Geological review of English coastal archaeological evidence portending multi-metre sea-level rise by 2100

Manuscript version 1, 19th March 2025

Roger Higgs, Geoclastica Ltd, UK

rogerhiggs@hotmail.com https://orcid.org/0000-0002-4827-9704

Abstract

English archaeological literature, its sea-level significance hitherto underappreciated, is reviewed here from a geological (sedimentological) perspective. Five Roman-built (~300AD) waterside forts and a seaside palace (~100AD), all meticulously excavated by archaeologists, tightly dated (tree-rings, coins, pottery), and published in great detail, yield evidence proving a ~4-metre (m) sea-level rise in only ~70 years, spanning ~430-500AD (early 'Dark Ages'), following 410AD Roman abandonment of Britain. (A comparably fast 2-3m rise within 100 years is known for the MIS5e interglacial, preceding our current Holocene interglacial.) The evidence includes excavated stumps, up to 2.5m tall, of Roman Londinium's Thames-estuary-side defensive wall, its entire waterside face eroded, implying that high-spring tide rose 3m+ after 300AD, constrained to pre-500AD by other archaeological evidence. The rise equates to the *geologically*-based global 'Rottnest transgression' (loosely carbon-dated ~350-950AD) of the celebrated 1961 'Fairbridge Curve' of Holocene sea level; and it explains enigmatic late-5th-Century mass-migration to SE Britain of Anglo-Saxons (birth of English nationhood), their NW European coastal-plain homelands 'pinched' between the eastwardly encroaching shoreline and west-advancing Huns. The Rottnest transgression can only be explained by Antarctic ice-cliff collapse, probably reflecting a solar-driven(?) known Arctic warm spike ~400AD; the resulting 'overwarmed' Arctic sea-surface-water reached Antarctica ~30 years later by 'conveyor-belt' ocean circulation. Since 2005, anthropogenically boosted Arctic warmth has continuously

exceeded the ~400AD spike, portending another decades-long, multi-metre SL rise, *ending* by ~2100.

1. Introduction

The following abbreviations are used throughout this article: C = Century AD; mm = millimetres; cm = centimetres; m = metres; y = years; ky = thousand years; ka = thousand years B.P. ('Before Present', i.e. before 1950, by convention); SL = sea level; O.D. = United Kingdom Ordnance Datum, 1915 to 1921 mean SL at Newlyn Tidal Observatory.

England's rich archaeology has been largely underappreciated in SL research. Notable exceptions include the work of Gustav Milne, renowned authority on London archaeology (e.g. see Milne, 1985, fig. 50 Thames Estuary SL chart spanning the last 3.5ka); and an invaluable compendium of evidence for m-scale SL change in the last 2ky from circum-Britain coastal archaeological sites, by Cracknell (2005). Archaeological data assessed in detail below, from the perspective of a seasoned sedimentologist, collectively indicate beyond reasonable doubt the reality of a fast (<100y), m-scale, SL rise in the 5thC.

Six localities are described and interpreted in turn, namely London and, stretching ~200km along England's south coast, four Roman-built sea-forts at Pevensey, Portchester, Lympne and Richborough, plus Fishbourne Roman palace. Dating of evidence from these archaeological sites is much more accurate (dendrochronology, coins, pottery) than for carbon-dated *geological* benchmarks of SL (e.g. Fairbridge, 1961). The sea-forts were built along the what was known by the Romans as the "Saxon Shore" of southeastern Britain, intended either to counter the threat of barbarian raids or to serve as ports (Pearson, 2002).

2. Background: 'Rottnest' & 'Romano-British' transgression

Based on a worldwide compilation of published age-and-elevation data for dozens of geological markers of former SL (loose carbon-dating, typically +/-200y), such as raised or drowned beaches, wave-cut benches and salt-marsh-peat beds, renowned geologist Fairbridge (1961) produced a controversial global SL curve (his fig.

15) for the current Holocene interglacial period (began ~11.7ka; Walker et al., 2009). The 1961 curve was updated by Fairbridge (1976), who referred to his 1961 original as the "Fairbridge Curve"; and again by Fairbridge and Hillaire-Marcel (1977). All three versions show repeated, m-scale, rapid (<300y) rises interspersed with m-scale falls during the last 6ky. Recognising the supra-regional extent of his SL oscillations, Fairbridge (1961) interpreted them as global, i.e. eustatic, specifically glacio-eustatic, stating "Every recorded glacial advance of the last 5000 years is matched by a eustatic lowering" (p. 173). Supporting Fairbridge, dozens of later authors found further evidence for Holocene SL fluctuations of up to 5m, while dozens of others deny oscillations >50cm (Higgs, 2025a).

The last m-scale rise on the original (1961) Fairbridge Curve is the ~3m "Rottnest transgression" (p. 171) or "Rottnest Submergence" (his table 2), roughly carbon-dated as spanning ~600y, ~350-950AD (his fig. 15 and table 2). On the updated (1976) curve, most (~2.5m) of this transgression, here termed 'Main Rottnest', is shown as being briefer (~250y) and earlier, ~50-300AD, reaching ~1.5m above modern mean SL and followed by two minor (0.5-1m) oscillations, culminating in the ultimate Rottnest highstand (~800AD), <0.5m higher than the Main Rottnest 300AD highstand (Fairbridge, 1976, fig. 3). Many later authors, using geological and/or archaeological data-points from localities around the world, recognised a m-scale transgression that can be equated, in terms of timing and amplitude, with the Main Rottnest (Table 1). Several authors before and after Fairbridge (1961) gave the transgression local names, e.g.: "Lytham IX" (Tooley, 1978, England); "dunkerquienne II" (Tavernier and

Table 1. Publications (chronological order except Fairbridge) recognizing a local or regional sea-level (SL) rise correlatable to the global "Rottnest transgression" of Fairbridge (1961, 1976). N/A = not applicable, NS = not stated, C = Century. Highstand elevation (column 5) is relative to modern mean sea level (NB some of the European and North American localities may need correcting for up to ~1m of glacio-isostatic uplift or subsidence, cf. Sella et al. 2007, Serpelloni et al. 2013).

Author & fig./table number (if any) & type of evidence geological (G) or archaeological (A)	*Study area*	*Transgression time-span (rounded to nearest 50y*	*Magni-tude (to nearest 0.5m)*	*High-stand elev. (m)*	*Transgression name given by author(s)*	*Notes*
Fairbridge 1961 fig. 15 & table 2 (G)	Global compilation	350-950AD	3	+1		Named for Rottnest Island, W Australia.
Fairbridge 1976 fig. 3 (G; minor A)	Ditto	50-300AD	2.5	+1.5		"Main Rottnest" (see Section 2); update of his 1961 SL curve, with corrections & Brazil archaeological data.
Godwin 1943 (G/A)	SW & E England	Post-40 pre-400AD	NS	NS	Romano-British	Interpreted as eustatic.
Van Liere 1948 (G/A)	Netherlands	Between 3rd & 10th C AD	NS?	NS?	Post-Roman	Cited by Ter Wee 1956

Bennema & van der Meer 1952 (G/A)	Netherlands	3rd to early 9th C AD	NS?	NS?	Vroeg-Middeleeuwse	In Tavernier & Moormann 1954.
Tavernier & Moormann 1954 (G/A)	Belgium	Early 4th to 8th C AD	NS	NS	dunkerquienne II	"Dunkirk II" in Wiki 'Dunkirk transgression' webpage.
Bloch 1963, fig. on p. 98 (A)	Europe & M East	250BC-550AD	2.5	+1.5		Based on history of salt trade.
Bloch 1965, fig. 4 (A)	Ditto	250BC-350AD	3.5	+1.5		Ditto.
Hume 1965 (G/A)	N Alaska	~250-350AD?	NS	+0.6-1.0		SL rose to +0.6-1.0m after 265AD; fell to ~-2m by ~500AD.
Cunliffe 1966 (G/A)	SW England	3rd & 4th C AD	3-6	NS		Same study area as Godwin 1943 (Somerset Levels).
Greensmith & Tucker 1973, fig. 6 (G/A)	SE England	200-750AD	4	+1	post Romano-British	Transgression "V" in their fig. 6.
Schofield 1977, fig. 7b (G)	C Pacific atolls	~50-450AD	>1.5	+1.5	Gilbert-V	
Godwin 1978, fig. 33 (G/A)	E England	150-300AD	1	+1.5	Romano-British	
Tooley 1974, fig. 10 (G)	NW England	350BC-350AD	1.5	+1.5	Lytham IX	"very rapid" (p. 33); p. 28 table of "transgressions" in fact gives age of ensuing *regression*, 1560-1380BP, 390-570AD; cycle based on only 3 data points (his fig. 10).
Tooley 1976, fig. 2 (G)	NW England	350BC-350AD	1.5	+1.5	Lytham IX	p. 144 table of "transgressions" in fact gives age of ensuing *regression*, 1560-1380BP, 390-570AD; cycle based on only 3 data points (his fig. 2).
Tooley 1978, fig. 37 (G)	NW England	350BC-350AD	1.5	+1.5	Lytham IX	p. 143 table of "transgressions" in fact gives age of last part of transgression plus ensuing *regression*, 1795-1370BP, 155-580AD; cycle based on only 3 data points (his figs 36, 37).
Cunliffe 1980 (G/A)	SE England	~300-500AD?	2m+	NS		"Some time in the late Roman and early Saxon period".
Mörner 1984, fig. 6 (G)	NW Europe incl. Scandinavia	100BC-350AD	1.5	+0		Transgression 9 in his fig. 6.
Raban & Galili 1985, fig. 26 (A)	Israel	550BP-550AD	2	+1.5		SL curve co-plotted with near-identical curve of Bloch, 1981 (reference not provided), e.g. same ~550AD highstand ~1.5 m above modern SL.
Colquhoun & Brooks 1986, fig. 1 (G/A)	USA (S Carolina)	500BC-200AD	3	-0.5		
Geng et al. 1987 (G/A)	E China	50-800AD	2.5	+2.5		In Pirazzoli 1991, plate 34.
Ters 1987, fig. 12-2 (G/A)	Atlantic France	50BC-250AD	2.5	+0.5	Saint Firmin	"extremely fast".
Stapor et al. 1991, fig. 14 (G)	USA (Gulf Mex.)	200BC-50AD	1.5	+1.0	Wulfert	Stapor is a co-author of Walker et al. 1995.
Walker et al. 1995, fig. 8 (A)	USA (Gulf Mex.)	100-250AD	2	+1.5	Wulfert	Even faster (2m in 150y) than Ters' "Saint Firmin".
Dionne 2001, p. 273 (G)	Canada (Quebec)	between 550BC & 450AD	2	NS	Mitis	"minor transgression"; omitted in his fig. 9 SL curve.
Behre 2007, fig. 1 (G/A)	German North Sea	50-350AD	1.5	+1		Equated with Dunkirk II transgression (his table 1; see definition in Wiki).
Mörner 2007, fig. 2 (G/A)	Maldives	400-450AD	1.5	+1		
Meier 2008, fig. 3 (G/A)	German North Sea	50BC-300AD	1.5	+1		
Pascucci et al. 2018, fig. 7 (G/A)	Sardinia	850-1700BP	5	+0	T3	
Yasur-Landau, 2021, fig. 5 (A)	Israel	~100BC-100AD	2	+0		~2m SL rise in 200-400y. Interpreted as non-tectonic.

Moormann, 1954, Belgium); "Saint Firmin" (Ters, 1987, France); and "Wulfert" (Stapor *et al.*, 1991). The earliest published local name was "Romano-British transgression" (Godwin, 1943; unmentioned by Fairbridge, 1961, 1976), which technically takes precedence over Fairbridge's "Rottnest", but the name "Romano-British" is incorrect, as the transgression in fact post-dated the 43-410AD Roman occupation of Britain (see Section 3.2 and Section 4).

Godwin (1943, 1955, 1978) interpreted his Romano-British transgression as probably eustatic, based on the great lateral extent of the evidence, i.e. on reclaimed coastal wetlands in both the far W and far E of England (Somerset Levels, bordering the Severn Estuary; and the Fens, bordering The Wash), thick (m) surficial mud extends 10-30km inland, resting sharply on peat. Interpreted as estuarine by its foraminiferal assemblage (Godwin and Clifford, (1938; Godwin, 1955), the mud has a sheet-like geometry (Godwin, 1943, fig. 12 cross-section; Godwin, 1955, fig. 1 map) more consistent with an open-coast tidal flat, outboard of a salt-marsh accumulating peat (cf. Dalrymple, 1992, fig. 12), as is the case today beside the Fens, seaward of the artificial coastal barrier (e.g. search 'Kirton' on Google Earth). Excavations in the Somerset Levels found Romano-British pottery sherds at multiple levels within the muds, so Godwin inferred that the Romano-British transgression must have occurred within the time-span of Roman occupation, e.g. ~150-300AD was estimated by Godwin (1978, fig. 33). Accordingly, Godwin (1955) called the Somerset deposits the "Roman Clay", a name adopted by the British Geological Survey (Green and Welch, 1965). However, this assumption of a Roman age overlooks the inevitability, in the tidal-flat model, of tidal creeks cutting into the mudflat and reaching landward into the salt-marsh (Dalrymple, 1992, fig. 12; cf. near Kirton, above), their laterally migrating cut-banks eroding the peat, liberating pot-sherds from numerous Romano-British pottery mounds (sites of salt-production and possible pottery-making; Rippon, 1997, p. 68-72 and fig. 17) on top of the peat (Godwin, 1953, fig. 12), for seaward dispersal by tidal currents. Supporting this idea, Hawkins (1973, p. 84) cited a description by Nash (personal communication) of a brick-pit where a vertical section 7m high and 94.5m long in the Roman Clay exposed six channels up to 4.6m across and 1.2m deep, with "Romano-British material ... in relative abundance in the bottom" of the channels and also "rarely on the ground surface" between the channels. Further support comes from Combwich Brick-Pit ~10km away, exposing a surficial 6.5m clay section (Godwin, 1941, fig. 9) with a thin (cm) peat at the base (elevation 0m O.D.) and a second peat (20cm) at 2m O.D. (cf. similar 5m surficial clay with two thin peats at same elevations at Puriton Drove [Godwin, 1943, fig. 12]). Between the two peats, sherds occur in "water-borne clay" and "earlier wares sometimes [occur] at higher levels than the later ones ... [suggesting] ... disturbance of earlier deposits and the redistribution of some of their contents at higher levels" (Dewar, 1941, p. 133), consistent with tidal-creek reworking.

