.s.l. (Lang 2006). The last marked decrease in temperatures in central Europe at the onset of the last cool period of the Pleistocene, often termed the Younger Dryas (Mangerud 2021), led to a shift in the timberline to about 750 m a.s.l. (Lang 2006) and a steppe-tundra probably replaced forests at higher elevation (Lang 2005).

Field trip: Traces of glaciations east of Feldberg

The hike (length: 9.6 km; Fig. 4.3.10) from the Feldberg-Bärental railway station to the Feldberg Caritas-Haus bus stop leads to key sites of the last glaciation of the Seebach valley.

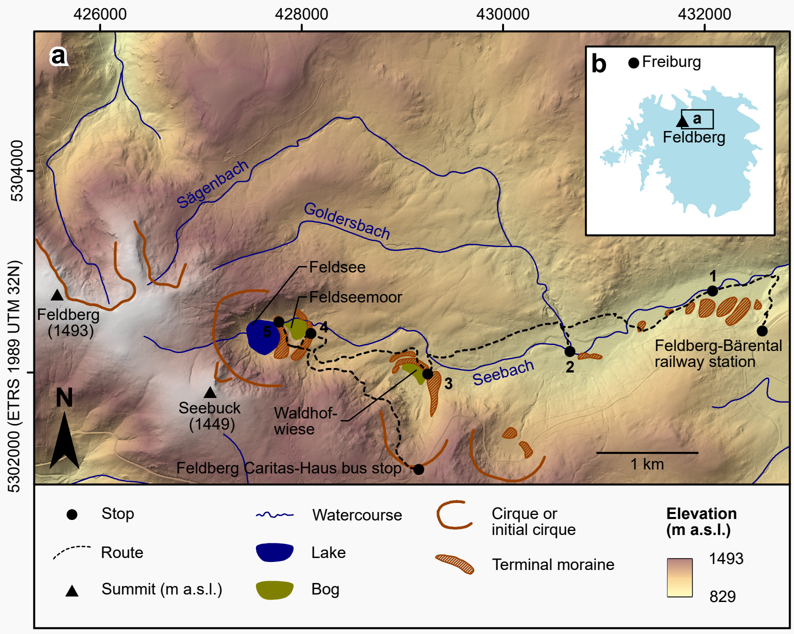

Figure 4.3.11 Map of the region east of Feldberg and maximum ice extent during the Late Pleistocene. **a** Topographic map of the region east of Feldberg showing the field trip's route, and glacial cirques, ice-marginal moraines, and bogs according to Geologisches Landesamt Baden-Württemberg (1990). Source of the DEM in the background: LGL, www.lgl-bw.de, dl-de/by-2-0. **b** Overview map including the Late Pleistocene maximum ice extent according to Hemmerle et al. (2016). Modified from Hofmann and Konold (2023)

At the first stop of the field trip, note the series of ice-marginal moraines on the southern valley wall. Several whalebacks occur on the flat valley floor at the second stop. The third stop lies at the eastern end of a bog (*Waldhofwiese*) in the former tongue basin of a cirque glacier, next to a prominent ice-marginal moraine. The fourth stop lies on a boulder-rich moraine that delimits Feldseemoor bog to the east. The fifth stop is situated at the eastern shore of Lake Feldsee, a moraine-dammed lake up to about 33 m deep. The field trip finally leads to a saddle (Feldberg Caritas-Haus) where a transfluent ice stream advanced from the south into the Seebach valley. For more photos of glacial landforms along the excursion route and a more detailed description, the reader is referred to Hofmann and Konold (2023).

4.3.2.5 Geomorphological evolution during the Holocene

After a phase of predominantly natural landscape development, human activities, such as agriculture, woodland clearance, or mining, increasingly determined the nature of geomorphological processes. During the Early Holocene, the timberline rose above the highest peaks of the Black Forest, and, with very few exceptions, dense forests covered the Black Forest. Note that the estimated timberline in the area around Feldberg lies at about 1600-1700 m a.s.l. (Bogenrieder 1982). The Early Holocene was a period of landscape stability, soil formation, and relatively low geomorphodynamics (Eberle et al. 2023).

