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Quaternary Earth-science and Palaeolithic conservation initiatives in the Tejo (Tagus), Portugal: Comparison with the Lower Thames, UK

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A B S T R A C T

Geoconservation measures in the River Tejo, the Portuguese reach of the Tagus, are compared with those in the Thames downstream of London (UK). Both are fluvio-estuarine reaches with staircases of Pleistocene depositional terraces, each with important sedimentary, palaeontological and archaeological records. In both rivers, conservation measures are in place that aim to protect these records, promote research and inform the public. Inevitably there are differences in approach. Whereas Thames Quaternary interests are protected by a network of British statutory site designations, outreach is to the fore in the Tejo. Contrasting examples are highlighted here. The Tejo has interpretative materials in local museums and detailed explanatory displays at the low-terrace archaeo-geological site of Foz do Enxarrique, near the border with Spain, and at other sites. The Thames, in contrast, has few examples of physical outreach provision and limited formal protection for Pleistocene archaeological material outside the geological network, although extensive informal protection is provided by interaction between local geological groups and county and local-authority administrations. There is also a considerable difference in the degree of threat, with the Tejo above Lisbon being a relatively undeveloped valley, albeit with sporadic quarrying for aggregate, whereas the Lower Thames is an established area for infrastructure development, lying to the east of London, close to the river crossing of the orbital motorway. The different climate in the two regions profoundly influences the longevity of exposures in Quaternary deposits, with significant implications for management strategies. The comparison exercise reveals that each region would benefit from greater development of approaches used more prominently in the other; outreach measures in the Portuguese style would greatly enhance some of the Thames sites, but formal designation of Tejo exposures could prevent damaging operations being undertaken by owners who lack knowledge of their value, as exemplified by a case study of sites at Alpiarça, ~130 km upstream from Lisbon.

1. Introduction

Collaboration between researchers in Britain and Portugal with mutual interests in the Quaternary evolution of the primary rivers in their respective countries has revealed contrasting approaches to geoconservation in the two systems, each largely successful and appropriate for the differing requirements and threats. This paper seeks to provide a comparison between these approaches in the context of the Quaternary records from the Tejo (Lower Tagus) in Portugal and the Lower Thames, UK, as a contribution to the thematic issue 'Valuing the Quaternary: nature conservation and geoheritage'. In particular, the mechanisms in place for the conservation of geosites and geodiversity related to the Quaternary evolution of these two rivers will be examined, with reference to differences and similarities in associated evidence for palaeoenvironments, faunal turnover and hominin occupation. Successful geoconservation is crucial for the future studies that will enhance knowledge of these important records, which will be of value in understanding and combatting the negative impacts of global environmental change or land-use change.

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Combinations of influences from glacio-eustatic variations in sea level, climatic control of fluvial activity and regional uplift have variously driven the formation of terrace staircases in both these systems, through the alternation of incision, dynamic equilibrium and aggradation phases (*e.g.*, Cunha et al., 2008, 2012, 2017a; Martins et al., 2009, 2010; Bridgland and Westaway, 2014; Bridgland et al., 2014). An important similarity between the Quaternary records from the Tejo and the Thames, and one of significance for their geoconservation status, is that both include an important Lower and Middle Palaeolithic artefact component, evincing early human occupation. This has led to the terrace deposits of each of the rivers attracting the attention of archaeologists as well as Earth scientists, with, for example, the leading mid-20th Century specialist, l'Abbé Breuil, contributing to the study of both (Breuil and Koslowski, 1932; Breuil and Zbyszewski, 1942, 1945). It also places research on the Quaternary evolution of these two rivers, as well as the geoconservation of important aspects of their fluvial archives, within the area of overlap between the disciplines of Earth science and archaeology, an interaction that has been discussed in a previous special issue in this journal (Bridgland, 2013; Last et al., 2013). In the Thames, the Lower–Middle Palaeolithic archive is exceptionally substantial, constituting in excess of 50,000 artefacts representing a variety of different industries and cultures, almost entirely using Cretaceous flint as the raw material (*e.g.*, Wymer, 1968; Roe, 1981; Morigi et al., 2011; Pettitt and White, 2012); as such it represents a template for the early archaeological record in Britain and NW Europe (Bridgland et al., 2006; Mishra et al., 2007; Bridgland and White, 2014, 2015; Chauhan et al., 2017; White et al., 2018) and includes an international Lower Palaeolithic type locality, which corresponds with a statutory geosite, a geological SSSI (Site of Special Scientific Interest) at Clacton-on-Sea, Essex (Breuil, 1932; Warren, 1955; Bridgland, 1994; Bridgland et al., 1999; White et al., this issue). In the Tejo the artefacts invariably use (ortho)quartzite, a raw material inferior to flint but plentiful in the coarse bedload gravels laid down by that river in its Pleistocene terraces.