If, as argued in Section 3.2 and Section 4, the transgression instead spanned ~430-500AD, the marsh occupants (Sub-Roman Britons in Somerset and, from ~450AD, Angle immigrants in the Fens [see Section 5.1]) were probably re-using Roman-era pottery, hence the lack of younger pot-sherds in the clay. (For evidence that little or no pottery was produced in 5thC Britain see Myres [1959, 1976], Whittock [1986, p. 100], Rippon [1997, p. 129], Fulford et al. [2000], Jones [2000, citing White, 1991], Gerrard [2016; his 5thC pottery "lacuna"], Fitzpatrick-Matthews and Fleming [2016] and Fleming [2018].)

Godwin estimated the amplitude of the SL rise as "small" (Godwin, 1945, p. 65), depicting it as only ~1m in a relative SL curve published later (Godwin, 1978, fig. 33). In contrast, Cunliffe (1966) concluded that "widespread flooding in the Somerset Levels during the third and fourth centuries ... could have been caused by an overall rise in sea level of 10-20 feet" (sic).

Godwin (1943) and Cunliffe (1966) were criticized at length by Hawkins (1973, p. 75-81), who dismissed the Romano-British transgression (see his fig. 2 non-oscillating Holocene SL curve for SW England). Hawkins, apparently skeptical that such a transgression could occur so quickly, "in a period of about 150 years" (p. 80), interpreted the presence of Roman sherds within the clay as indicating a mudflat upon which people worked at pottery manufacture, "restricted mainly to the summer months" (p. 84). This interpretation is untenable because, by definition, a tidal mudflat is flooded daily by the tide (e.g. Dalrymple, 1992, fig. 12). Hawkins further stated (p. 81): "If we accept the Romano-British Transgression, then it is necessary to put forward an explanation for its non-existence elsewhere in the world", apparently dismissing or unaware of the Fairbridge Curve. Hawkins received support from the eminent Professor J.R.L. Allen, sedimentologist and authority on Romano-British settlement and industry on the wetlands of the Severn Estuary (e.g. Allen and Fulford, 1987), who said "Hawkins finally disposed of the notion of a Roman transgression by pointing at length to the shallow depth (0.3 to 0.6 m) at which many Romano-British artefacts occurred in the Somerset Levels" (Allen and Fulford, 1992, p. 92).

3. London 'sea-level' curve, 1AD to 1500AD

Using age- and elevation data from 32 archaeological data-points along the ruined Roman Londinium-city Thames-estuary-side wall (all remnants are below ground), a high-spring-tide-level (HSTL) curve has been constructed for the interval 1AD to 1500AD (Figure 1). For each data-point in Figure 1, basic information and literature sources are given in Table 2. Some of the more crucial data-points are discussed below.

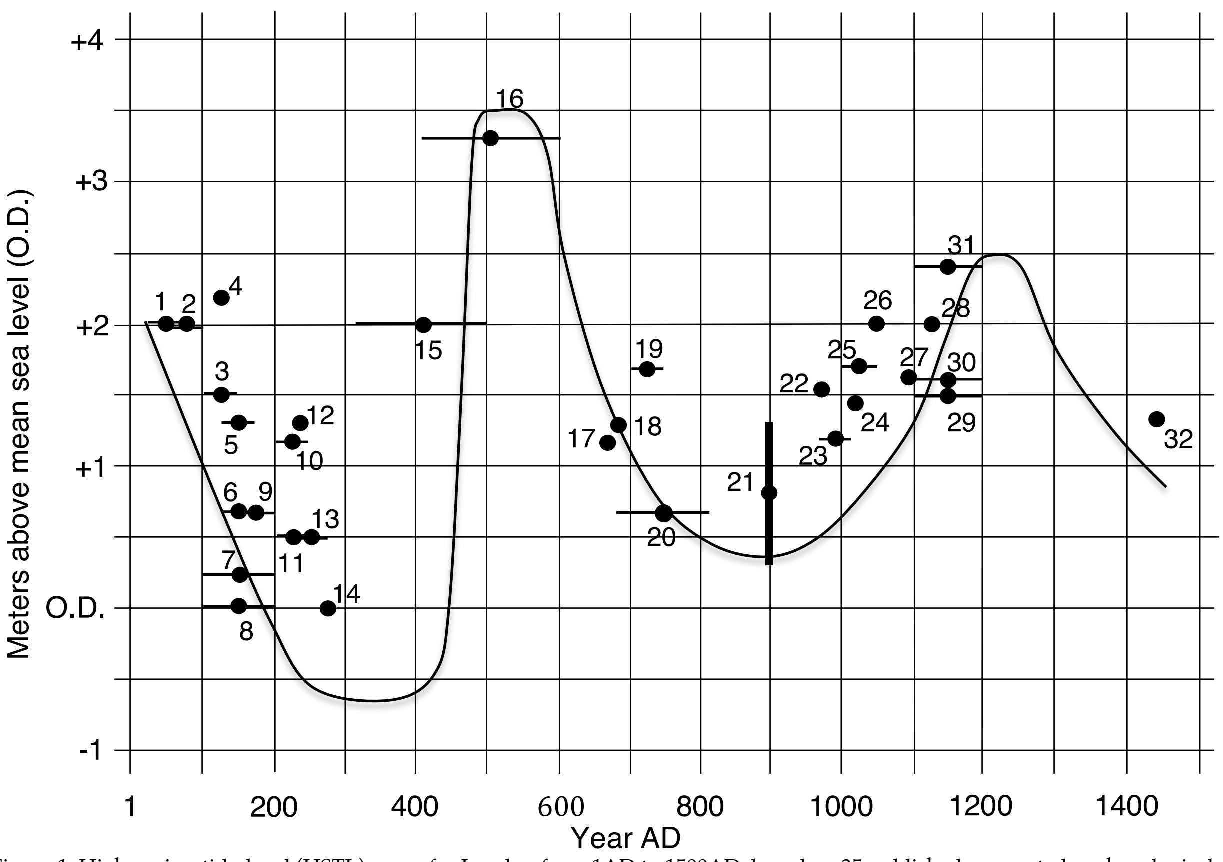

Figure 1. High-spring-tide-level (HSTL) curve for London from 1AD to 1500AD, based on 35 published, excavated, archaeological data-points (listed in Table 2) dated by pottery (sherds), coins, or dendrochronology. All sites are on the north bank of the Thames Estuary, except Data-Points 6 and 7 on the south bank (Southwark). All north-bank sites are between the eastern and western extremes of the Roman estuary-side wall (e.g. Hill et al., 1980, fig. 1) except Data-points 17-19 and 30 (The Strand) ~1km upstream of the western extreme, and Data-points 27 and 32 (Westminster) ~2km upstream of the western extreme. Elevations are relative to UK Ordnance Datum (O.D.). Uncorrected for ~1mm/y subsidence (see Section 3.2). The curve separates data-points formed above contemporary HSTL (e.g. top of waterfront quay or revetment [assume at least 0.5m freeboard; cf. Brigham, 1990, p. 144]) from those

formed below HSTL (e.g. top of "waterlaid clay"). Horizontal bars indicate age uncertainty (no bar shown if <+/- 10 y). Estimated elevation uncertainty is <+/- ~20 cm, except Data-point 21.

Table 2. List of data-points in Figure 1 and their sources. All elevations are relative to UK Ordnance Datum (O.D.; defined in Section 1).

1 - Brigham 1990 fig. 12, timber waterfront (quay or revetment), mid 1stC (dendro), top at 2.0m O.D.
2 - Brigham 1990 fig. 12, timber waterfront, late 1stC (dendro), top at 2.0m O.D.
3 - Brigham 1990 fig. 12, timber waterfront, early 2ndC (dendro), top at 1.5m O.D.
4 - Parnell, 1985 p. 7, 8 and figs 6, 7, 12, sand and gravel reclamation dumpings with late 1stC pot-sherds, impaled by foundation timbers dated 126-127AD (dendro); highest top seen is 2.2m O.D.
5 - Brigham 1990 fig. 12, timber waterfront, mid 2ndC (dendro?), top at 1.3m O.D.
6 - Graham 1978 p. 511, Southwark "water-laid deposits", ~mid 2ndC (pottery?), top at ~0.7m O.D.
7 - Graham 1978 fig. 224 & p. 511, Southwark peat with 2ndC pottery, base ~0.25m O.D.
8 - Mackinder 2015, p. 7, foreshore sediment, probably 2ndC, ~0.0m O.D.
9 - Brigham 1990, fig. 12, timber waterfront, late 2ndC (dendro?), top at 0.7m O.D.
10 - Steedman et al. 1992, p. 22, timber piles of quay, early 3rdC, highest top 1.2m O.D. (~1.5m above HSTL curve, suggesting piles projected above quay top).
11 - Brigham 1990, fig. 12, timber waterfront, early 3rdC (dendro?), top at 0.5m O.D.
12 - Miller et al. 1986, p. 30, 44 & fig. 4, St Magnus, timber piles of quay, c.225-245AD, highest top 1.3m O.D. (~1.5m above HSTL curve, suggesting piles projected above quay top).
13 - Brigham 1990, fig. 12, quay timbers, mid 3rdC? (pot-sherds in the infill), highest top ~0.5m O.D.
14 - Brigham 1990, figs 10, 12, Thames riverside wall, "constructed in or shortly after A.D. 255-270" (p. 132), lowest observed elevation is 0.4m O.D., base "presumably" at ~0.0m O.D. (p. 127).
15 - Hill et al.1980, p. 32 & fig. 15, culvert (drainhole) through ~270AD estuary-side wall, deliberately plugged with clayey rubble building material, containing post-320AD 4thC pot-sherds; floor elevation at inner end 2.0m O.D.. Probably plugged to prevent water ingress from estuary (see Section 4.1).
16 - Hill et al. 1980, p. 30, 32 & 78 & fig. 16, eroded front face of remnant stumps of Londinium river-wall (built ~255-270AD, Brigham 1990); highest known top of eroded face at 3.3m O.D.. Erosion is assumed to be: post-410 Roman abandonment; and pre-600AD, given the collective evidence that HSTL had fallen by at least 2m by 700AD (Data-points 17-19 below).
17 - Killock & Boyer 2015, p. 29 & fig. 12 & appendix 1, 1.2m O.D. top of foreshore deposits (layer 100/101) containing coin provisionally dated 655-675AD. Truncated by "concrete foundation".
18 - Cowie 1992, p. 164 & fig. 3, top of 1m-tall truncated timber waterfront, 679AD (dendro), 1.0m O.D. (overlain by "waterlaid clay", Data-point 30, i.e. subsequent rise in HSTL).
19 - Killock & Boyer 2015, p.33 & fig. 12 & appendix 1, floor of waterside building, pottery post-600, pre-750AD (layers 26, 33, i.e overlies/post-dates Data-point 17 coin, above); "provisionally dated to the early to mid 8th century", based on pottery; assume 700-750AD, 1.7m O.D.
20 - Ayre & Wroe-Brown 2015a, p. 130 & 133, Bull Wharf skeleton (Burial 1) within interpreted intertidal gravel; burial also interpreted as intertidal, 680-810AD (95% confidence) based on associated bark, ~0.7m O.D.
21 – Dyson 1978, Saxon royal grant of 898-899AD at Queenhithe, for a land parcel (see Ayre & Wroe-Brown 2015a illus. 3 map) immediately inboard of the Roman estuary-side wall; includes moorage rights outside wall; excavation in western portion found wall base ~1.8m O.D. (Roach Smith 1841 in Marsden 1967, p. 151), so elevation of moorage-space outer edge is estimated here as 0.8m O.D. +/- 0.5m.
22 - Ayre & Wroe-Brown 2015a, p. 136-138, floor of waterside house, 3rd quarter 10thC, 1.55m O.D.
23 - Steedman et al. 1992, p. 99-103, New Fresh Wharf jetty, ~1000AD ("probable late 10th- or possibly early 11th-century"), top of lowest posts (deck level?; cf. cover illustration), ~1.2m O.D.
24 - Ayre & Wroe-Brown 2015b, p. 200-201, revetments, felling 1020-21AD; up to 1.45m O.D. (Ayre pers. comm. in Watson et al. 2001, p. 27).
25 - Steedman et al. 1992, p. 104-106, 120, "early to mid-11th-century embankments" (dumped material), pot-sherds 1020-50AD, timber felled 1039-40AD, fenced areas down to 1.7m O.D.
26 - Steedman et al. 1992, p. 106, embankment (dump), top at 2.0+m O.D., pottery 1020-50AD, timber felled 1039-40AD.
27 - Horsman & Davison 1989, p. 286, Westminster, Great Hall foundation, 1090sAD, 1.6m O.D.
28 - Ayre & Wroe-Brown 2015b, p. 220, Waterfront 10, revetment 12, felled 1120-21, top ~2.0m O.D.; "timber waterfront over 2 m high".
29 - Hill et al. 1980, fig. 16 & p. 52, top (pinchout edge) of "river" sand and gravel (Layer 9) abutting estuary-side Roman wall, abraded 4th and 12thC pot-sherds, 1.5m O.D.
30 - Cowie 1992, p. 165 & 167 & fig. 3, top of "waterlaid clay" with 7th to 12thC artefacts, 1.6m O.D.
31 - Hill et al. 1980, fig. 15 & p. 52, 53, top (pinchout edge) of "river" sand and gravel (Layers 13, 59), onlapping erosionally truncated Roman clay bank behind residual stump of estuary-side wall, 12thC pot-sherds, 2.4m O.D.
32 - Horsman & Davison 1989, p. 290 & fig. 5, Westminster, base of fountain 1441-1444AD, 1.3m O.D.