Periglacial cover beds and glacial deposits were the parent material for soil formation (Zwölfer and Fleck 2011).

Initial land use at high elevations in the central Black Forest may have already begun during the Mesolithic. Miera et al. (2019) attributed the first phase of colluviation to the Younger Neolithic. The appearance of human indicators in pollen profiles, such as cereals (e.g., Henkner et al. 2018; Rösch 2000), document this phase of more intense land use. However, humans did not significantly affect landscape evolution during the Bronze Age (Mäckel et al. 2009) Woodland clearance occurred during the La Tène culture and during Roman times (Mäckel et al. 2003). The retreat of the Romans marks the onset of another period of geomorphic stability. Alluvial sedimentation in the Black Forest began during the colonisation of the Black Forest, correlated with the medieval climatic optimum (Mäckel et al. 2009). Pollen records indicate that the first agricultural activities in the valleys began during the Middle Ages (e.g., Friedmann 1999, 2002). The main phases of colluviation in the central Black Forest occurred during the Middle Ages and in the early Modern Period as a response to high settlement and agricultural activities (Henkner et al. 2018). Sedimentation rates remained at a high level during the Modern Period (Mäckel et al. 2009).

4.3.3 Protected areas

After a controversial debate (cf., Reif 2012), the State Parliament of Baden-Württemberg voted in favour of the establishment of a national park in the northern Black Forest in 2014. The Northern Black Forest National Park became the first national park in the state of Baden-Württemberg. The about 100 km^2 large protected area encompasses two distinct areas in the region around Hornisgrinde. In 2024, it was decided that the two parts of the national park would be connected. The national park lies in the Central and Northern Black Forest Nature Park. With an area of 4200 km^2, the latter is the largest nature park in Germany and slightly larger than the adjacent Southern Black Forest Nature Park (protected area: 3940 km^2). It should be noted that nature parks have a lower conservation status and aim to protect the cultural landscape. In addition, the Black Forest Biosphere Reserve was created in 2016 to preserve the cultural landscape of the Black Forest, such as extensive grasslands (Konold and Seitz 2018). The UNESCO officially recognised this protected area in 2017. In addition, many smaller areas have been protected as natural reserves (highest conservation status), such as the area around Feldberg.

4.3.4 Concluding remarks

The present-day landscape of the Black Forest is the result of long-term landscape evolution. Metamorphic and plutonic rock of the Variscan basement dominate large parts of the Black Forest. Overlying Mesozoic sedimentary rocks have mainly been preserved in the northern Black Forest and in the western part of the central Black Forest. Tectonic activity and the formation of the Upper Rhine Graben favoured erosion. Different erosion rates, i.e. higher erosion rates in the west and lower erosion rates in the east, resulted in two contrasting relief types (Rhenanian and Danubian relief types). Quaternary glaciations shaped the relief of regions at high elevation, while periglacial processes led to the formation of the widespread periglacial slope deposits in non-glaciated and deglaciated areas. After a period of landscape stability during the Early Holocene, human activity led to processes such as soil erosion or colluviation.

References

Bogenrieder A (1982) Pflanzenwelt: Die hochmontanen Wälder und subalpinen Gebüsche. In: Landesanstalt für Umweltschutz Baden-Württemberg – Institut für Ökologie und Naturschutz (ed) Der Feldberg im Schwarzwald: Subalpine Insel im Mittelgebirge. Institut für Ökologie und Naturschutz, Karlsruhe, pp 317–364

Bundesanstalt für Landeskunde und Raumforschung (1953-1962) Handbuch der naturräumlichen Gliederung Deutschlands. Bundesanstalt für Landeskunde und Raumforschung, Bad Godesberg