1.1. Geomorphology

The Tejo (Fig. 1) is one of Europe's great rivers, the longest (~1000 km) on the Iberian Peninsula. In Spain it is called Tajo and is ~700 km long. It forms about 47 km of the border with Portugal (International

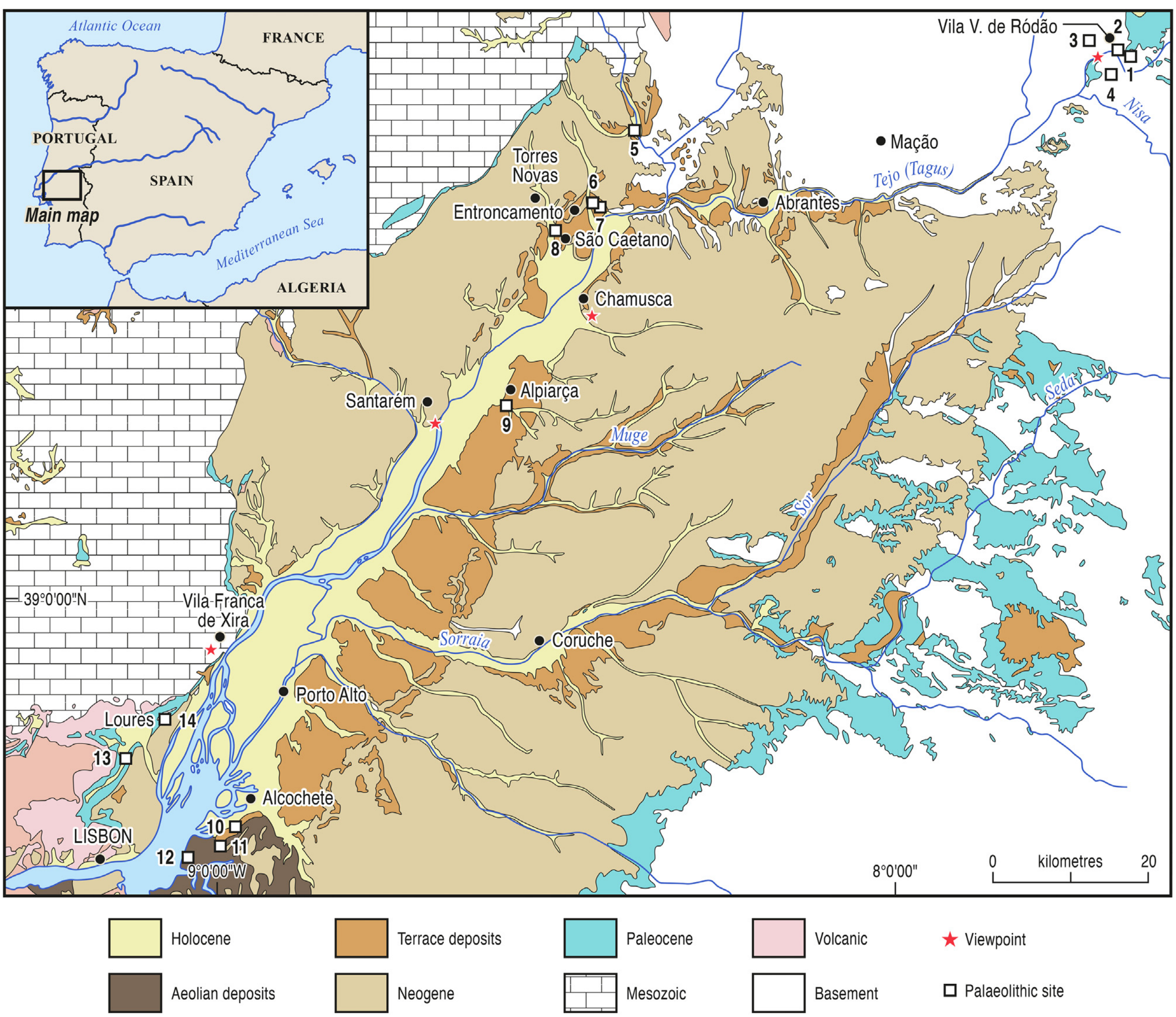


Fig. 1. The River Tagus. Main map shows the location of sites described in the text. The inset shows its location within the Iberian Peninsula. Squares indicate Palaeolithic sites: 1 – Monte do Famaco; 2 – Foz do Enxarrique; 3 – Vilas Ruivas; 4 – Conhal do Arneiro; 5 – Santa Cita; 6 – Ribeira da Ponte da Pedra; 7 – Atalaia (Vila Nova da Barquinha); 8 – Riachos; 9 – Vale do Forno (Alpiarça); 10 – Cascalheira; 11 – Conceição; 12 – Base Aérea do Montijo; 13 – Santo Antão do Tojal; 14 – Esteio da Princesa. Red stars indicate the selected viewpoints: Portas de Ródão gorge (Vila Velha de Ródão); Sra. do Pranto (Chamusca); Portas do Sol (Santarém); and Monte Gordo geodetic landmark (Vila Franca de Xira).