A HSTL curve is a proxy for mean SL if the tide-range was essentially constant over time, as was assumed, for example, by Tooley (1974, fig. 10). Indeed, based on modelling of the macrotidal Bay of Fundy (Canada), Scott and Greenberg (1983) calculated an average increase in tidal amplitude of only 1-2% with each 1m rise in SL during Holocene time. Similarly, modelling by Khan et al. (2017) found that "Paleotidal range in the Caribbean remained relatively constant throughout the Holocene" after ~7ka (their p. 28 and fig. 4). Relative SL reconstructions in North Carolina, USA "implicitly assumed that tidal range during the late Holocene was unchanged from the observable, modern tidal regimes ... However, estuaries in North Carolina are prone to tidal-range change by opening/closing of inlets, or larger discontinuities, in the Outer Banks barrier islands" (Kemp et al. 2017b, p. 24). No such natural barriers front the Thames Estuary eastward of London. Since ~1800AD, bank raising in London on both sides of the Thames, to reduce flooding and accommodate larger vessels, has confined the channel, increasing the tidal range. For example, Bowen (1972) cited a 1.7m increase between 1799 and 1875 documented by Redman (1877). Previously, extensive Roman and Saxon (pre-Norman, i.e. pre-1066AD) embanking occurred on the north bank (Milne, 1985; Steedman et al., 1992), but this would not have affected the tidal range if the low-lying south bank was not embanked too. South-bank raising is known from the 13thC onward (Milne, 2003). "The attempted constriction of the Thames between two advancing banks had a severe effect on the hydrology of the river, causing increased erosion, for example" (Milne, 2003, p. 20). At about the same time, London's new stone bridge was completed ~1200AD, affecting tidal heights (Watson et al., 2001) and probably tidal range too. Reflecting the progressive constriction of the Thames, London's tidal range is estimated to have increased from ~2m in the 1stC, to ~3.5m in 14thC, and ~8m in the 1980s (Milne, 1985, fig. 50). London tides are semi-diurnal; modern mean spring-tide range is ~7.5m at London Bridge.

3.1. Pre-Rottnest SL fall (>2m)

On the original Fairbridge Curve, the Rottnest transgression was preceded by a ~5m SL fall, the "Florida emergence" (Fairbridge, 1961, fig. 15), later revised to ~3m and named the "Roman or Florida emergence" (Fairbridge, 1976, fig. 3). London's HSTL curve (Figure 1) captures the last 2.5m of this regression and dates the lowstand as

~350AD, as opposed to ~200AD (Fairbridge, 1961, fig. 15) and ~50AD (Fairbridge, 1976, fig. 3).

The London evidence for this regression is persuasive: five timber waterfronts (quays and revetments), sequentially dated ~50-250AD, step downward ~1.5m into the Thames Estuary (Milne, 1985, fig. 7; Brigham, 1990, fig. 12.1; Milne, 1995, fig. 56a; Data-points 1-3, 5, 9, 11 in Figure 1). Starkly highlighting the drop in HSTL, the oldest three waterfronts lie *landward* of the later (~270AD) Thames-side city wall (Milne, 1995, fig. 56a). The waterfront evidence led Brigham (1990, fig. 12.2c) to invoke a ~2m drop in HSTL, attributing this "regressive interval in the Roman period" to polar-icecap expansion (his p. 171), i.e. eustasy. From the same evidence, Milne (1995, p. 79) envisaged a drop in estuary level by perhaps "as much as 1.5m", without mentioning any connection to world SL. The same SL fall was called "Roman regression" in Holland (Ter Wee, 1956) and "Roman Emergence" in France (~2m; Ters, 1987).

3.2. Rottnest SL rise (~4m, ~430-500AD)

Figure 1 shows that the Rottnest transgression raised London's HSTL by ~4m and lasted only ~70y, ~430-500AD (early 'Dark Ages'), excluding the preceding slow (gradually accelerating) rise since ~350AD, which amounted to perhaps ~30cm (Figure 1). Constraints on the deduced ~430-500AD age-span include: (a) Data-points 14 to 17 in Figure 1, all discussed in Section 4.1; (b) diverse evidence from other southern English archaeological sites (see Sections 4.2. to 4.6); and (c) the 5thC age of the Anglo-Saxon mass exodus to Britain (see Section 5.1). The significance of this rise was recognised by Milne (1985, p. 86): "Further research is now urgently required to establish the precise nature of the river [Thames] in the late Roman period. What is certain is that the Thames subsequently began to rise and early to mid-Saxon radiocarbon dates were obtained from wood within clay deposited by the river at Westminster during this period (Mills 1980, 22). There seems little doubt that by the mid to late-Saxon period London was sitting on a tidal reach of the Thames, ready to take advantage of the commercial potential such a situation afforded". The dated pieces of oak plank from Westminster were interpreted by Mills (1980) as floated "probably out of context" (his p. 25); moreover, their elevation (O.D.) was not stated (only roughly calculable from his fig. 6 cross-section, layer 120), so they are excluded from Figure 1.

In remarkable agreement with the age (~430-500AD) and amplitude (~4m) of the Rottnest transgression interpreted here from London evidence (Figure 1), Greensmith and Tucker (1973), studying chenier sand ridges in the outer Thames Estuary at a location ~70km downstream from London, determined a SL rise of ~4m, shown on their SL curve (fig. 6; reproduced in Milne, 1985, fig. 50) as spanning ~200-750AD (their transgression "V"), based on archaeological and loose carbon-dating. This transgression, included here in Table 1, was referred to as the "post Romano-British submergence" (Greensmith and Tucker, 1973, p. 201).

The ~4m value deduced for London requires a negligible correction for subsidence, currently ~1mm/y in the City of London based on combined GPS, AG and PSI data (Aldiss et al., 2014, area 4B in fig. 4), i.e. only ~7cm of subsidence occurred during the ~70y rise. (The rate of subsidence, by glacial forebulge relaxation, is unlikely to have changed appreciably in the last 2ky [cf. Clark et al., 1978, fig. 7B relative SL curve essentially straight since 2ka].) The ~4m rise in HSTL implies that world SL likewise rose ~4m (assuming negligible change in tide-range [see Section 3.1]), somewhat more than the 2.5m shown by Fairbridge (1976, fig. 3) for the 'Main Rottnest' (see Section 2). A 4m rise in 70y is ~6 cm/y on average, twenty times the modern rate (3mm/y; NASA, 2025), and similar to the ~5cm/y determined in two widely separated locations (Barbados and Sunda Shelf) for 'Meltwater-pulse 1a' of the last Pleistocene deglaciation (Blanchon, 2011, table1), although that pulse was of greater magnitude (15-20m) and occurred at a time (~14.5ka) of greater global ice volume than the Holocene (Deschamps et al., 2012; Grant et al., 2014).

The following five publications similarly indicate rapid SL rises in Holocene time. Schofield (1960, p. 479) doubted his own New Zealand evidence for "an extraordinary rapid rise in sea level of 5 ft in less than 50 years" (>3cm/y) about 2.5ka (his fig. 8d), stating (p. 479) that the key data-point "is more happily placed if considered to be 100 years younger" (i.e. 5-foot rise in 150y). In France, the "Saint Firmin Submergence", which probably equates to the Rottnest rise (Table 1), "appears to have been extremely fast" (Ters, 1987, p. 227). Ters' SL curve (her fig. 12.2) depicts the Saint Firmin as a ~2.5m rise in ~300y (~0.8cm/y) but, given the long time-gap (~300y) between the two defining data-points, the rise could have lasted <100y (i.e. >2.5cm/y). On the Florida (USA) Gulf of Mexico coast, Tanner et al. (1989, p. 533) proposed two complete m-scale SL oscillations in the last 5ky and envisaged that "The rate of short-term change was about 5cm/yr". On the same coast, the "Wulfert sea-level rise" (Walker et al., 1995, p. 208; based on archaeology), here equated to the Rottnest transgression (Table 1), amounted to ~2m in ~150y (~1.3cm/y; their fig. 8). The Brazilian SL curve of Martin et al. (2003, fig. 7B) shows a SL rise of ~3.5m in ~200y (~2cm/y) at ~3.6ka. However, given the wide error-bars (typically 150-300y), the rise may have lasted <100y (i.e. >3.5cm/y).

3.3. Post-Rottnest SL fall (~3m, ~550-900AD)

Figure 1 indicates a rapid post-Rottnest HSTL fall of ~3m from ~550 to ~900AD (~1cm/y). Supporting evidence comes from other English archaeological sites (e.g. Portchester and Lympne, see Sections 4.3, 4.4). Similarly, Behre (2004) invoked SL fall to explain 7th and 8thC resettlement of NW German coastal-plain dwelling-mounds (see Section 5.1) and of land lying to seaward of them.

The resulting ~850AD lowstand (Figure 1) is ~1m higher than the pre-Rottnest lowstand (~350AD), or ~0.5m after correcting for 500y of subsidence (~1mm/y; see Section 3.2). The ~850AD lowstand was unknown to Fairbridge (1961, fig. 15; 1976, fig. 3), probably due to the difficulty of finding index points below modern mean low-tide level.

Holocene SL falls of similar rapidity have been proposed. In Florida, the Wulfert transgression was followed by a regression of ~2m in ~100y (Walker et al., 1995, fig. 8), i.e. ~2cm/y. The Brazilian SL curve of Martin *et al.* (2003, fig. 7B) shows a SL fall of ~3m in ~200y (~1.5cm/y) at ~2.7ka, but the error-bars allow a shorter duration (<100y, i.e. >3cm/y). In Australia, soon after ~3.8ka, "there appears to have been a rapid lowering of sea level by ~1 metre ... The fall appears to have been rapid because of the preservation of the higher relic shellcrust [intertidal tubeworms] from marine erosion. Such evidence supports a Fairbridge fluctuation at this time" (Baker et al., 2005, p. 10-11). Indeed, the Fairbridge Curve shows a SL fall of ~4m in ~200y (~2cm/y) at ~3.4ka, and two others of ~5m in ~200y (~2.5cm/y) at ~4.5ka and ~2.1ka. The updated curve (Fairbridge 1976, fig. 3) shows a ~3.5m fall in ~100y (~3.5cm/y) at ~4.5ka and ~2.5m in ~100y (~2.5cm/y) at ~3ka.

3.4. Subsequent SL rise (~2m, ~900-1200AD)

Figure 1 shows a second transgression, of ~2m, from ~900 until ~1200AD. In contrast, Willcox (1975, fig. 4 and p. 290), based on an age-versus-elevation graph for eleven London waterfronts (quays, revetments, estuary wall), proposed "a positive, continuous rise in the level of the Thames" from 100AD to 1975, but his graph has three data gaps of 400-550y each, one of them (175-750AD) spanning the entire Rottnest rise and much of the ensuing fall.

In this second transgression, HSTL rose high enough to topple sectors of the estuary-side Roman wall (see Section 4.1). Failure of this rise to reach as high as the Rottnest (Figure 1) explains deeper frontal erosion near the base of the wall, forming a notch 1.3m tall, its top at 2.6m O.D. (Hill et al., 1980, fig. 16; see also restored notches in fig. 29b, c), constraining the elevation of the highstand (shown as 2.5m O.D. in Figure 1). Banked against the basal 20cm of the notch are "river" sand and gravel (Hill's fig. 16, layer 9) that yielded 12thC pot-sherds (see Section 4.1). Another notch reaches almost the same height (2.5m O.D.) in the broken-off southern edge of a toppled wall sector (Hill et al., 1980, fig. 21).

The ~900-1200AD SL rise is not evident on the original Fairbridge Curve (Fairbridge, 1961, fig. 15) or the updated version (1976, fig. 3). However, there is a good match with: (a) the "Gilbert-VI" transgression (~3m, ~950-1200AD) recognised in the Pacific Ocean (Schofield, 1977, fig. 7b), on the opposite side of the world, suggesting the rise was global; and (b) a 1.5m transgression determined for the German North Sea coast, estimated to span ~950-1400AD (Behre, 2007, fig. 3) or ~900-1350AD (Meier, 2008, fig. 3).

4. Six English archaeological sites jointly proving 5thC metre-scale SL rise

4.1. London Roman estuary-side wall

Nearly 900 years ago, in the 12thC, William Fitzstephen wrote: "On the south, London was once walled and towered ... but the Thames, that mighty river, teeming with fish, which runs on that side with the sea's ebb and flow, has in course of time, washed away those bulwarks, undermined and cast them down" (translated from Latin by H.E. Butler, in Stenton, 1990). This account was evidently written when the remains of the wall were clearly visible, before burial under "medieval" and later embankment fill (Hill et al., 1980, figs 16, 19, 28) dumped behind progressively taller Thames waterfront revetments (Milne, 1985, fig. 7). (Note: Hill et al. [1980] used the term "medieval" in the sense of post-Anglo-Saxon period, i.e. post-1066AD.)

Londinium's Thames estuary-side wall, 1.9km long (Hill et al., 1980, fig. 1 map), was constructed by the Romans in the late 3rd C ("in or shortly after A.D. 255-70", based on dendrochronology of foundation piles; Brigham, 1990). At the wall's western end (same map, Sector RW8 study area of Hill et al. [1980], site of late 11-12thC Baynard's Castle), excavated remnant stumps up to 2.5m high all show severe frontal erosion (irregular relief), thinning the wall >50% in some cases (Hill et al., 1980, figs 16, 19, 27). In other cases, the wall is entirely missing, leaving only the truncated foundation (Hill et al., 1980, figs 15, 25 and p. 30). The interpretation of Hill et al. (1980, p. 29) was that "The south (or riverside) face ... had been destroyed by river action". The erosion surface spans the entire height of even the highest stump 2.0m tall (Hill et al., 1980, fig. 16; N.B. above this Roman stump are "medieval" and "post-medieval" raisings); this implies a 3+m rise in HSTL, assuming an initial ~1m of freeboard. Confirming the magnitude of this rise and its likely 5thC (or later) age, across the Thames at Southwark, barren "river clay" at least 2.8m thick, resting sharply on peat containing 4thC pot-sherds, reaches as high as 3.5m O.D. (truncated by modern construction work?; Graham, 1978, p. 504, 524 and fig. 244 cross-section C-C), i.e. ~3.5m higher than Londinium's lowest excavated Thames-side wall-foundation (Data-point 14 in Figure 1).

A postulated alternative to erosion by estuary-flow is stone-robbing (Hill et al., 1980, p. 15, 38, 42). However, in nearly all of the excavated stumps, the erosion surface reaches far (dm) into the wall's core (Hill et al., 1980, figs 16, 17, 19, 21-23, 26, 29 and plates 3, 4; Brigham, 1990, figs 10.2, 11.1), which comprises near-equal amounts of gravelly mortar and rough (unsquared) limestone pebbles and cobbles (Parnell, 1977, 1978, 1981, 1985 [plate 6]; Hill et al. 1980, same figs as above; Brigham, 1990, fig. 10.2). This core-material would have been much less attractive to robbers than the courses of squared limestone of the wall's landward face (Parnell, 1977 [figs 1, 2], 1978, 1981 [fig. 1], 1985 [plates 5, 7-10]), locally buttressed internally by a "clay bank" (Hill et al., 1980, figs 16, 19, plate 3; Brigham, 1990, fig. 11.1); and also the riverward face in three low (~1m) excavated stumps (Parnell, 1985, p. 16 and fig. 11; Miller et al., 1986, figs 4 and 59; Mackinder, 2015, figs 8, 9) that evidently escaped flow-erosion (protected by Thames sand/gravel formerly banked against them?).