Coch T (2014) Der Südschwarzwald. Paradies für Mensch und Natur. In: Albert-Ludwigs-Universität Freiburg. Professur für Landespflege, Landesanstalt für Umwelt, Messungen und Naturschutz Baden-Württemberg (eds) Kulturlandschaften in Baden-Württemberg. G. Braun, Karlsruhe, pp 134–139

Eberle J, Eitel B, Blümel WD, Wittmann P (2017) Deutschlands Süden – vom Erdmittelalter zur Gegenwart, 3rd edn. Springer, Berlin, Heidelberg

Eberle J, Eitel B, Blümel WD, Wittmann P (2023) Deutschlands Süden – vom Erdmittelalter zur Gegenwart, 4th edn. Springer, Berlin, Heidelberg

Fezer F, Günther W, Reichelt G (1961) Plateauverfirnung und Talgletscher im Nordschwarzwald. Abhandlungen der Braunschweigischen Wissenschaftlichen Gesellschaft 13:66–72

Franke W, Cocks LRM, Torsvik TH (2017) The Palaeozoic Variscan oceans revisited. Gondwana Res 48:257–284. https://doi.org/10.1016/j.gr.2017.03.005

Friedmann A (1999) Pollenanalytische Untersuchungen zur holozänen Vegetations- und Landschaftsgeschichte des westlichen Hochschwarzwalds. Ber Naturf Ges Freiburg i Br 88/89:57–84

Friedmann A (2002) Die Wald- und Landnutzungsgeschichte des Mittleren Schwarzwalds. Ber z dt Landeskunde 76:187–205

Geologisches Landesamt Baden-Württemberg (ed) (1990): Geologische Karte von Baden-Württemberg 1:25 000. Blatt 8114 Feldberg. Landesvermessungsamt Baden-Württemberg, Stuttgart

Geyer M, Nitsch E, Simon T (2011): Geyer, O. F./Gwinner, M. P.: Geologie von Baden-Württemberg, 5th edn. Schweizerbart, Stuttgart

Giermann G (1964) Die würmeiszeitliche Vergletscherung des Schauinsland-Trubelsmattkopf-Knöpflesbrunnen-Massivs (südlicher Schwarzwald). Ber Naturf Ges Freiburg i Br 54:197–207

Glaser R, Schönbein J, Wang Q (2013) Die „gemäßigten Breiten" – Europa klimatisch. In: Gebhardt H, Glaser R, Lentz S (eds) Europa – eine Geographie. Springer Spektrum, Berlin, Heidelberg, pp 50–60

Groschopf R, Kessler G, Leiber J, Maus H, Ohmert W, Schreiner A, Wimmenauer W (1996) Geologische Karte von Baden-Würtemberg 1 : 50 000: Erläuterungen zu Blatt Freiburg i. Br. Und Umgebung, 3rd edn. Landesvermessungsamt Baden-Württemberg, Freiburg

Hebestreit C, Schiedek T, Bauer M, Pfaffenberger C (1993) Zeitmarken der Wutacheintiefung – Terrassenkorrelation, Terrassenstratigraphie und Kalktuffe. Jber Mitt oberrhein geol Ver 75:291–312

Hemmerle H, May J-H, Preusser F (2016) Übersicht über die pleistozänen Vergletscherungen des Schwarzwaldes. Ber Naturf Ges Freiburg i Br 106:31–67

Henkner J, Ahlrichs J, Fischer E, Fuchs M, Knopf T, Rösch M, Scholten T, Kühn P (2018) Land use dynamics derived from colluvial deposits and bogs in the Black Forest, Germany. J Plant Nutr Soil Sci 181:240–260. https://doi.org/10.1002/jpln.201700249

Hofmann FM (2023a) Geometry, chronology and dynamics of the last Pleistocene glaciation of the Black Forest. E&G Quaternary Sci J 72: 235–237. https://doi.org/10.5194/egqsj-72-235-2023

Hofmann FM (2023b) Geometry, chronology and dynamics of the last Pleistocene glaciation of the Black Forest. Dissertation, University of Freiburg https://doi.org/10.6094/UNIFR/241069