Tejo/Tajo), from the confluence of the River Erges to the Cedillo dam, situated 15 km upstream of the small town of Vila Velha de Ródão. There, the river passes through, in a gorge (formed by superimposition) named 'Portas de Ródão', ridges of resistant Ordovician quartzites. On account of its grandeur, beauty and scientific interest, the Portas de Ródão is classified as a Natural Monument.

Upstream–downstream geomorphological differences between the Spanish 'Tajo' and the Portuguese 'Tejo' are several: in Spain the Tajo has up to sixteen terraces (Santonja and Pérez-González, 2000–2001; Santisteban and Schulte, 2007; Silva et al., 2017; Karampaglidis et al., 2020) in an impressive staircase incised largely into the Cenozoic sediments filling the Madrid Basin, these representing the sedimentary record of endorheic fluvial systems that drained the central area of the Iberian Peninsula at least until the end of the Zanclean, ~3.7 Ma (Cunha et al., 2019; Karampaglidis et al., 2020). In Portugal the Tejo terrace system has a maximum of six levels (*e.g.*, Cunha et al., 2005, 2008, 2012, 2017a, 2017b, 2019; Martins et al., 2010; Fig. 2), again recording downcutting into basin-fill, here representing the Lower Tejo Cenozoic Basin (LTCB; Cunha, 2019), re-opened to the Atlantic since ~3.7 Ma (*e.g.*, Gouveia et al., 2020). The LTCB also contains superficial fluvial sediments that are inset into the basin-fill and record breaks in the otherwise progressive incision from the culminant surface of the basin to the present river bed; these are the river terraces of the Portuguese Tejo (Cunha et al., 2008, 2017a; Martins et al., 2009, 2010; Rosina et al., 2014).

The Thames has also incised its valley into the fill of a Cenozoic depocentre: the Palaeogene sediments of the London Basin. This synclinal basin was inverted in the mid-Cenozoic (Bridgland et al., 2020). The Thames can be shown to have been a significantly larger system in the early Quaternary, with headwaters in the English Midlands, and perhaps the Welsh Borders and parts of Wales (Bridgland, 1994; Rose, 1994), as well as a more northerly course that extended across East Anglia (Rose et al., 1976, 1999; Hey, 1980; Rose, 1994; Allen et al., 2022); the present-day Thames has only 35 % the length [346 *versus* 1007 km] and 20 % the catchment area [16,200 *versus* 78,467 km^2] of the Tagus (Tajo–Tejo combined). In its present reduced form it remains the axial river of the London Basin syncline but also receives a substantial upper headwater system from the north-west. Draining from the Jurassic Cotswolds dip-slope, this Upper Thames enters the Basin through the Goring Gap, a short, incised reach through the Chilterns chalk escarpment (Fig. 3). During Pleistocene sea-level lowstands, the Thames has been a tributary of the much larger Rhine, feeding into a Rhine–Thames delta (Cameron et al., 1992) prior to MIS 12 and then flowing through the English Channel after the Strait of Dover was formed by glacial-lake overflow during that glacial stage (Gibbard, 1995; Bates et al., 2003; Westaway and Bridgland, 2010).