In Sector RW8, one excavated wall segment (Area II) now lies horizontally on its inner face, i.e. toppled northward. The former riverward face (now top side) is an undulating erosion surface (Hill et al., 1980, figs 21, 23, 28 and plate 9). A proposal that this portion was deliberately demolished centuries later (using oxen; Hill et al., 1980, p. 72) is negated by erosional relief on the broken-off riverward edge of the toppled slab (figs 21, 23, 28d), indicating that HSTL was still high when the slab tipped over. ("The undercut profile of the surviving broken south edge of the collapsed Wall (fig. 23) might possibly indicate river erosion after collapse" [Hill et al., 1980, p. 42].) Northward collapse suggests that the river broke through a nearby wall segment and eroded the (now absent) clay bank in Area II (cf. Hill et al., 1980, p. 33, 71 and fig. 15A [cross-section A-A]). The breach may have been at either of two *southward*-toppled segments 20-25m away, one up- and the other downstream (Hill et al., 1980, fig. 3 map, see two cross-hatched slabs south of main wall alignment). No clay bank was found in any of the excavations in this western half of the study area (Hill et al., 1980, p. 42, 61).

A "crucially important layer" (Hill et al., 1980, p. 97) for dating the collapse of another northward-toppled wall segment, in Area VIII (far-west part of Sector RW8), lies immediately under and northward of it, comprising "clay soil" and "black earth" containing unsquared "ragstone lumps", Roman tile fragments, mortar, gravel, bone, and shell fragments (Hill et al., 1980, figs 12, 13 and 27, layers 181, 199 and 402, p. 14 and 56), with abundant Roman-age pot-sherds, three Saxon-style chaff-tempered sherds "dating from between the 5th and 8th centuries" (Hill et al., 1980, p. 51) or, more specifically, 450-750AD (Schofield et al., 2008, table 1), "a piece of shell-tempered ware" (Hill et al., 1980, p. 99) of 770-900AD (Schofield et al., 2008, table 1), and a small medieval sherd, "late 12th century or later ... possibly an accidental intrusion" (Hill et al., 1980, p. 97). Chaff-tempered pottery was the dominant type between ~650 and 730AD in proto-Lundenwic townsite (see Section 5.2), <1km up-estuary from walled Londonium (Cowie and Blackmore, 2012, p. xxiii). The pottery-bearing material, resting directly on bedrock (London Clay), reaches at least 1.6m thick (Hill et al., 1980, fig. 13, layers 199 plus 181). Hill et al. (1980) interpreted these deposits as "Dumping (perhaps Saxon) into natural hollow to the north of Riverside Wall, prior to its collapse [p. 56] ... northward into a natural hollow, perhaps a stream bed running north-south" [p. 49]. The hollow is a west-deepening depression (Hill et al., 1980, fig. 3 bedrock contours), possible an eastern tributary of the south-flowing Fleet River (cf. Ayre and Wroe-

Brown, 2015a). According to Hill et al. (1980, p. 14), "the most likely interpretation is that these dumps represent the redeposition of Romano-British material in the 6th-8th centuries". The pottery collectively suggests late 8thC or later. The dumping was possibly aimed at raising the ground to make it less waterlogged. The dump's highest observed (excavated) top is at +1.7m O.D. (fig. 13, layer 181). According to Figure 1, HSTL did not fall below this level until the mid 7thC, reaching a lowstand of ~+0.8m O.D. in the mid 8thC. Thus, the dumping was probably 8thC; any earlier would have been ineffective, not reaching above the water table. The depression's floor-elevation at the dumpsite is ~0.0m O.D. (Hill et al., 1980, figs 12 and 13), so a dump 1.6m thick would have raised the ground ~0.8m above the 8thC HSTL. Middle Saxon (i.e. 650-850AD [Cowie and Blackmore, 2008]) shell-tempered ware was found on and near the same site (Cowie and Blackmore, 2012, gazetteer numbers 110-112 and references therein). Apart from the ragstone lumps, the dumped material is very similar in composition to the Roman-age clay bank buttressing the wall ~80m to the east, in easternmost RW8 (Areas I and IV; figs 15, 16, 19, layers 16, 109, described on p. 52 and 54), suggesting transference of the clay-bank material from a previously collapsed wall segment nearby. Indeed, only ~10m southeast of Area VIII, a "large collapsed fragment" (Hill et al., 1980, p. 49) 6m long was seen (their fig. 3, between areas VIII and VII), but not studied or illustrated. The slab's southerly position suggests southward toppling. It is possible that this fallen segment had a clay bank (area not excavated by Hill et al., 1980) which was the source of the ?8thC reclamation dumping.

The dump's inclusion of unsquared ragstone lumps (Hill et al., 1980, figs 12, 13) suggests that, by the 8thC, eroded wall-core material was strewn on the foreshore, available for gathering (see below). However, *toppling* of this wall sector post-dates the (underlying) dump, i.e. 8thC or later. Possible "river" sand and gravel thought to be "early medieval" (i.e. post-Saxon, in Hill et al. terminology) onlap the lateral flank of the toppled wall stump (fig. 27 and p. 51, 56, layer 403), i.e. they post-date the toppling. These deposits are "similar to those observed in other Areas" (p. 51), meaning layers 9, 10, 13, 59, 147, 154, 226, 316, 351, whose highest-seen elevations differ by <1.5m (p. 52-56 and figs 15-17, 19, 23-27). These "river" ("foreshore" in the case of 147) sands and gravels variably: (a) underlie a northward-toppled wall stump (Area II, fig. 23 layer 226); (b) onlap the erosional front (estuary side) of an upright stump and its foundation (Area I, fig. 16 layers 9, 10; Area VI, fig. 19 layer 316); (c) onlap the erosional front of a northward-tilted stump (Area VII, fig. 26 layer 351); (d) onlap the rear (land-side) of an upright stump (Area I, fig. 15 layer 59); (e) onlap the erosional lateral flank of a northward-tilted stump (Area VIII, fig. 27 layer 403); (f) onlap the front of an upright wall foundation (Area I, fig. 17 layer 9); and (g) overstep the erosional top of an upright wall foundation (Area I, fig. 15 layer 13; Area III, figs 24 and 25 layers 147/154). In the case of (g), it "is probable that the river had broken through the Wall at this point, penetrating behind the structure and partially eroding the clay bank behind" (p. 33).

Three of the excavated "river" layers, all in Area I, yielded abraded (transported) 12thC sherds, accompanied in two cases by reworked Roman ones, also abraded (layers 9, 10, 13; see p. 33, 52, 98, 101). No sherds were reported in the other layers (due to small sample sizes?). A reasonable assumption is that the age of final immobilisation of these deposits was the same for all. Supporting a 12thC age (youngest discovered sherds) for this final deposition, the fallen wall in Area VIII is abutted by "Possibly ... river" sand and gravel whose onlap edge is at 1.4m O.D. (Hill et al., 1980, fig. 27 and p. 56 layer 403), 0.3m lower than that of a 12th-13thC road (fig. 12 and p. 16 layer 160). It is pertinent to ask why no intervening 5th-11thC sherds were recovered. The limited amount of material (sand, gravel) studied is partly responsible, explaining why Roman sherds were not found in every sample. Other possible reasons include: (a) no pottery was made in Britain in the 5thC (see Section 2); (b) from ~450 to ~700AD, very few people (Early and Middle Saxons) lived in Lundenwic and even fewer, if any, in intramural London (Cowie and Blackmore, 2012, fig. 99); and (c) notwithstanding the aforementioned ?8thC land reclamation in westernmost RW8, 8th and 9thC activity in the vicinity of RW8 was apparently minimal, both on the foreshore and behind the wall (Cowie and Blackmore, 2012, fig. 186), even during King Alfred's late 9thC restoration of London (Haslam, 2010, fig. 1 map). The nearest known Alfredian waterfront activity was ~200m eastward (and beyond; same map), including a royal land grant with wall-front moorage rights (Data-point 21 in Figure 1). The above-mentioned 12thC sherds at RW8 probably reflect the presence there of a waterfront "Baynards Castle ... founded in the 11th century by William the Conquerer and given to Ralph Baignard. It was demolished in about 1213" (Historic England, 2025a), coinciding with a HSTL highstand (Figure 1) which possibly made the castle unusable.

Accepting a 12thC depositional age for the "river" and "foreshore" deposits, it is proposed here that the northward-tilted and -toppled wall segments (Areas II, VII, VIII) were felled by 12thC estuary-flow eroding their buttressing clay bank. Supporting this suggestion: (a) HSTL reached a second highstand ~1200AD (Figure 1; see Section 3.4), lower than the ~500AD highstand by ~1.0m (Figure 1; corrected to ~1.7m assuming ~1mm/y subsidence [Section 3.2]); and (b) wherever the clay bank is still present (contiguous Areas I and VI), the wall, although heavily eroded in front, is still upright.

Summarising the foregoing evidence, and integrating it with other evidence incorporated in Figure 1, two episodes of wall toppling can be invoked, related to the two recognised marine transgressions (see Sections 3.2, 3.4). The first transgression, the Rottnest (peak ~500AD; Figure 1), caused flow-erosion of the wall's outer side, up to a level at least 2m above the base (cf. Hill *et al.*, 1980, fig. 16), liberating wall-stones onto the foreshore and causing the above-mentioned wall segment between Areas VII and VIII to topple southward, probably by undermining. More than 200y later, in the 8thC (HSTL low; Figure 1), Saxons collected the loose stones and used them, along with recycled Roman clay-bank material, to reclaim a low area behind the Area VIII wall segment (still upright at that time). In the second transgression (peak ~1200AD; Figure 1), estuary water penetrated behind the wall via the breach between Areas VII and VIII, causing the wall segments in those Areas (and Area II, adjacent to VII) to fall northward by the tidal flow and ebb eroding the wall's clay bank. Farthest (east) from the breach, the thickness of the residual clay bank in Areas I and VI increases eastward, from zero where the wall is missing and only the piled foundation persists, to ~2m behind still-erect wall segments (figs 15, 16, 19). Estuary-flow erosion continued to erode the front face of upright wall segments, probably up to a lower elevation than before, as indicated by a pronounced notch (fig. 16; see Section 3.4).

About 1km east of Sector RW8, wall-front excavations revealed a different configuration of layers. Roman dumped deposits (passing under the wall) are upwardly truncated by an undulating to stepped erosion surface (with upward-protruding timber piles of a ruined Roman quay), overlain by 10th and early 11thC (Late Saxon period ~850AD until 1066) dumped-clay waterfront embankments (Miller et al., 1986, p. 21 and fig. 4; Steedman et al., 1992, p. 98 and figs 56, 59), which are preceded in one locality by a ~1000AD dock and rubble hardstanding for boats (see below). Locally capping the erosion surface are discontinuous silts and gravels up to at least 15cm thick, interpreted as "riverlain foreshore deposits" (Steedman et al., 1992, fig. 54). In RW8, a similar undulating erosion surface at a similar elevation again incises Roman dumpings, but instead of being overlain by Saxon waterfront dumps it directly underlies the "river" and "foreshore" deposits discussed above (Hill et al., 1980, figs 16, 19), last mobilised in the ~900-1200AD transgression, which are missing in the central area because the Saxon dumps raised the ground above the 1200AD highstand level. This erosion surface, constrained to pre-1000AD by the suprajacent dock and hardstanding, can be attributed to high tidal-current velocities when the site was below low-tide level, near the Rottnest highstand (see Section 3.2).

Despite the above evidence for erosion, there are no dislodged wall-stones on the erosion surface or in the (RW8) "river" and "foreshore" layers. A likely reason is that fallen stones were gathered from the foreshore manually, to be re-used in other structures. A probable early example of such recycling is ~1.5km west (upstream) of RW8, where excavations by Cowie (1992) in Lundenwic Saxon townsite (see Section 5.2) exposed a timber waterfront built in 679AD (dendrochronology) or soon after, whose backfill includes flint cobbles, Roman tile, and unsquared ragstone blocks (Cowie, 1992, fig. 3; Cowie and Blackmore, 2021, fig. 103 photo; Data-point 18 in Figure 1), all of which are components of the Roman wall (Hill et al., 1980, p. 32). This re-use of presumed wall-stone constrains the onset of (Rottnest) raised-HSTL wall erosion to pre-679AD. The erosion is further constrained to pre-~580AD by assuming that at least 100y were required for HSTL to fall the ~2m separating Data-points 16 and 17 (Figure 1; see Section 3.3), re-exposing the foreshore.

A subsequent case of wall-stone recycling by Saxons is the ?8thC land reclamation behind the wall in RW8, mentioned above. Later, in Late Saxon time, King Alfred's late 9thC restoration of London (Haslam, 2010) probably spawned larger-scale gathering of fallen stones, for construction of public buildings such as churches. Although remnants are sparse, at least six Late Anglo-Saxon churches existed in London (Haslam, 2010, fig. 1 map). According to Schofield (1994, p. 44), "the majority of pre-Conquest churches in London were of stone, others were of timber". Of one church's relict Saxon arch, Mason (2019) remarked "the top of the arch is made up mostly from recycled Roman bricks and tiles"; in his photograph, the pale stones supporting the arch are possibly ragstone. Robbing of stones directly from the wall can be discounted, as Alfred wanted "refurbished defences" for London (Haslam, 2010, p.

208), following a "devastating" seaborne Viking raid on London in 851AD and a Viking army over-wintering in London in 871-872AD (p. 211). Thus, stone-robbing from (what remained of) London's estuary-side defensive wall would have been illogical. In post-Alfredian time, by 1017AD an early, pre-Norman, version of Baynard's Castle at RW8 (see above) may have existed (Page, 1923, p. 138), and is likely to have used recycled wall-stone. Later stone-gathering can be inferred from an excavation in front of the wall 1.1km downstream from RW8, which discovered a timber jetty and an adjacent hardstanding rubble bank (area 18 x 4m) up to 1m thick, of "probable late 10th- or possibly early 11th-century" age (dendrochronology and pot-sherds; Steedman et al., 1992, p. 103; see also Miller et al., 1986). The bank "comprised ragstone, flint, chalk, and reused Roman building material" (Steedman et al., 1992, p. 99-103 and fig. 7). Thus, wall-stones were apparently still available for gathering from the foreshore in ~1000AD. Indeed, the Steedman book cover-illustration, a painting by Martin Bentley depicting the dock and hardstanding in use, shows a stone-strewn beach fronting the heavily eroded wall. The presence of a jetty (Data-point 23 in Figure 1) implies that HSTL was low enough at ~1000AD for a permanently (24-hour) emergent belt to exist in front of the wall.