Hofmann FM, Konold W (2023) Landschaftsgeschichte des oberen Seebachtals, Südschwarzwald (Exkursion D am 14. September 2023). Jber Mitt oberrhein geol Ver, NF 105: 63–89. https://doi.org/10.1127/jmogv/105/0004

Hofmann FM, Rauscher F, McCreary W, Bischoff J-P, Preusser F (2020) Revisiting Late Pleistocene glacier dynamics north-west of the Feldberg, southern Black Forest, Germany. E&G Quaternary Sci J 69:61–87. https://doi.org/10.5194/egqsj-69-61-2020

Hofmann FM, Preusser F, Schimmelpfennig I, Léanni L, ASTER Team (2022) Late Pleistocene glaciation history of the southern Black Forest, Germany: ^{10}Be cosmic-ray exposure dating and equilibrium line altitude reconstructions in Sankt Wilhelmer Tal. J Quaternary Sci 37:688–706. https://doi.org/10.1002/jqs.3407

Hofmann FM, Steiner M, Hergarten S, ASTER Team, Preusser F (2024a) Limitations of precipitation reconstructions using equilibrium line altitudes exemplified for former glaciers in the Southern Black Forest, Central Europe. Quaternary Res 117: 135–159. https://doi.org/10.1017/qua.2023.53

Hofmann FM, Rambeau C, Gegg L, Schulz M, Steiner M, Fülling A, Léanni L, Preusser F, ASTER Team (2024b) Regional beryllium-10 production rate for the mid-elevation mountainous regions in central Europe, deduced from a multi-method study of moraines and lake sediments in the Black Forest. Geochronology 6: 147–174. https://doi.org/10.5194/gchron-6-147-2024

Huth T, Zedler H (2019) Along the continental suture in the Southern Black Forest - the area between Badenweiler and Lenzkirch (BLZ). Schriftenreihe der Deutschen Gesellschaft für Geowissenschaften 94:166–192. https://doi.org/10.1127/sdgg/94/2019/166

Jarvis A, Reuter HI, Nelson A, Guevara E (2008) Hole-filled seamless SRTM data V4. https://srtm.csi.cgiar.org. Accessed 21 September 2022

Kleber A, Terhorst B, Bullmann H, Hülle D, Leopold M, Müller S, Raab T, Sauer D, Scholten T, Dietze M, Felix-Henningsen P, Heinrich J, Spies E-D, Thiemeyer H (2013) Subdued Mountains of Central Europe. In: Kleber A, Terhorst B (eds) Mid-latitude slope deposits (cover beds), 1st edn. Elsevier, Amsterdam, Heidelberg, pp 9–93

Konold W, Seitz B-J (2018) Das Biosphärengebiet Schwarzwald: Mensch und Natur im Einklang, 1st edn. Silberburg, Tübingen

Korn D, Montenari M (2021) Re-assessment of ammonoid specimens from the Early Carboniferous Protocanites Beds of the Badenweiler–Lenzkirch Zone (Schwarzwald, Central Variscan Belt): age constraints for a lithostratigraphic key bed. PalZ. https://doi.org/10.1007/s12542-021-00577-4

Lahner L, Toloczyki M (2004) Geowissenschaftliche Karte der Bundesrepublik Deutschland 1: 2 000 000. Bundesanstalt für Geowissenschaften und Rohstoffe, Hannover

Lang G (2005) Seen und Moore des Schwarzwaldes als Zeugen spätglazialen und holozänen Vegetationswandels. Stratigraphische, pollenanalytische und großrestanalytische Untersuchungen. Andrias, vol 16, Karlsruhe

Lang G (2006) Late-glacial fluctuations of timberline in the Black Forest (SW Germany). Veget Hist Archaeobot 15:373–375. https://doi.org/10.1007/s00334-006-0048-8

Lehmkuhl F, Zens J, Krauß L, Schulte P, Kels H (2016) Loess-paleosol sequences at the northern European loess belt in Germany: Distribution, geomorphology and stratigraphy. Quaternary Sci Rev 153:11–30. https://doi.org/10.1016/j.quascirev.2016.10.008