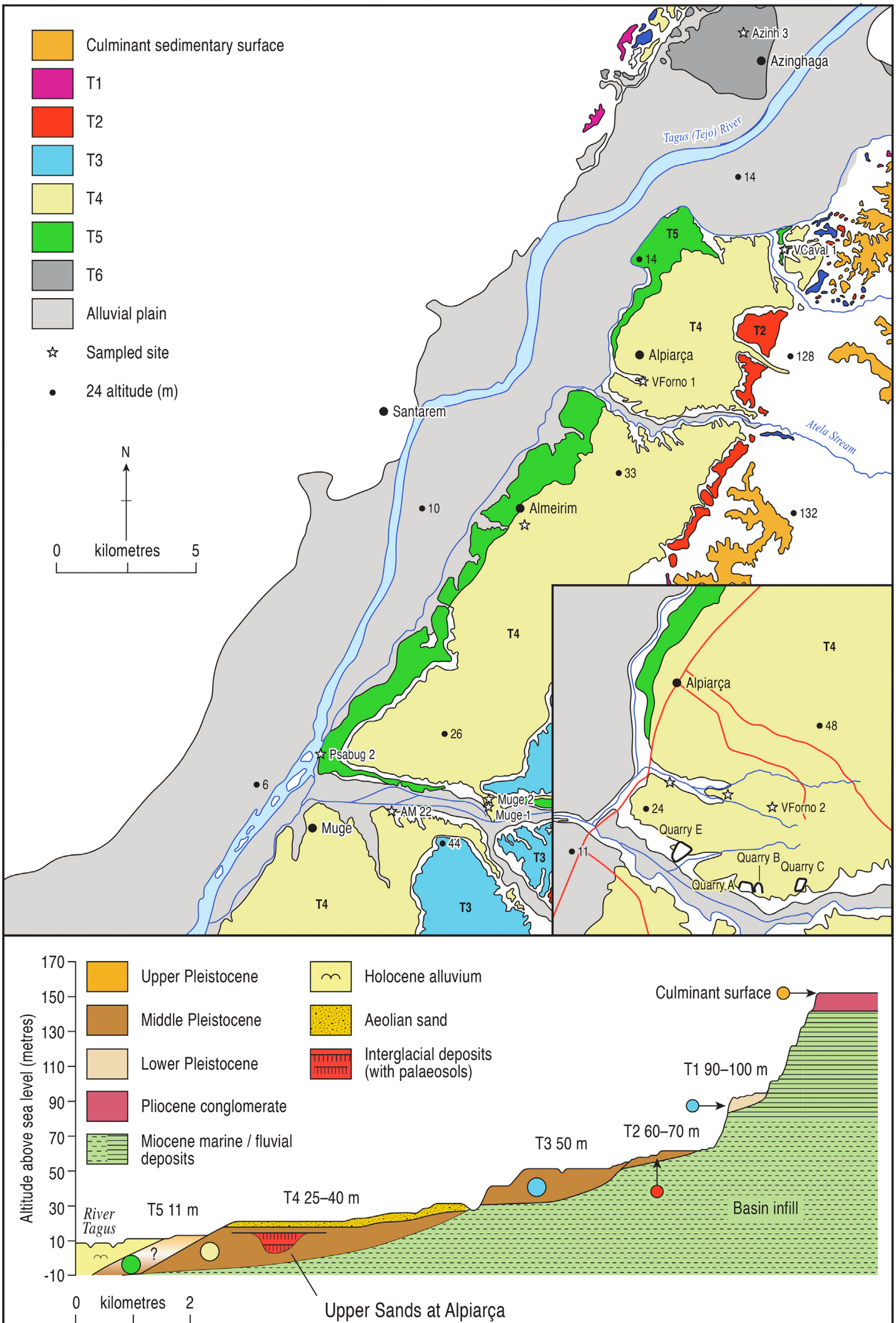
Quarry exposures of river-terrace deposits fare rather differently in the Tejo and Thames. The UK climate leads to weathering of unconsolidated sediments and rapid accumulation of talus, with subsequent vegetation development, rapidly obscuring exposures, whereas the hot summers and 'flashier' precipitation in the Tejo valley cause less rapid talus build-up and the gullying of sun-baked sediments, which, if anything, improves access to their geological features (Fig. 4). Nonetheless, even if the hot Mediterranean summers contribute to longer-lasting outcrops, the intense winter rains and the vigorous character of runoff and flooding can make their long-term preservation difficult.

1.2. Geoarchaeology

As already noted, Lower and Middle Palaeolithic artefacts are important components of the sedimentary archives of both these rivers and, as such, can perhaps be regarded as 'trace fossils' (*cf.*, Bridgland and White, 2018). In the Tejo, supposed 'Early Acheulian' industries were found at Alpiarça (Breuil and Zbyszewski, 1942, 1945), Monte do Famaco, at Vila Velha de Ródão (Raposo et al., 1993), and at the Ribeira da Ponte da Pedra, in Vila Nova da Barquinha (Grimaldi and Rosina, 2001; Martins et al., 2010; Oosterbeek et al., 2010). The Lower Gravels division of the T4 terrace, yielding rare artefacts that are the oldest from the Tejo sequence, are older than 300 ka (Cunha et al., 2017a, 2017b) and perhaps as old as ~400 ka, taking into account the dated hominin skull from a nearby cave (Daura et al., 2017). The typical Acheulian archaeological levels have been dated as ranging between ~300 and 200 ka (Cunha et al., 2017a). Middle Palaeolithic industries abound on the lower terraces of the Tejo, between Vila Velha de Ródão and the estuary at Lisbon (Raposo, 1995a, 1995b, 1996; Raposo and Cardoso, 1998). An interesting detail concerning the Palaeolithic industries found in the Tejo valley is an apparent preference for repeated occupation of the same locality, giving some continuity in human presence in selected places since the Lower Palaeolithic, during the Middle Palaeolithic and, in some cases, continuing into Upper Palaeolithic and Mesolithic times. The different archaeological sites within the depression of Vila Velha de Ródão show this particularity well. It is also seen at Alpiarça, where late Acheulian succeed early Acheulian industries (Mozzi et al., 2000; Cunha et al., 2017a).