Norman-age stone-robbing directly from the (already damaged) Roman estuary-side wall is also likely. Near the wall's far eastern end, site of the White Tower (first stage of the Tower of London), built in the 1070s for William the Conqueror, largely of Kentish ragstone (Parnell, 1993), stone-robbing is implied in three artist's reconstructions depicting sequential oblique aerial views of the Tower area (Lapper and Parnell, 2000, p. 15, 17, 23). In the first reconstruction, representing the late 9thC, the Roman wall is fairly intact apart from a single breach and numerous collapses of the upper portions; fallen masonry lies on the foreshore. In the second reconstruction (late 11thC), the wall segment fronting the partially built White Tower is shown fully repaired, but the segment immediately upstream is reduced (implicitly by robbing) down to flat-topped stumps and, in part, completely removed. The third reconstruction (late 12thC) shows the robbed Roman wall sector replaced by a 12thC wall that still stands in the SW corner of the Inner Ward of today's Tower of London (wall coloured blue on foldout map of Impey and Parnell, 2000, inside-front-cover). By 1200AD, the Tower of London was entirely enclosed by a stone wall and a moat (Impey and Parnell, 2000, fig. 18), leaving the eroded remains of the Roman estuary-side wall upstream to the west fully redundant.

Another likely constraint on the age-span of the post-Roman (Rottnest) rise in HSTL is a deliberately blocked culvert (drain-tunnel) piercing the lower part of the estuary-side wall in RW8 (Data-point 15 in Figure 1). The floor of the culvert is at +2.0m O.D. in the wall's north face (Hill et al., 1980, fig. 15). The culvert was fed by a duct through the buttressing clay-bank behind the wall. Excavation by Hill et al. (1980) showed the duct was later eliminated by trenching downward into the bank and extracting the duct's (timber- or lead-?) lining, then backfilling the duct and the trench with "clay soil with much building material" (Hill et al., 1980, p. 32, fig. 15 [layers 20, 21] and plate 6), similar to the clay-bank itself. The backfill yielded late 3rd(?) and 4thC pot-sherds, one post-dating ~270AD and another post-dating ~320AD (Hill et al., 1980, p. 52, 95). This laborious plugging operation was "possibly to prevent water flowing in behind the Wall as the river level rose in the late Roman period" (Willcox in Hill et al., 1980, p. 78). Brigham (1990) doubted this interpretation and opined that "the river level could hardly have risen almost 2m in half a century" (time elapsed since the wall's construction), evidently unaware that a comparable 2-3m SL rise in <100y is proven for the previous interglacial MIS5e (Blanchon, 2011), and overlooking the possibility that the plugging was done in the 5thC (see below), in which case the ?3rd/4thC sherds were either intrinsic to the 'recycled' (for plugging) clay-bank material, or were new additions derived from 'inherited' pottery still in use in the 5thC (see Section 2).

Brigham instead followed Hill et al. (1980, p. 33), interpreting the deliberate blocking as an alteration in Londinium's drainage system shortly after wall construction. However, it is difficult to conceive how plugging a culvert would improve drainage. Lending support to Willcox' suggestion is a second culvert (floor at +1.6m O.D.) discovered in the wall's south face, and filled with (undated) "successive layers of grey, green, brown organic and finally grey silt" (Miller et al., 1986, p. 54 and fig. 40), possibly tidal deposits. Another blocked culvert is known at Pevensey Roman-built shore-fort (see Section 4.2).

The first culvert might have been plugged after the Romans' 410AD departure, either (a) by sub-Roman Britons, prior to their abandoning Londinium by ~450AD, when migrating Saxons began settling in the Thames valley (Booth et al., 2007), after which London was "a crumbling, overgrown ghost town" (Cowie and Blackmore, 2012,

p. 201) for ~400y; or (b) by late 5thC Saxons who, while beginning to settle the future site of Lundenwic ~1km upstream (see Section 5.2), also visited the intramural area, as shown by: (i) a mid-5thC saucer brooch discovered immediately inside the estuary-side wall, 1.2km downstream from Area VIII (Cowie and Blackmore, 2012, p. 100-101, gazetteer no. 131); and (b) two 5thC "Germanic" sherds found at St Bride's Church (Blackmore and Williams in Milne, 1997, p. 54), 300m NW of Area VIII, ~200m outside Londinium's western land-wall (Cowie and Blackmore, 2012, fig. 99 map, St Bride's = site Gaz103).

Previous authors interpreted the Thames-side wall flow-erosion as occurring (or continuing until) long after the ~450-700AD invoked here (i.e. main interval of rapidly rising and falling HSTL in Figure 1). Willcox (1975), based on a summary of published excavation results by other workers, interpreted the erosion as "Late Saxon" (his fig. 3), i.e. ~850-1066AD. According to Hill (1975, p. 261), "This process of destruction seems to span the long period of Saxon and early medieval England". Later, Hill et al. (1980, p. 33) wrote: "After the completion of the riverside wall there began the slow but effective erosion and partial destruction of the structure by river action during the marine transgression of the post-Roman period"; their figure 14 refers to the "Erosion Phase" from "Late Roman to 12th/13th centuries". In contrast, the same authors depicted (fig. 28) an "early medieval erosion period" (i.e. post-Saxon in their terminology), followed by "12th/13th century redevelopment" (revetments and dumping). Millett (in Hill et al., 1980, p. 16) reasoned that the "absence of deposits that can be dated to between the 6th-8th century and the 12th-13th century ... would indicate that a rise in river level in the late Saxon and early medieval periods caused the site to become marshy, as a result of marine transgression".

Another London excavation is fully consistent with the interpreted timing, magnitude and rapidity of the transgression that caused erosion of the estuary-side wall. At Queenhithe, ~400m east of RW8, a pit excavated <25m in front of the wall revealed Roman quay pilings driven through "foreshore gravel", *sharply* overlain by ~0.8m of laminated silt (Ayre and Wroe-Brown, 2015a, illus. 4 photo), suggesting that a *rapid* rise in HSTL turned the gravelly foreshore into an intertidal mud (silt) flat. The lack of intervening sands suggests that, besides being rapid, the rise was substantial (m-scale). Notably, the silt's delicate parallel-lamination exposed in the pit-wall is largely intact (illus. 4), lacking obvious evidence for human disturbance such as footprints or boat-keel marks, consistent with a London occupation hiatus (see Section 5.2) caused by the elevated HSTL. Regarding its age, the silt obviously post-dates the (truncated) Roman quay beneath, dated as "just before AD 200" (Ayre and Wroe-Brown, 2015a, p. 123). Sharply overlying the silt (contact indented, possibly by human or quadruped footprints) is ~20cm of weakly stratified gravel (illus. 4), interpreted by Ayre and Wroe-Brown (2015a, p. 129) as "foreshore deposits", followed by "reclamation" material (near-structureless dark mud with scattered pebbles and cobbles; illus. 4), presumably dumped behind a revetment, raising the surface above HSTL. The sharpness of the silt/upper-gravel contact, and lack of intervening sand, suggest a rapid and substantial fall in HSTL (cf. 'forced regression'; Plint and Nummedal, 2000). Constraining the end-date of silt deposition, carbon-dated pieces of bark associated with a skeleton carefully buried in the upper gravel indicate a burial date of 680-810AD (Ayre and Wroe-Brown, 2015a; Data-point 20 in Figure 1). Thus, deposition of the silt may have ended as early as pre-680AD. According to Ayre and Wroe-Brown (2015a, p. 129), the "early and middle Anglo-Saxon silt" had "probably taken over five centuries to accumulate and yet ... contained little archaeological material. Other indicators of human activity, including magnetic susceptibility and phosphate content of the silt, were found to be low and, together with the scarcity of micro-artefacts, implied little or no permanent local post-Roman occupation until about the mid-ninth century" (see also Section 5.2).

The (Rottnest) SL rise responsible for eroding the wall may also have destroyed Londinium's Roman-built bridge. Rhodes (1991, p. 190) used coin evidence to propose that the bridge was "swept away" before 330AD. Brigham (2001) suggested deliberate demolition in the 4thC or the (sic) 12thC. Instead, it is proposed here that the bridge succumbed to excessive stress caused by the magnitude (~4m) and rapidity of the 5thC rise in HSTL (Figure 1). A royal land charter of 672-674AD, thought to pertain to Southwark (the southern bridgehead), makes no mention of a bridge (Dyson, 1980, p. 91), suggesting it was gone by then.

4.2. Pevensey Roman sea-fort

On England's south coast, Pevensey sea-fort (Roman-built ~290AD; Fulford and Tyers, 1995) straddles a promontory that protrudes northeastward into Pevensey Levels, a reclaimed former intertidal embayment beside the English Channel (former "Bay of Pevensey"; Goodall, 1999, p. 20). The fort today lies 1.5km inland, enclosed on three sides by lowlands mostly <2m above mean SL (Google Earth), i.e. *lower* than nearby Eastbourne's HSTL (~+4m O.D.; spring-tide range ~7m), necessitating artificial coastal defences to prevent marine inundation of Pevensey Levels. The position of the fort's Roman dock is unknown.

Suggesting that HSTL rose at least 2m in the 5thC (cf. Figure 1), a defensive-ditch fronting the fort's southwestern gate contains early-5thC pot-sherds (Lyne, 2009, p. 51 and 115) in a mud bed (layer 6 in Lyne's fig. 6B trench section from Pearce 1938-39 unpublished notes) that Pierce interpreted as tidal (considered by Lyne [2009, p. 50] to be "very unlikely as it would imply a rise in sea-level of several meters"). The top of layer 6 is ~1m below the modern ground surface, whose elevation is ~8m above O.D. (Google Earth), i.e. HSTL reached at least as high as ~7m O.D., i.e. no less than ~1m higher than the external ground surface beside the northwest wall (~6m; Google Earth), and <2m lower than the ground surface fronting the southeast wall (~9m). Thus, wall-collapse in both sectors (see outward-toppled slabs on maps of Salzmann [1908a, fig. 1], Goodall [1999, inside back cover] and Lyne [2009, fig. 1]) is attributable to undermining by waves and/or tidal flow due to SL rise (cf. Wikipedia "Plan of Pevensey Castle, showing that the south wall has been washed away by the sea", https://en.wikipedia.org/wiki/Pevensey_Castle, accessed 2nd February 2025).

Due to collapse of the southeast wall, strata that were banked up behind it slid onto the residual wall stump (Lyne, 2009, fig. 15b trench-wall section). The slipped (and tilted) layers yielded an Early-Saxon-style sherd of probable mid- or late 5thC age and, higher up, Early and Late Saxon sherds, the latter possibly "intrusive" (Lyne, 2009, p. 44). Thus, "fort-wall destruction at this point took place after the mid-5th c. and probably before the Late Saxon period" (Lyne, 2009, p. 44-46), consistent with the London evidence for a ~4m rise in HSTL (SL) spanning ~430-500AD (Figure 1), i.e. the Rottnest transgression. Sediments draping the slipped deposits contain 11thC sherds (Lyne, 2009, p. 46), constraining the latest possible date of wall collapse.

The modern topography behind the former line of the (fallen) southeast wall shows evidence for land-sliding, probably dating to the time of wall collapse, namely a seaward-facing slide-scar visible in aerial images and on maps by Goodall (1999, inside back cover) and Lyne (2009, fig. 1). A few metres farther inboard, a smaller slide and its basal slip surface are shown in cross-section in Lyne (2009, fig. 14A, trench X, after Cottrill, 1937). Confirming that the sliding predated Norman occupation of the fort (from 1066AD; see below), an excavated sector of a Norman-age wall, replacing the collapsed Roman southeast wall, trends inboard of the slide scars (Lyne, 2009, fig. 1 and p. 44). Lyne (2009, p. 44) concluded: "Much of the south wall of the Roman fort had already been overthrown before the late 11th c ... Its total ruin on this side of the fort, nearest to the shore, suggests that the wall may have been undermined by rising sea levels".

Also consistent with a 5thC SL rise, a drainage culvert through the base of the northwest wall, "loosely blocked" with material (soil, animal bones, pieces of sandstone and flint, Roman potsherds and a coin of the Constantine period, 307-337AD), whose "general appearance ... suggested that the drain had become blocked at an early date, soon after the building of the wall" (Salzmann, 1908b, p. 125, 126), may have been deliberately plugged to prevent sea-water entry (compare London culvert, see Section 4.1).

Within the fort, an elaborately constructed (timber-lined) Roman water-well contains sticks, animal bones, greensand boulders, Roman pot-sherds, and leather fragments. Salzmann (2008b, p. 129) deduced that "These finds point to the well having been disused and, as was not infrequently the case, converted into a rubbish pit; while the fact that fragments of coarse black Roman pottery were found some 5 feet from the mouth, and no remains of post-Roman date were found within it, is conclusive evidence that the well was disused and filled up before the end of the Roman occupation; amongst the rubbish cast into the well appear to have been quite a number of old shoes, many fragments of leather being recovered, some of which showed the characteristic sewing of the period, though no nail-studded soles occurred". Thus, Salzmann (2008b) interpreted the well to have been abandoned before 410AD, i.e. within about a century of the fort's construction. Alternatively, abandonment could have been later, given that 5thC sub-Roman Britons probably re-used old Roman-era pottery (see Section 2). It is possible that Britons living in the fort (slaughtered by Saxons in 491AD, or 471AD if the Anglo-Saxon Chronicle's 5thC dates are 20y too late [Lyne, 2009]) abandoned the well due to saline-groundwater ascent driven by rising HSTL (cf. BGS, 1998, fig. 2). This idea accords with the London evidence that the Rottnest rise spanned ~430-500AD (Figure 1; see Section 3.2 and Section 4), and is consistent with the absence of Roman military nail-studded soles in the well (Romans departed Britain 410AD). Another abandoned well, apparently backfilled *methodically* (piecemeal?) in the 5thC, occurs at Portchester fort (see Section 4.3).