Lehmkuhl F, Pötter S, Pauligk A, Bösken J (2018) Loess and other Quaternary sediments in Germany. J Maps 14:330–340. https://doi.org/10.1080/17445647.2018.1473817

Leiber J (2000) Geologie der Umgebung von Triberg und St. Georgen im Schwarzwald. Ber Naturf Ges Freiburg i Br 90:29–56

LGRB (ed) (2011) Geologische Übersichts- und Schulkarte von Baden-Württemberg. Erläuterungen, 13th edn. LGRB, Freiburg

LGRB (2013) Geologische Karte von Baden-Württemberg 1 : 50 000 (GeoLa). LGRB, Freiburg

LGRB (2020) Battertfelsen beim Schloss Hohenbaden. https://lgrbwissen.lgrb-bw.de/geotourismus/landschaftsteile-felsen/schwarzwald/battertfelsen-beim-schloss-hohenbaden. Accessed 17 October 2022

LGRB (2022) Die Wutachschlucht. https://lgrbwissen.lgrb-bw.de/printpdf/23738. Accessed 6 January 2023

LGRB (2023a) Schwarzwald. https://lgrbwissen.lgrb-bw.de/unser-land/schwarzwald. Accessed 20 June 2024.

LGRB (2023b) Kreide. https://lgrbwissen.lgrb-bw.de/geologie/schichtenfolge/kreide. Accessed 20 June 2024.

Liehl E (1982) Landschaftsgeschichte des Feldberggebietes. Altlandschaft - Eiszeit - Verwitterung und Abtragung heute. In: Landesanstalt für Umweltschutz Baden-Württemberg - Institut für Ökologie und Naturschutz (ed) Der Feldberg im Schwarzwald: Subalpine Insel im Mittelgebirge. Institut für Ökologie und Naturschutz, Karlsruhe, 13-147

Lisiecki LE, and Raymo EM (2005) A Pliocene-Pleistocene stack of 57 globally distributed benthic $\delta^{18}O$ records. Paleoceanography 20: PA1003. https://doi.org/10.1029/2004PA001071

Mäckel R, Schneider R, Seidel J (2003) Anthropogenic impact on the landscape of Southern Badenia (Germany) during the Holocene—Documented by colluvial and alluvial sediments. Archaeometry 45:487–501. https://doi.org/10.1111/1475-4754.00123

Mäckel R, Friedmann A, Sudhaus D (2009) Environmental changes and human impact on landscape development in the Upper Rhine region. Erdkunde 63:35–49. https://doi.org/10.3112/erdkunde.2009.01.03

Mangerud J (2021) The discovery of the Younger Dryas, and comments on the current meaning and usage of the term. Boreas 50:1–5. https://doi.org/10.1111/bor.12481

Matzarakis A (2012) Klima. In: Regierungspräsidium Freiburg (ed) Der Feldberg: subalpine Insel im Schwarzwald. Jan Thorbecke Verlag der Schwabenverlag AG, Ostfildern, pp 95–106

Metz B, Saurer H (2012) Geomorphologie und Landschaftsentwicklung. In: Regierungspräsidium Freiburg (ed) Der Feldberg: subalpine Insel im Schwarzwald. Jan Thorbecke Verlag der Schwabenverlag AG, Ostfildern, pp 14–62

Miera JJ, Henkner J, Schmidt K, Fuchs M, Scholten T, Kühn P, Knopf T (2019) Neolithic settlement dynamics derived from archaeological data and colluvial deposits between the Baar region and the adjacent low mountain ranges, southwest Germany. E&G Quaternary Sci J 68:75–93. https://doi.org/10.5194/egqsj-68-75-2019

Migoń P, Waroszewski J (2022) The Central European Variscan Ranges. In: Oliva M, Nývlt D, Fernández-Fernández JM (eds) Periglacial Landscapes of Europe. Springer International Publishing, Cham, pp 225–251