The Thames terrace sequence has long been renowned as an archive of palaeo-environmental evidence, particularly from sedimentary and faunal indicators, and for the provision of a morphostratigraphical record of the evolution of the river; these data were summarized in the mid-20th Century by Zeuner (1959), since when further work has enhanced understanding (*e.g.*, Gibbard, 1985; Bridgland, 1994, 2006, 2010). The Middle Thames valley, ~50 km upstream of London, preserves the most complete record of Pleistocene terraces, with a rich Palaeolithic artefact content representing human occupation during the last ~0.5 Ma (Wymer, 1968, 1988, 1999; Roe, 1981). This is the reach of the Thames with a terrace record most similar to that in the Tejo: the sands and gravels are rich in artefacts but faunal remains are scarce. In contrast, the faunal record in the Lower Thames, within and downstream of London, is exemplary, with each of the four interglacials of the past 0.5 Ma well represented (Bridgland, 1994, 2006; Bridgland et al., 2003; Fig. 5). The Lower Thames also has a plethora of important Lower and Middle Palaeolithic sites, many yielding large numbers of artefacts and some with primary-context preservation. These include the MIS 11 and MIS 9 Clactonian and Acheulian localities (White and Schreve, 2000) at Swanscombe, Clacton, Purfleet and Little Thurrock (see Online Supplement 2; see also White et al., this issue) as well as early Middle Palaeolithic MIS 8/7 Levalloisian sites at Baker's Hole and Lion Pit Tramway Cutting. Taken together this group of sites, well represented amongst the designated geosites (see below), has been instrumental in forming a clear picture of the Pleistocene settlement history of the British Isles and non-linear changes in material culture through time (Bridgland and White, 2014, 2015; White et al., 2018, 2019). The importance of the numerous museum collections, amassed predominantly during the era of hand excavation of gravel pits and representing another form of archaeo-geological conservation, in providing the archival material to make such advances cannot be overstated (*cf.*, Dale et al., this issue).

In the Tejo, the lithological characteristics of the terraces, being composed of siliciclastic deposits, do not generally favour fossil preservation. However, at the archaeo-geological sites of Foz do Enxarrique (Vila Velha de Ródão) and also at Esteiro da Princesa and Santo Antão do Tojal (Loures), near Lisbon, fossil bones of relevant megafauna and smaller animal species are preserved in fluvial deposits of the Tejo terraces (Raposo et al., 1985; Cardoso, 1993; Raposo, 1995a; Sousa and Figueiredo, 2001; Figueiredo and Sousa, 2003, 2005; Figueiredo, 2012; Cunha et al., 2019). Geochronological methods, in particular optically stimulated luminescence (quartz-OSL and pIRIR), electron-spin resonance (ESR) and U-series dating, have provided a temporal framework for the Tejo terrace sequence, as summarized most recently by Cunha et al. (2017a). In turn, such dating methods have been applied sporadically in the Thames (*e.g.*, Bridgland et al., 2013; Voinchet et al., 2015); the age model for the Lower Thames is, however, substantially derived from



Culminant sedimentary surface
T1
T2
T3
T4
T5
T6
Alluvial plain
Sampled site
24 altitude (m)
N
0 kilometres 5
Azinh 3
Azinghaga
Tagus (Tejo) River
14
T5
VCaval 1
T4
T2
128
Alpiarça
VForno 1
Santarem
Atela Stream
33
10
Almeirim
132
T4
26
Psabug 2
6
Muge 2
Muge 1
AM 22
Muge
44
T3
T4
T3
48
24
VForno 2
Quarry E
11
Quarry B
Quarry C
Quarry A
Altitude above sea level (metres)
170
150
130
110
90
70
50
30
10
-10
Upper Pleistocene
Middle Pleistocene
Lower Pleistocene
Pliocene conglomerate
Miocene marine / fluvial deposits
Holocene alluvium
Aeolian sand
Interglacial deposits (with palaeosols)
Culminant surface
T1 90–100 m
T2 60–70 m
T3 50 m
T4 25–40 m
T5 11 m
River Tagus
Basin infill
0 kilometres 2
Upper Sands at Alpiarça