The amount by which modern HSTL would have to rise in order to touch Pevensey fort's walls can be crudely estimated using the Firetree online adjustable-SL map (https://flood.firetree.net, based on Google Earth ground elevations above global mean SL), which depicts the extent of coastal flooding under whatever simulated SL-rise value the reader chooses. On this 'flood-map', a +4m SL essentially depicts modern HSTL (~+4m O.D. at Eastbourne), showing how the shoreline configuration would look today at high tide if there were no coastal defences. Pevensey Levels would (again) become an intertidal embayment, with Pevensey-fort promontory protruding into it, surrounded by a tidal flat on three sides. At modern *low* spring tide (3m below O.D. at Eastbourne), the embayment would be fully emergent. Raising HSTL by 2m (i.e. +6m on the flood-map) would turn the promontory into an island, with the shoreline touching the SE wall and intruding beyond (inside) the NW wall. Adjusting for subsidence (currently ~1mm/y in southernmost England, based on GPS; Stockamp et al., 2015, fig. 8c) totalling ~1.5m ~ since 500AD (assuming no change in subsidence rate) would increase the necessary rise to ~3.5m above modern HSTL. Thus, assuming constant tidal range over time (see Section 3.1), global mean SL at the Rottnest highstand was likewise, very approximately, 3.5m above modern mean SL, compared to the ~1.0m of Fairbridge (1961, fig. 15; 1976, fig. 3). The same amount, ~3.5m, can be calculated for Fishbourne Roman palace (see Section 4.6).

William the Conqueror landed his invading army in Pevensey Bay in 1066. A 12thC castle was built (modified over ensuing centuries) within the Roman fort walls (Goodall, 1999), which by then were already partially collapsed. World SL was then ~1.5m lower than the Rottnest 500AD highstand (cf. Figure 1; ~2m when adjusted for subsidence). Simulating this lowering by reverting to the +4m flood-map option shows that the high-tide shoreline had retreated ~100m from the wall in the southeast, and barely touched the wall in the northwest. Consistent with this inference, excavations found a 13thC boat-quay ~300m east of the fort (Dulley, 1967).

The Rottnest transgression explains similar collapse of the seaward wall at two other Roman-built (~300AD) shore-forts on England's south coast, namely Lympne and Richborough (see Sections 4.4, 4.5).

4.3. Portchester Roman sea-fort

Portchester fort, 100km west of Pevensey, is a globally unrivalled 'dipstick' of SL fluctuations between 300 and 1400AD, thanks to numerous archaeological features carefully excavated, well-dated (pot-sherds, metal artefacts, documents) and scrupulously documented, but hitherto under-interpreted with respect to their SL significance. The fort is at the inner (northern) end of 'bottlenecked' Portsmouth Harbour, a naturally sheltered historic anchorage. The square fort has its entire eastern wall facing the water, which reaches to within 7m (laterally) of the wall at high spring tide, and actually touches three projecting bastions, and the watergate, and the fort's southeast corner (Google Earth). Eight principal indicators of SL change are as follows, in temporal order.

1) During normal high spring tides, the base of the wall at the fort's southeast corner, its lowest point (Strutt et al., 2004 detailed topographic map, contour interval 10cm), is awash by a few decimetres (hence lateral disappearance of outboard grass fringe on Google Earth images, due to salt-water wetting). In contrast, during the wall's construction (~300AD; Goodall, 2008), HSTL must have been at least 2m lower than now, *relative to the base of the wall,* otherwise the wall's 1.5 m-deep foundation trench (Cunliffe, 1975, p. 13 and fig. 8) would have penetrated the water-table (i.e. permanent waterlogging), and would have undergone frequent storm-wave inundation. Subsidence for 1.7ky at the current southern England rate of ~1mm/y (Stockamp et al., 2015, fig. 8c) accounts for ~1.7m of the 2m+ difference. Eustasy must also be taken into account: accepting the updated Fairbridge Curve's pre-Rottnest SL lowstand of 1m below modern mean SL (Fairbridge, 1976, fig. 3), Portchester's 300AD (pre-Rottnest HSTL lowstand in Figure 1) relative HSTL (and relative SL) was at least 2.7m (1.7 plus 1) lower than today (assuming no change in tidal range; Section 3.1).

2) The location of the fort's Roman wharf is unknown; it presumably lay somewhere seaward of the watergate (in the east wall; Goodall, 2008, fort plan, inside back cover). Extending ~70m seaward across the modern intertidal-flat in front of the watergate are two raised (dm), diffuse, seaweed-covered, parallel, slightly curving features ~7m apart and each ~5m wide, vaguely merging distally into an indistinct mass (Google Earth images, especially April and June 2015, low tide; Google Earth Street View images; Britain from Above, 2024, Portchester low-tide aerial photos EAW005094, 95 and 97). These features are interpreted here as (storm-wave-dispersed)

Roman 'in' and 'out' stone causeways, built on *supra*-tidal marshland, and servicing a timber wharf whose remnants, if any (e.g. stumps of pilings?), are probably buried under intertidal deposits. To facilitate access by wheeled carts, the causeway was presumably level with the wharf platform, which would have been positioned just above 300AD HSTL (perhaps 30-50cm freeboard). This assessment largely agrees with an artist's reconstruction by Peter Dunn (formerly of English Heritage), depicting a Roman galley in ~330AD approaching a timber wharf at the end of a slightly raised roadway crossing marshland and leading to Portchester's watergate (Alamy, 2025; Alchetron, 2025).

3) Excavations in the fort's SW quadrant found an infilled Roman water-well, only ~50m from the modern high-spring-tide line, bottoming (base of fill) 6.1m below the surface of the natural geological substrate ('brickearth'; i.e. Quaternary wind-blown silt with flints [Wikipedia]; Cunliffe, 1976, p. 84 and fig. 63), which today is ~1m below the ground surface at the well location (elevation ~+3m O.D. [Google Earth; Strutt et al., 2004]), under dumpings containing "19th Century Rubble" (Cunliffe, 1976, layers 3, 4, 5 in fig. 157 cross-section 10; also fig. 158 cross-section 14). If a well were dug to that depth today, it would be 'overdeep', needlessly tapping several metres of fresh groundwater (only about a 'bucket-depth' is required; cf. Dean et al., 2019, fig. 2), since the water-table is near the surface, as indicated by the "permanently water-logged" well-fill (Cunliffe, 1976, p. 84). However, if 300AD relative HSTL was at least 2.7m lower than today (see '1' above), the need for a deep well is evident.

4) The basal 2m of the well-fill comprises dark silt with "close-packed bands of flint nodules" (Cunliffe, 1976, p. 84 and fig. 63), suggesting the filling was systematic, interpreted here as a deliberate attempt to combat saline-groundwater ascent due to rising HSTL. Roughly dating the rise, the basal fill yielded two Saxon-style metal artefacts, namely an iron purse-mount and a disc-brooch, *both assigned to the second half of the 5thC* (Cunliffe, 1976, p. 84, 197, 206, 301 and fig. 63), consistent with the interpreted 430-500AD span of the Rottnest rise (Figure 1). Above the basal fill, "the upper sides of the well were eroded back by spring sapping to create an irregularly shaped water-hole" (p. 84), consistent with a rising water-table driven by rising HSTL. The fill of this sector consists of 2.1m of silt with dispersed flint nodules (p. 84 and fig. 63), presumably sloughed from the walls (brickearth).

5) Three lines of evidence suggest that, despite the raised SL, no sea water invaded the fort (through the watergate) during the Rottnest SL rise and highstand: (a) Cunliffe (1976) reported no Saxon dumpings (to raise the ground elevation) in his main excavation area in the fort's SW quadrant, whose average elevation *after* ~1m of 19th dumping (see '3' above) is ~1m higher than the NE and SE quadrants (Google Earth; Strutt et al., 2004 topographic map]; (b) an excavated Saxon-style sunken-floor hut, incised 2m into the brickearth, contains mid-to-late-5thC material, so "It is reasonable therefore to assign the sunken-floor huts to the early part of the Saxon occupation" (Cunliffe, 1976, p. 57), implying that the fort's SW area remained dry throughout the Rottnest SL rise; and (c) Cunliffe (1976) reported no foraminifera-bearing layers in the SW quadrant, nor in his limited excavations in the SE quadrant (Cunliffe, 1977), nearer the sea. This deduction implies that the Early Saxons blocked (earthen bank?) the watergate, like the Normans probably did in the early 12thC (see '8' below), when SL was rising again (Figure 1).

6) The above-mentioned well was re-dug to 4.3m (i.e. 1.8m shallower than before) and elaborately timber-lined by Saxons in the last quarter of the 6thC (dendrochronology; Fletcher and Dabrowska, 1976), suggesting that soon after the ~500AD Rottnest highstand, SL quickly fell ~2m (cf. Figure 1).

7) In the early 12thC, the Normans upgraded Portchester, building a castle inside the fort's NW quadrant and largely surrounding it with a tide-filled moat (Goodall, 2008). At modern high spring tide, sea water part-fills the moat (up to the edge of the grass border) throughout its length (Google Earth, April 2020 image). When the castle was built, the land was ~1m higher (assuming subsidence ~1mm/y since 1100AD), therefore HSTL must have been at least 1m higher than today (cf. Figure 1, 12thC steep rise in HSTL, reaching highstand ~1200AD) for the moat to function. The northern sector of the moat, directly connected to the sea (via a sluice), has a bank-full width of ~10m, which could have accommodated sizeable vessels transferring cargo and men to and from sea-going ships anchored in Portsmouth Harbour.

8) A priory was built in the fort's SE quadrant in the 1130s (Historic England, 2025b). The only remnants are today's St Mary's Church and part of the monks' reredorter, a "communal toilet in mediaeval monasteries ... designed so that waste was carried away by a stream, river or other water channel" (Historic England, 2025c; see Tower of London ~1275AD example that emptied into a tide-filled moat, photograph in

Impey and Parnell, 2000, fig. 35). The reredorter remnant at Portchester comprises nine seaward-dipping outlet-chutes piercing the fort's Roman-built south wall, near its eastern end (Cunliffe, 1977, p. 100-101 and plates XXVIa, b), an impressive engineering feat, given the wall's thickness (at least 1.2m; cf. Cunliffe, 1976, fig. 8). The chutes' external apertures can be studied on Google Earth Street View (view from external perimeter path around the fort). A sketch reconstruction of the chute outfall being 'flushed' by sea water lapping the base of the wall appears in Historic England (2025b). Given that sea water at HSTL nowadays touches none of the south wall except its eastern extreme, at the corner (see '1' above; grass-free area reaches only to the eastern [seaward] end of the chute-array, Google Earth Street View), in the 12thC when HSTL was at least 1m higher (see '7' above) it would have reached at least 1m up the wall under the chutes, ensuring efficient flushing, not only at HSTL, but also at high *neap* tide (i.e. potentially twice-daily flushing all year), assuming today's mean-spring-versus mean-neap-high-tide differential (85cm in neighbouring Portsmouth; NTSLF, 2025) was similar in early Norman time.

Any tide high enough to reach 1m up the wall's SE corner should have been able to penetrate the watergate (sill elevation ~20cm higher than base of wall's SE corner; Strutt et al., 2004 topographic map) and reach tens of metres inside the fort, flooding the SE and NE quadrants, and also the SW quadrant, of about the same elevation prior to ~1m of 19thC dumpings (see '3' above). Storm wind/wave surge would have exacerbated sea-water entry. Such flooding would have prevented construction of the priory, therefore it is likely that the Normans sealed the watergate (using mortared stonework?). The watergate was superfluous anyway if Norman ships anchored offshore and trans-shipped via the moat (see '7' above). The suggested sealing cannot be archaeologically proven, as the watergate was extensively rebuilt between 1321 and 1325AD (Cunliffe, 1977; Goodall, 2008), when SL was probably falling (Figure 1). With HSTL so high, the water-table in the priory area would have been near to the ground surface, consistent with the church's shallow foundation, comprising "broad strip footings ... in places functioning as sleeper walls" (Cunliffe, 1977, p. 100; a "sleeper wall is a short wall ... constructed ... when a suspended floor is required due to bearing conditions or ground water presence" [https://en.wikipedia.org/wiki/Sleeper_wall, accessed 3rd February 2025]). Despite the effort and expense of construction, Portchester Priory was very short-lived (<20y), transferring to a site 4km inland at some time between 1147 and 1150AD (Historic England, 2025b). Abandonment probably reflects intolerable, increasingly frequent waterlogging due to steep SL rise in the 12thC (Figure 1).

The foregoing analysis sheds light on the unresolved age of a recognised phase of remodelling of the original Roman watergate. From the sum of the evidence, Cunliffe (1976, p. 14) suggested three possibilities: (a) early 10thC (Late Saxon); (b) late 10th/early 11thC; or (c) "at the very beginning of the Norman period before the main phase of castle building had begun", i.e. latest 11th or earliest 12thC. The third alternative seems least likely, as rising SL (throughout 10th, 11th, 12thC; Figure 1) may already have caused the early Normans to dam the watergate (see above), whereas the remodelled watergate has arched openings (originally presumably gated) on both landward and seaward sides (Cunliffe, 1976). Consistent with continuing SL rise through the 12thC (Figure 1), the rebuilt "gate was subsequently damaged by the encroaching sea, as was the Roman wall along this side of the fort" (Goodall, 2008, p. 22). Ensuing SL fall through the 13th and 14thC (Figure 1) would have enabled the aforementioned 1321-1325AD rebuild.

4.4. Lympne Roman sea-fort

The Rottnest transgression explains collapse, by wave-undermining, of the seaward wall of another south-coast Roman-built (~300AD) shore-fort, namely Lympne, 55km northeast of Pevensey, and similarly stranded inland (2km) from the nearest modern beach. The fort was built on a hillside overlooking Romney Marsh, which is nowadays a coastal plain. Like Pevensey, remnants of the toppled wall-slabs are still there, displaced by sliding (Cunliffe et al., 1980). Repeating the flood-map exercise applied to Pevensey (see Section 4.2), a 6m simulated SL rise again indicates that, during the Rottnest highstand, the HSTL shoreline impinged on Lympne fort's seaward wall. A trench cut at the base of the hillside bottomed in black organic clay, grading up into a transgressive sequence (cf. Queenhithe, see Section 4.1) comprising a thin (dm) layer of "beach" pebbles with sand and shells, followed by ~2m of "estuarine silt" with a microfauna in which "All the species present ... were marine and indicated a community supported by water of full salinity ... [in] ... open water" (Cunliffe et al., 1980, p. 258). Cunliffe et al. inferred (p. 259) that at "Some time in the late Roman and early Saxon period a rise in sea level led to the flooding of the estuary and of the surrounding surface of the marsh which had hitherto been settled. ... [The] conditions ... favoured rapid sedimentation in the old estuary. By the eighth century, charter evidence shows that silting was virtually complete and by the tenth century the newly created landscape was extensively settled. Thus, the 2m of marsh deposit ... [his "estuarine silt", above] ... immediately south of the fort must have accumulated within the broad time bracket A.D. 300-700". This reoccupation of Romney Marsh from ~700AD is consistent with the London evidence for a post-Rottnest SL fall from ~550 to ~900AD (Figure 1).