NASA Jet Propulsion Laboratory (2013) NASA Shuttle Radar Topography Mission Global 1 arc second. https://doi.org/10.5067/MEaSUREs/SRTM/SRTMGL1.003. Accessed 31 May 2021

Rahm G (1987) Die Vergletscherung des Belchengebietes (Südschwarzwald) zur Würmeiszeit. E&G Quaternary Sci J 37:31–40. https://doi.org/10.3285/eg.37.1.03

Reichelt G (1996) Zum eiszeitlichen Geschehen im Mittelschwarzwald (1) – Interpretation einer geomorphologischen Karte. Schriften des Vereins für Geschichte und Naturgeschichte der Baar 39:182–189

Reichelt G (1998) Zum Eiszeitgeschehen im Mittelschwarzwald (3). Ergebnisse und Probleme der bisherigen Untersuchungen. Schriften des Vereins für Geschichte und Naturgeschichte der Baar 41:95–125

Reif A (2012) Nationalpark Nordschwarzwald? Die zweitbeste Lösung für den Naturschutz! Naturschutz und Landschaftsplanung 44:218–224

Rösch M (2000) Long-term human impact as registered in an upland pollen profile from the southern Black Forest, south-western Germany. Veget Hist Archaeobot 9:205–218. https://doi.org/10.1007/BF01294635

Rotstein Y, Schaming M (2011) The Upper Rhine Graben (URG) revisited: Miocene transtension and transpression account for the observed first-order structures. Tectonics 30:TC3007. https://doi.org/10.1029/2010TC002767

Schinke K, Paul W (1997) Die glaziomorphologische Sonderstellung des Mittleren Schwarzwalds im Jungpleistozän. Jh geol Landesamt Baden-Württemberg 36:205–213

Schlund W (2014) Der Nordschwarzwald. Wandern und Kuren in urwüchsiger Natur. In: Albert-Ludwigs-Universität Freiburg. Professur für Landespflege, Landesanstalt für Umwelt, Messungen und Naturschutz Baden-Württemberg (eds) Kulturlandschaften in Baden-Württemberg. G. Braun, Karlsruhe, pp 144–149

Schreiner A (1986) Neuere Untersuchungen zur Rißeiszeit im Wutachgebiet (Südostschwarzwald). Jh geol Landesamt Baden-Württemberg 28:221–244

Schreiner A (1995) Zur Quartärgeologie des unteren Wehratals und zur Frage der Vergletscherung des Dinkelberges in der Rißeiszeit (SW Deutschland). E&G Quaternary Sci J 45:62–74. https://doi.org/10.3285/eg.45.1.07

Schreiner A, Groschopf R (2002) Zur Geologie und Morphologie des Hotzenwalds. Mitteilungen des Badischen Landesvereins für Naturkunde und Naturschutz e.V. Freiburg i. Br. 18:29–44

Schumacher ME (2002) Upper Rhine Graben: Role of preexisting structures during rift evolution. Tectonics 21:6-1-6-17. https://doi.org/10.1029/2001TC900022

Semmel A, Terhorst B (2010) The concept of the Pleistocene periglacial cover beds in central Europe: A review. Quatern Int 222:120–128. https://doi.org/10.1016/j.quaint.2010.03.010

Ziegler PA (1992) European Cenozoic rift system. Tectonophysics 208:91–111. https://doi.org/10.1016/0040-1951(92)90338-7

Zienert A (1970) Würm-Rückzugsstadien vom Schwarzwald bis zur Hohen Tatra. E&G Quaternary Sci J 21:58–70. https://doi.org/10.3285/eg.21.1.05

Zienert A, Fezer F (1967) Vogesen- und Schwarzwald-Kare. E&G Quaternary Sci J 18:51–75. https://doi.org/10.3285/eg.18.1.02

Zwölfer F, Fleck W (2011) Böden. In: LGRB (ed) Geologische Übersichts- und Schulkarte von Baden-Württemberg. Erläuterungen, 13th edn. LGRB, Freiburg, pp 289–297