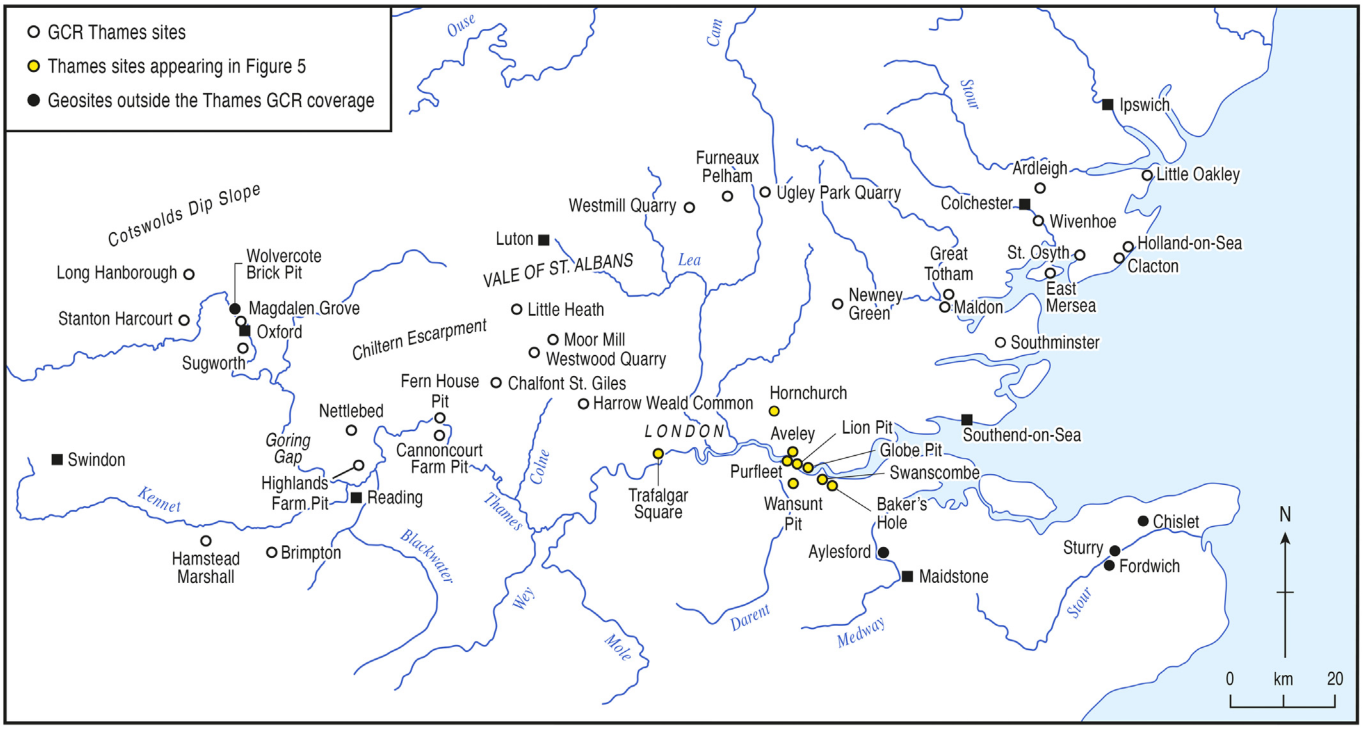


Fig. 3. Locations of Lower Thames geosites (yellow-infilled circles) within the context of the wider distribution of 'Quaternary of the Thames' GCR sites (open circles) and Thames and Thames-tributary GCR sites within wider coverage (solid back circles). For more detailed explanation, see Supplement 2 (online), Fig. S2.2.

biostratigraphy (*cf*., Schreve, 2001; White et al., 2013), with strong support from amino acid racemization dating (Penkman et al., 2011, 2013).

1.3. Conservation of geosites and archaeo-geosites

In Portugal, the mechanisms for legal protection of geological and archaeological heritage are quite broad, but archaeological heritage is the better defended of the two. The legal basis of cultural heritage, Law No. 107/2001 (September 8, 2001), establishes archaeological and palaeontological heritage as cultural heritage and defines the legal mechanisms for its protection (https://dre.pt/dre/detalhe/lei/107-2001-629790). For archaeological sites, there is a greater variety of national legislation aimed at regulating archaeological activity and the protection and preservation of archaeological heritage. Amongst this can be mentioned the Regulation of Archaeological Works (Decree Law No. 164/2014 of November 4, 2014: https://dre.pt/dre/detalhe/decreto-lei/164-2014-58728911). At the municipal level there are also 'Municipal Master Plans' (PDM, in the Portuguese shortening), which is a fundamental legal instrument in the management of municipal territory for the designation of protected areas, including archaeological and geological sites. The agency of the state responsible for the classification of geosites and the management of geological heritage is the Institute for Conservation of Nature and Forests (ICNF), whereas that which manages archaeological activity and protects archaeological heritage is the Directorate General of Cultural Heritage (DGPC). The most widely used designation for classification of geological heritage (national or local) is that of Natural Monument. The full list of existing designations comprises National Park, Natural Park, Natural Reserve, Protected Landscape and Natural Monument; with the exception of the 'National Park', protected areas of regional or local scope may adopt any of the typologies referred to above, and these must be accompanied by the prefix 'Regional' or 'Local', as appropriate ('Regional' when more than one municipality is involved, 'Local' when only one municipality is involved).