Cunliffe et al. (1980, p. 259) concluded: "The precise difference in high tide level between the early Roman situation and that prevailing at the height of the transgression is difficult to estimate but it *must have been in excess of 2m* (emphasis added). Such a rise, with its potential consequences for changing the height and intensity of the fresh-water springs, may have activated the already unstable cliff and thus may have initiated the land-slips which destroyed the fort. At what time during the period A.D. 300-700 the collapse began cannot yet be ascertained". These deductions regarding both the amplitude and timing of the transgression are fully consistent with Figure 1.

4.5. Richborough Roman sea-fort

Richborough fort is on a low hill 30km northeast of Lympne. Ground elevation inside the fort is ~12m (Google Earth). The invading Roman army landed at this hill in 43AD (Cunliffe, 1968b), suggesting that the shoreline, which currently lies 3km to the east across the modern coastal plain, lay nearer at that time. The fort's stone walls, built ~290AD (Cunliffe, 1968b, p. 245), were probably arranged in a square (Bushe-Fox, 1928, p. 6), like Portchester (see Section 4.3). However, there is no longer an eastern wall. Instead, the north and south walls are truncated eastward at a SE-facing gentle slope ~7m tall and ~30m wide (Google Earth; i.e. gradient ~13°), referred to as a "cliff" (Wilmott, 2012, p. 4, 32) and an "eroded scarp" (Wilmot and Smither, 2020, p. 149). Stretching ~50m along the northern sector of the base of this slope is a string of recumbent wall-slabs (Cunliffe, 1968a, fig. 1; Cunliffe, 1968b, fig. 33; Wilmott, 2012, inside back-cover; Google Earth January 1960 image, free of vegetation). The fallen slabs measure ~5m (downslope width); the highest surviving *in situ* wall is 7.5m tall (Cunliffe, 1968b, p. 245). There are no tumbled slabs corresponding to the eastern wall's original southern sector; they were possibly removed during construction of the railway that runs obliquely across the projected former position of the missing wall (Wilmott, 2012, inside back-cover).

Describing the fallen slabs, Bushe-Fox (1949, p. 81) said: "The earth round these was cleared away. Only one of the masses of masonry showed bonding-tiles, in two courses 4 ft. apart, of one layer each. From another mass a wall of four rows of flints was found to pass beneath the present path to the face of the bank, while in the angle between two others was a series of rows of medieval tiles lying regularly one upon the other. Late Samian and other· Roman ware was found scattered about the remains with medieval pottery in larger quantity. These researches have not furnished any evidence for the *date of the fall* [emphasis added here] of the east wall, but Mr. O'Neil recently found in the Hatfield House Collections of manuscripts a plan ... of east Kent dated by Dr. Lynam of the British Museum as A.D. 1560-70 showing Richborough with the east wall intact. If this evidence can be accepted it would indicate that the wall fell some time after this date. It would not be in accord with the engineering services of the Romans to build a wall likely to collapse in a few centuries and a medieval date for the fall is more likely than an earlier one". However, the cited map is either inaccurate or older, as later excavations (see below) unearthed intact 15thC masonry, an interpreted dock, abutting a tumbled slab. The remark on Roman builders' prowess is irrelevant in view of the exceptional magnitude and speed of the Rottnest transgression.

Cracknell (2005, p. 112) attributed the destruction of the east wall to "the river Stour which shifted its course westwards, undermining the foundations of the wall", at some time between 1000 and 1400AD. In contrast, Perkins (2007, p. 259) invoked "the eroding effect of south-easterly gales" and interpreted "the collapsed state of Richborough's eastern defences and the steep fall of the bluff as being the result of wave erosion", implying storm waves, without estimating the date of collapse.

The area of the fallen slabs was further excavated in 2008. Some of the findings and provisional interpretations were reported in The Telegraph (Tibbetts, 2008): "The dig at Richborough Roman Fort near Sandwich, Kent, suggests that Emperor Claudius' men landed at a point two miles inland from the present coastline. It is thought the fort overlooked a lagoon which disappeared as the area gradually silted up. Tony Wilmott, a senior archaeologist with English Heritage who led the excavation, said: 'It is widely known that Richborough Roman Fort was the gateway to Roman Britain 2,000 years ago, but what is really exciting is that we have actually found the Roman foreshore while digging in a deep trench alongside the remains of a Roman wall. The bottom of the trench continually fills with water and by trowelling you can feel the hard surface, which was the Roman beach. We have long been curious about this fallen Roman fort wall and now we know there was a Roman harbour sitting out there.' The Roman beach was found six feet down. ... 'The exact location of the Roman shoreline has always been a mystery', said Mr Wilmott. 'One hypothesis was that the fort and Roman settlement extended a lot farther over the railway line, river and beyond. Another theory was that the shore was close to the fort. We have found the latter. This is important because it is the context for the Roman invasion of Britain in AD 43. We knew Richborough was the site of that first landing (but) the relationship of land and sea for the invasion fleet has been a really important research question. It's very exciting to finally nail it.' ... Archaeologists also discovered a mediaeval wall from what they believe was a 14th century dock, used by trading boats. It may also have been associated with the nearby St Augustine's chapel." Photos of the fallen wall and the interpreted medieval quay were published in newspaper articles by Kennedy (2008) and Derbyshire (2008); the latter sketched the interpreted position of the Roman shoreline. Brief provisional interpretations appear in a guidebook by Wilmott (2012): "Excavations on the slope to the east of the chapel showed that during the 15th century the chapel stood above a small *riverside* dock with buildings using the fallen ... fort wall as a foundation" (p. 16; italics added here); and "At some point before the 15th century, the cliff edge eroded and the eastern side of the fort collapsed" (p. 4). After the Romans abandoned Britain (410AD), the inferred marine bay fronting Richborough fort (Wilmott, 2012, maps on p. 7, 41) "began to silt, becoming partially marshland, and the cliff on which the food stood eroded. This made the east wall unstable and it collapsed, sliding down the slope into the mud" (p. 43). A 2020 magazine article by Wilmott says: "The work indicated that open water conditions existed at the base of the scarp until the late medieval period, when silts began to accumulate. Before this an unknown amount of erosion of the scarp had caused the collapse of the east wall of the Saxon Shore fort. At a depth of 2 metres beneath the silting and the eroded material, a foreshore deposit was discovered upon which lay waterworn Roman ceramics. Research continues on these questions, and the location of an actual waterfront remains to be discovered. However there is little doubt that the Roman shoreline was quite close to the present scarp" (Wilmott, 2020, p. 10-11).

Wilmott and Smither (2020) dated the collapse of the east wall as "late fourth century (at the very earliest) or ... 11th to 12th century (at the very latest ...)" (p. 171). The same publication proposed that the entire missing east wall was built farther west than shown in the conventional reconstruction (Cunliffe, 1968b, fig. 33 map), instead positioning the east wall's northern sector on level ground, ~10m inboard of the slope's present-day inner edge (Wilmott and Smither, 2020, fig. 19), begging the question of how the wall slid to the bottom of the slope. This repositioning by Wilmott and Smither (2020) also contradicts their interpretation (p. 149) that "erosion of the scarp" caused the wall's collapse. Moreover, in the Wilmott and Smither (2020) reconstruction, the west wall and (imagined) east wall are non-parallel, unlike the square interpretation (see above). Wilmott and Smither (2020) stated: "Nine blocks of collapse [their figs 5-8 photographs] were recorded ... they represent a single catastrophic episode ... the largest single block ... comprises a continuous unbroken length of walling of 11.70 m, while the original vertical height of the largest measurable section ... was 5.15m – close to the height of the surviving north wall, which stands some 6m high" (p. 151); "the loss of a substantial part of the area of the fort ... is conventionally attributed to marine erosion ... and this is certainly the most likely explanation. During the 2008 excavation, foreshore deposits, including water-worn Roman ceramics, were encountered immediately adjacent to the fallen wall. ... Two segments of collapse were linked by a medieval wall [their fig. 7 photograph] which formed a small inlet or dock ... It is at [sic] yet impossible to state where the coastline lay at the time of the [Roman] fort; in all likelihood ... this was close to the fort. If this was indeed the case, the proposed east wall on the Cunliffe plan would effectively have been on the beach. ... If the east wall was adjacent to the collapse, then the fort would have had to have been built on two levels, with the foundations of the north and south walls terraced down a slope with a vertical height of 9 m" (p. 169). This criticism of Cunliffe's map neglects post-Roman erosional retreat of the scarp (from a former position farther east), both before and after the east wall's collapse.

None of the above authors invoked SL rise as a factor in the wall's collapse. In contrast, it is proposed here that the Rottnest transgression of ~4m in only ~70 years (~430-500AD; Figure 1) would have made the slope recede by storm-wave erosion/or tidal-current scour, undermining the wall. The slope is cut into near-horizontal Paleocene sand, silt and clay (the sand is "rather soft"; Wilmott, 2020, p. 13), relatively easy to erode. The slope's southern sector diverges progressively farther westward from the missing wall's projected line, such that the projected southern end of the wall is ~60m east of the base-of-slope (Cunliffe, 1968b, fig. 33; Wilmott, 2012 inside back-cover map), implying that this sector of the slope continued to recede after the wall collapsed.

Repeating the flood-map exercise applied to Pevensey and Lympne forts (see Sections 4.2, 4.4), a 6m simulated SL rise again indicates that, during the Rottnest highstand, HSTL impinged on the Richborough slope (its base is ~4m above mean SL; Google Earth). On the +6m flood-map, Richborough hill becomes an island. Assuming a ~4m spring-tide range (cf. ~5m modern range at nearby Ramsgate), at low spring tide (+2m flood-map) the hill was evidently connected westward to the 'mainland' by a narrow neck, which happens to be the site of an excavated causeway of flint cobbles capped by mixed stones (including broken Roman bricks and tiles), resting on clay and draped (to surface) by ~40cm of "silt" (Ogilvie, 1968, fig. 14 and p. 37, 39) interpreted here as tidal, deposited during and after the Rottnest transgression.

Immediately northeast of Richborough, a low-lying, sinuous tract of land isolates the northeasternmost Kent peninsula, significantly still known today as the *Isle* of Thanet (Moody, 2008). Richborough fort lies part-way along this depression, nearer its SE end. Another Roman shore-fort, Reculver, lies at the NW end (Wilmott, 2012). The depression hosts 'back-to-back' rivers, the Wantsum and Stour, which flow in opposite directions, respectively NW and SE into the outer Thames Estuary and the English Channel. Hitherto the depression's geographic configuration (fluvial versus seaway) in Roman and Saxon times has been uncertain, but it is called the Wantsum Channel (Whittock, 1986; Pearson, 2002; Perkins, 2007; Moody, 2008). According to Ekwall (1960), the name Wantsum derives from an Anglo-Saxon word meaning "winding"; its first known use is in Bede's early 8thC book (Moody, 2008). Elucidating the geography, on the +6m flood-map, simulating 500AD (Early Anglo-Saxon) high spring tide, the Wantsum Channel is a throughgoing seaway. On the +2m map, simulating *low* spring tide, the channel is dotted with islets and interrupted by transverse land barriers in two places (including Richborough hill). The +2m map also represents 300AD (time of fort construction) *high* spring tide. Thus, Richborough and Reculver forts were built beside two embayments (one facing NW and the other SE), rather than beside a marine strait bisecting Kent.

Saxon mercenaries, hired by the king of the Britons to fight against Picts and Scots (intruding after the Romans' 410AD departure), supposedly landed at Ebbsfleet, in the SE bay, in 449AD (Myres, 1986). By that time, SL was ~1m higher than the ~300AD lowstand (Figure 1). Subsequent "silting up" of Wantsum Channel so that by 700AD it was, according to Bede, "only 645 yards wide" (Cracknell, 2005, p. 109) is consistent with low SL at that time (Figure 1). Subsequently, Fordwich, today landlocked at the end of a southwestern branch off the Wantsum Channel (e.g. see location on flood-map), was a port in Norman times, importing French building-stone for use in Canterbury Cathedral (built 1070-77AD [Cook, 1949]), attesting to the channel's navigability at that time (note SL was high, Figure 1). However, by ~1500AD the channel was narrow enough to build a bridge across it (Cracknell, 2005) at Sarre, near the modern Wantsum-Stour drainage divide, attesting to SL fall (cf. Figure 1 and Fairbridge Curve).

Consistent with a net fall in world SL (by ~1.5m on the Fairbridge Curve 1976 update) between 300AD (construction date) and today, Richborough fort, built beside the sea, is now well inland (like Lympne and Pevensey), *despite southern England subsidence* (~1mm/yr; see Section 4.2).

4.6. Fishbourne Roman seaside palace

On the south coast, 20km east of Portchester fort, Fishbourne Roman palace (construction spanned ~75-100AD; Cunliffe, 1971a) yields more evidence for the Rottnest transgression. The palace's southern wall was ~250m from the modern high-spring-tide line (Cunliffe, 1971c, fig. 2).

A late Roman or post-Roman SL rise is indicated by three trenches excavated by Cunliffe (1971a, fig. 51, cross-sections 2-4 and explanations on p. 204, 205, 211). The first trench, its northern end ~50m south of the palace's south wing, found a ~10cm gravel bed "closely dated to the Roman period by the fact that an early Roman well had been cut from the level of its surface" (p. 6; see location of the 'Well' indicated on fig. 39 map). "That a well could be dug so close to the sea is an interesting comment on the force of the fresh-water springs hereabouts" (p. 132; distance to dredged "Deep water channel" ~40m, p. 133 and fig. 39). The well was timber-lined and 1.8m deep (fig. 51, cross-section 2). Capping the gravel bed up to the modern ground surface are 25-50cm of "grey-brown silt, representing post-Roman flooding" (p. 6). The silt was interpreted as "estuarine" by Osborne (in Cunliffe, 1971b, p. 393), although no foraminiferal or other evidence for salt-water was reported. The grain size (silt), lack of rootlets (marsh plants) and proximity to the Roman harbour suggest intertidal deposition. Indicative of marine flooding on the landward (northern) flank of the palace too, the second trench (cross-section 3), terminating southward ~2m short of the north wing (Cunliffe, 1971a, figs 51, 60), found 35cm of silt described as (all the following quotations in this paragraph are from Cunliffe's p. 8) "dating to the third-fourth centuries" (evidence not stated) overlying the ground-levelling "make-up layers contemporary with the first-century building" of the palace, and pinching out sideways against a 1stC Roman gravel road (p. 205 and fig. 51, cross-section 3, layer 3). "The clogging of the stream may have been one factor in the periodic flooding north of the building; another of some importance was a general rise in sea-level in the late Roman and post-Roman period". In the third trench (cross-section 4), which abuts the south wing (fig. 60), a Roman make-up "terrace which lay between the building and the sea" is onlapped on its south flank by a silt bed up to at least 50cm thick (fig. 51, layer 3 at south end of cross-section 4). This bed "and indeed the flats which surround the harbour end, must have been the direct result of the sea-level change. Since the upper limits affected lie at about 13 ft. (3·96 m.) O.D., late or post-Roman high tides must have risen to at least this height ... Precise dating for the deposition of the silt layers is impossible, but sufficient evidence is now available from elsewhere in the country to show that flooding was beginning in the late Roman period [1]" (footnote 1 cites Cunliffe 1966, describing Somerset Levels, see Section 2). Instead of a late-Roman age, the silt, lacking datable artefacts, is attributed here to the Rottnest transgression (~430-500AD). Cunliffe's elevation (above) of 3.96m O.D. for the top of layer 3 needs raising ~1.5m to restore 1.5ky of southern England subsidence (~1mm/y; see Section 4.2), i.e. HSTL was at least +5.5m O.D., which is ~3.5m higher than modern HSTL at nearby Portsmouth (~+2m O.D.). Therefore, mean SL at 500AD was likewise at least ~3.5m higher than today, assuming unchanging tidal range (see Section 3.1). The same amount, ~3.5 m, was calculated for Pevensey fort (see Section 4.2).

By the time of the Rottnest transgression, Fishbourne had already been abandoned in the 4thC. "About 280-90 the occupied part of the building was destroyed by fire. Then followed a period of systematic demolition lasting into the early years of the fourth century" (Cunliffe, 1971a, p. xxvi). Of the "very small number of fourth-century coins recovered from the site all except one belong to the first quarter of the century ... The implication is that after c. 310-20 all activity had ceased ... Two questions need some consideration: what caused the fire and why was the building not re-inhabited? The fire could, of course, have been the result of an accident - a careless builder perhaps - but it remains a possibility that it might have been started by raiders. Fishbourne is very close to the sea and, judging by the number of coin hoards of the period deposited along the south coast, threat of pirate attack was in the air" (p. 192). "Events became so serious by the mid-280s that Carausius was appointed for the task of 'ridding the shores of Belgica and Armorica of pirates' - a briefing which clearly implies that the pirates had broken through the Straits of Dover and were raiding the southern shores. ... We are unlikely ever to know why the building was not re-occupied. Several factors would have had a bearing on the decision: the extent of the destruction may have made rebuilding impracticable, it may have been thought unsafe to live so close to an undefended shore and, of even more significance, *it seems that a rise in sea-level was causing flooding* (p. 193; emphasis added here). Cunliffe (1966) similarly invoked 3rd and 4thC SL rise in the Somerset Levels (see Section 2). In contrast, the London evidence shows falling SL from 50AD until ~350AD (Figure 1).

5. Discussion

5.1. Anglo-Saxon 5thC exodus to Britain: driven by Rottnest SL rise?

The Rottnest transgression, interpreted here as spanning 70y, ~430-500AD (see Section 3.2 and Section 4), may have been the main driver of the 5thC exodus to eastern Britain, underway by 450AD (based on skeletal-DNA; Curry, 2022), of Saxon and Angle communities fleeing their human-made village-mounds (e.g. https://en.wikipedia.org/wiki/Terp) on the coastal plain of present-day NW Germany. This 'Adventus Saxonum' (Keynes, 1984), the birth of English nationhood, is one of the world's greatest historical controversies (e.g. https://en.wikipedia.org/wiki/Anglo-Saxon_settlement_of_Britain). Immigrants settling in the central part of eastern England, including the region still called East Anglia, were mostly Angles, whereas Saxons went primarily to the southeast, including today's Essex and Sussex (Higham and Ryan, 2013). Among other evidence, archaeological studies of these dwelling-mounds (wurten in German; terpen or wierden in Dutch) reveal discontinuous occupation attributable to changes in SL, leading Behre

(2007, fig. 1) and Meier (2008, fig. 3) to each produce a SL curve showing oscillations of 1-2m in the last few thousand years. Both curves include a transgression identifiable, based on magnitude and timing, as the Rottnest (Table 1). According to Behre (2004, p. 47-48), "In the middle of the 5th century AD, the Feddersen Wierde and all the other Wurten were abandoned ... This coincides with population movement in the Migration period, when the Saxons emigrated from Lower Saxony to England. Extensive areas, in particular along the North Sea coast, were abandoned at that time".

Decades ago, Hawkes (1968, p. 229, footnote 3) pointed out that "a Romano-Saxon submergence ... is generally considered to be one of the principal reasons for the mass migration to Britain in the fifth century of Germanic peoples from the densely inhabited coastlands of north Germany and Holland"; she subsequently reiterated that 5thC mass-migration of refugee Anglo-Saxon "'boat people'" was driven by SL rise (Hawkes, 1982, p. 65). Similarly, Jones (2000, p. 29) stated that during the 440s and 450s, "a great impetus to the emigration of the Anglo-Saxons was the rising sea levels". But what prevented the migrants from simply moving eastward, inland? A likely explanation is that hostile Huns were advancing from the east (https://en.wikipedia.org/wiki/Migration_Period; map shows site of 451AD Battle of Châlons, western limit of Hun incursion). Thus, Anglo-Saxons may have been intolerably 'squeezed' between west-advancing Huns and rapid eastward shore-retreat (~300m/y, assuming 4m SL rise in 70y, which would have caused the high-spring-tide line to migrate ~20km across the nearly-flat coastal plain [verify using https://flood.firetree.net]). Anglo-Saxon immigration into eastern Britain was apparently unopposed militarily. A likely explanation is rebellion (Myres, 1986) by the Saxon mercenaries (see Section 4.5), who soon subjugated the native Britons of that region. "By the middle of the century large tracts of eastern and midland England had been taken over by the English" (Hawkes, 1982, p. 65). A more precise date of 441AD was deduced by Jones and Casey (1988).

A similar case of human displacement by rising SL has been proposed in Florida, where the same transgression (named Wulfert there; Table 1) was invoked by Walker (2000) to explain 300-500AD coastal depopulation and landward migration.

5.2. London occupation hiatus and Lundenwic enigma

According to Cowie and Blackmore (2012, p. 200-201), "Archaeological evidence recorded on literally hundreds of expertly excavated sites strongly suggest that Londinium was abandoned at the time of the Roman military withdrawal or soon after". Similarly, archaeologically near-barren "early and middle Anglo-Saxon silt" excavated in front of the riverside wall "implied little or no permanent local post-Roman occupation until about the mid-ninth century" (Ayre and Wroe-Brown, 2015a, p. 129).

Cowie and Blackmore (2012, p. 201) attributed London's early-5thC abandonment to "its role as a market and an imperial administrative and military centre having ceased". An alternative interpretation is that, from ~430 to 500AD (Rottnest transgression), with high-spring tide reaching ever-higher up the estuary-side wall due to the Rottnest transgression, the ~250AD Roman wall-front quay (Milne, 1985, fig. 7) became inoperable (underwater) for an increasing portion (eventually 100%) of the 24-hour day. If the tidal range was only ~2m (see Section 3.1), it follows that during the ~500AD Rottnest peak, when HSTL reached at least 3.3m above the lowest-known wall-base (Figure 1, Data-points 14, 16), there would have been no foreshore throughout the day, preventing boat-beaching, even at low tide. The same would have applied for several decades before and after 500AD (cf. Figure 1).

At about the same time, around 450AD, west-migrating Saxons (displacing native sub-Roman Britons?) began to settle upstream in the Thames valley (Booth et al., 2007), including a new beach-front settlement (at modern London's 'The Strand', <1km from walled London's western edge; Ayre and Wroe-Brown, 2015a, illus. 2 map), first occupied by Saxons in the middle 5th C (Cowie and Blackmore, 2012), and later called Lundenwic (see below). Regarding the Early Saxons' avoidance of London, McCourt (2010, p. 214) asked "why did they pass up a relatively easy task of rebuilding a ready-made city?". The city's other apparent advantages were that it was an almost uninhabited "ghost town" (McCourt, 2010, p. 213; Cowie and Blackmore, 2012, p. 201) and easily defendable by virtue of its encircling Roman wall. McCourt (2010, p. 214) suggested that "The city might have seemed an alien, hard environment constructed out of stone". An arguably better explanation, again, is the lack of 24-hour boat beaching, unlike the unconfined estuary-shore at the proto-Lundenwic site, as depicted in an artist's reconstruction of Lundenwic in the 7th/8thC (Cowie and Blackmore, 2012, fig. 100), by which time wharves existed there (cf. late 7thC timber waterfront excavated by

Cowie, 1992; Data-point 18 in Figure 1). Dyson (1990, p. 101) interpreted the Saxons' preference for The Strand as follows: "There is at present no clear explanation for the phenomenon, common at this date around the coasts of the North Sea, of new urban settlements (wics) adjacent to ancient centres, but in the case of London one obvious attraction at least would have been the greater spaciousness and adaptability of the Strand's eponymous foreshore and its freedom from the physical constraints of the mouldering Roman city, particularly of its waterfront."

The new site grew into a Middle Saxon proto-urban settlement by the late 7thC (age of the earliest-known written references to the name Lundenwic and "port of London"; Cowie and Blackmore, 2012). Lundenwic was abandoned in the 9thC, whereas London became repopulated (Cowie and Blackmore, 2012), probably by former Lundenwic residents seeking protection from Viking raids (Inwood, 1998). By 900AD, HSTL had fallen by ~3m (from its ~500AD highstand), reaching as low as ~0.3m O.D. (Figure 1), lower than the base of the estuary-side wall in every excavation (Parnell, 1978, p. 172; Miller et al., 1986, fig. 4; Hill et al., 1980, figs 16, 19) except one (Brigham, 1990, fig. 10.2; Data-point 14 in Figure 1), enabling 24-hour boat-beaching along much of the wall.

5.3. Any written record of Rottnest transgression?

Except possibly the 'Groans of the Britons' (below), the author is unaware of any reported mention of a 5thC SL rise in contemporary writings from anywhere in the world. Possible reasons include:

1) deliberate elimination of written records. Libraries, in particular, have always been liable to destruction by invaders or rebels (e.g. Ovenden, 2020). For example, Vikings burned the library of York Cathedral in 867AD (Norman, 2025). Of Anglo-Saxon England's magnificent illustrated manuscripts, "only a tragic few survived the Viking attacks and the vicissitudes of a thousand years" (Hills, 1980, p. 81). Little or no 5thC literature written in Britain is known to have survived (Blair, 1984), partly due to such vandalism;

2) a ~4m SL rise in 70y equals nearly 6cm/y (annual average), far from life-threatening. For literate seafaring cultures of the time (e.g. Rome, Byzantium, India, China), such a rate would certainly have been inconvenient (e.g. need to raise wharves every 10-20 years), but unlikely to excite much written comment in an era of frequent

war, plague and famine. In addition, circum-Mediterranean countries were (as now) under constant threat of occasional natural disasters (earthquakes, volcanic eruptions, tsunamis); and

3) the Fairbridge Curve shows that, between 5,000BC and 1,000AD, it was generally the *norm* for SL to rise or fall rapidly (>2cm/y) for centuries, i.e. for multiple human generations. Such SL behaviour, imprinted in folk memory, is unlikely to have caused alarm.

The 'Groans of the Britons' (e.g. Wikipedia), a lost 5thC document quoted by Gildas in his renowned 6thC manuscript, perhaps refers indirectly to the Rottnest transgression. The Groans document, interpreted to have been written sometime between 425 and 454AD (Snyder, 1998, p. 259), says "The barbarians drive us to the sea, the sea drives us to the barbarians" (translated from Latin). The unknown writer was possibly a monk in Beckery (near Glastonbury, SW England), where carbon-dates on seven male skeletons from a cemetery of more than sixty individuals, almost all adult males, suggest that this site is the earliest-known monastery in Britain, which "may have begun in the later 5th century and possibly even at the end of the 4th century" (Brunning, 2021, p. 84). Perhaps Beckery, at the eastern edge of the broad Somerset Levels coastal plain (see Section 2), was squeezed in the late 5thC between west-advancing Saxons (ironically) and rapid, Rottnest-driven, eastward shore-retreat. A Saxon-style throwing-axe of ~450-550AD found 30km east-northeast of Beckery contradicts the general consensus that the Saxons did not reach this far west until the mid-7thC (https://www.bbc.co.uk/news/uk-england-somerset-64967007).

Weak *anecdotal* support for the Rottnest transgression and its age comes from western Wales, at Sarn Badrig, a shingle bank ~20km long exposed at low tide, where "Tradition says, that all this part of the sea had been a habitable hundred, called *Cantrér Gwaelod*, or *The Lowland Hundred*; and that it was overwhelmed by the sea about the year 500" (Pennant, 1781 [sic], p. 113).

5.4. Cause of Rottnest rise and ensuing fall

Such a large, rapid transgression can only be explained by an Antarctic ice-cliff-collapse event, probably reflecting a solar-driven(?) known Arctic warm spike ~400AD ('overwarmed' Arctic seawater carried to Antarctica by 'conveyor-belt' ocean circulation?), portending another m-scale rise before ~2100, because Arctic average annual surface-air temperature, boosted anthropogenically, has since 2005 continuously exceeded the ~400AD spike (Higgs 2024, 2025b).

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