There is also the classification 'geosite' ('geossítio'), which has only non-statutory status. A geosite corresponds to a place where geological heritage occurs; *i.e.*, where one or more elements of geodiversity (which may be minerals, rocks, soils, fossils, waters, relief forms or active geological processes) have been considered as having high scientific value. They may also have other types of value (aesthetic, ecological, cultural, economic). The attribution of legal protection status to geosites must comply with the concept of creating a protected area (PA), following the existing legislation for nature conservation in Portugal, namely the procedures described in the Legal Framework for Nature Conservation and Biodiversity, established by DL 142/2008, of 24 July, with modifications introduced by DL 242/2015, of 15 October (https://dre.pt/dre/detalhe/decreto-lei/242-2015-70693924?_ts=1675987200034). The designation of Protected Areas at national level may be proposed by the national authority (ICNF) or by any public or private entities; the technical assessment belongs to the ICNF, and the classification is decided by the relevant authority. In the case of Protected Areas of regional or local scope, the classification may be carried out by municipalities or associations of municipalities, subject to the conditions and terms set out in Article 15 of the above-mentioned legislation.

By these combined means, several Palaeolithic archaeological sites and Quaternary or geomorphological geosites in the Tejo are formally protected.

Coverage of Thames Quaternary geosites, including those with an overlapping importance within Palaeolithic archaeology, was overhauled as part of the Geological Conservation Review (GCR), an exhaustive programme of re-evaluation and reinforcement of statutory geosite coverage that took place from the late 1970s onwards (Ellis et al., 1996; Ellis, 2011). The GCR of the Thames Quaternary culminated

Fig. 2. The terraces of the lower Tejo. The main map is modified from Cunha et al. (2017a). The upper inset is an enlargement of the area of old quarries at Alpiarça (see text and Online Supplement 2, Section 3). The lower inset shows an idealized transverse section through the terraces of the illustrated reach of the Tejo (modified from Bridgland and Westaway, 2014.

Fig. 4. Section in Terrace 4 gravels and sands of the Lower (Portuguese) Tagus at Vale de Atela, Alpiarça. Photo: David Bridgland, 2016, during an annual field trip visit of Durham University first-year geographers, who are trained in sediment analysis using these sections (see also Online Supplement 1, Section 3).

in the publication of a monograph (Bridgland, 1994), although later elements of the programme are being published as special issues of this present journal.

2. (Archaeo-)Geoconservation measures

2.1. Tejo

Studies of the Pleistocene terraces of the Lower Tagus and the evidence for human occupation preserved therein allow the reconstruction of the environments and climates of that time, as well as the interpretation of the strategies of the human occupants and their adaptations to the hydrographic and geomorphological conditions. The evolved Acheulian industries of Terrace T4 at Alpiarça, with an age range of ~ 300–200 ka, were mainly collected from floodplain (*e.g.*, overbank and oxbow) deposits (Cunha et al., 2017a, 2017b). The archaeological sites of Vale do Forno (T4), Ponte da Pedra (T4), Vilas Ruivas (T4), Santo Antão do Tojal (T5) and Foz do Enxarrique (T5 and T6) are located near to confluences of small tributaries with the main river (Fig. 1), where animals were going to drink and potentially were easily hunted (Raposo, 1995a; Figueiredo, 2012; Figueiredo and Raposo, 2018; Pereira et al., 2019; Figueiredo et al., 2021). Those places also offered, in addition to drinking water, specific biotic resources that were reduced during the colder episodes in other places outside the valley. The Foz do Enxarrique archaeological site, in the Vila Velha de Ródão depression, appears to have been one of the last refuges for both Neanderthals and megafauna in this southwestern part of Europe (Cardoso, 1993; Raposo, 1995a; Brugal and Raposo, 1999; Figueiredo and Raposo, 2018; Figueiredo et al., 2021). The aggradation intervals represented by the younger Pleistocene units are estimated as ~136 to 70 ka (T5), 62 to 32 ka (T6) and 32 to 12 ka (cover unit of aeolian sands). Thus warm (interglacial or interstadial) conditions predominated during MIS 5e (128–116 ka) and MIS 3 (58–44 ka), whereas cold and dry climate (glacial) conditions dominated during MIS 4 (71–59 ka) and MIS 2 (29–12 ka). It is worth noting that the Mousterian industries and megafauna of the Foz do Enxarrique level were dated to 44 $\pm$ 3 ka (Cunha et al., 2019). This age coincides with the transition from the relatively mild conditions of Greenland interstadial (GI) 12, ~46.8–44.4 ka, to full-glacial conditions during Greenland stadial (GS) 12, ~44.2–43.3 ka (Rasmussen et al., 2014). The abrupt climatic changes during the Last Glacial period, the Dansgaard–Oeschger (D–O) cycles, could have been important in the disappearance of the megafauna and in the replacement of the Middle Palaeolithic industries of the Neanderthals by the Upper Palaeolithic industries of the more culturally evolved modern humans.

2.1.1. Museums and other relevant Pleistocene heritage initiatives

2.1.1.1. The Museum of the Portuguese Centre of Geo-History and Prehistory. This valuable initiative is an achievement of the Portuguese Centre of Geo-History and Prehistory (CPGP), recognized by the Portuguese government since 2017 as a public utility institution with the aim of developing scientific research and dissemination in Earth and life sciences and the humanities. In 2013, the CPGP founded a small museum and library in a disused primary school (Fig. 6), with exhibits spanning geology, palaeontology, geomorphology and archaeology (Figueiredo et al., 2018, 2020; see Supplement 1, online; Fig. S1.1). The museum is on the right bank of the Tejo, in the small village of São Caetano, Municipality of Golegã, 110 km NNE of Lisbon. It aims to show, in an educational and interactive way, the evolution of life and of humanity (physical, cultural and technological). Highlights of relevance here are Palaeolithic artefacts, including replicas of some of the most impressive finds from sites such as Vale do Forno (see above).

2.1.1.2. Centro de Interpretação de Arte Rupestre do Vale do Tejo (CIART). Established in 1984 in the old town hall at Vila Velha de Ródão, the CIART houses permanent exhibitions on (1) aspects of the archaeology of the Ródão region and (2) the rock art of the Tejo. The archaeological exhibition documents the Tejo terraces and modern valley floor, with geological specimens, fossils and prehistoric artefacts included, whereas the Tejo rock art exhibition includes engravings rescued prior to inundation by the Fratel reservoir, as well as replicas (see Supplement 1, online; Fig. S1.2).

2.1.1.3. Museu de Arte Pré-Histórica e do Sagrado do vale do Tejo. The collections of this museum, located in the town of Mação, cover natural history, ethnography, religious art and archaeology (see Supplement 1, online; Fig. S1.3). It also has a conservation section and has developed several didactic activities, especially in the area of experimental archaeology (Oosterbeek, 2009).

2.1.1.4. The Várzea de Loures area. Located ~8 km NE of Lisbon, on a terrace of the River Trancão at its confluence with the Loures tributary, the Várzea de Loures is of significant value in terms of archaeological (especially Palaeolithic), paleontological and geological heritage. There are a few dozen Palaeolithic sites in this area, amongst which Esteiro da Princesa stands out; here, in the 1940s and 1970s, remains of *Palaeoloxodon antiquus* were discovered associated with lithic artefacts (Zbyszewski, 1943, 1946, 1977; Sousa and Figueiredo, 2001). The rich archaeological and geological heritage of this area, and its proximity to Lisbon, gives it considerable potential for projects of cultural and environmental value (Figueiredo et al., 2005; for further details, see Supplement 1, online).

2.1.1.5. The Natural Monument of Portas de Ródão. Established in 2009, mainly for its geomorphological relevance (Gouveia, 2009; Cunha et al., 2020), this natural monument includes a spectacular gorge through which the Tejo traverses a ridge of NW–SE oriented highly resistant quartzite strata (Supplement 1, online; Figs. S1.4 and S1.5). Amongst other relevant features, there are also elements of the terrace sequence, an exhumed part of the Ponsul fault (crossed by the Tejo), outcrops of the Cenozoic sedimentary basin-infill and a panoramic view of the 'Southern Portugal Planation Surface'. The Tejo terraces at Vila Velha de Ródão, just upstream of the Portas de Rodão gorge, form one of the best-developed staircases on this, the largest Iberian river, and are thus of considerable scientific value (Cunha et al., 2005, 2008, 2012, 2019; Pereira et al., 2015). The international significance of the Tejo gorge along the Portugal–Spain border is recognized in Spanish and Portuguese geoheritage inventories (*e.g.*, Brilha et al., 2005; Pereira et al.,

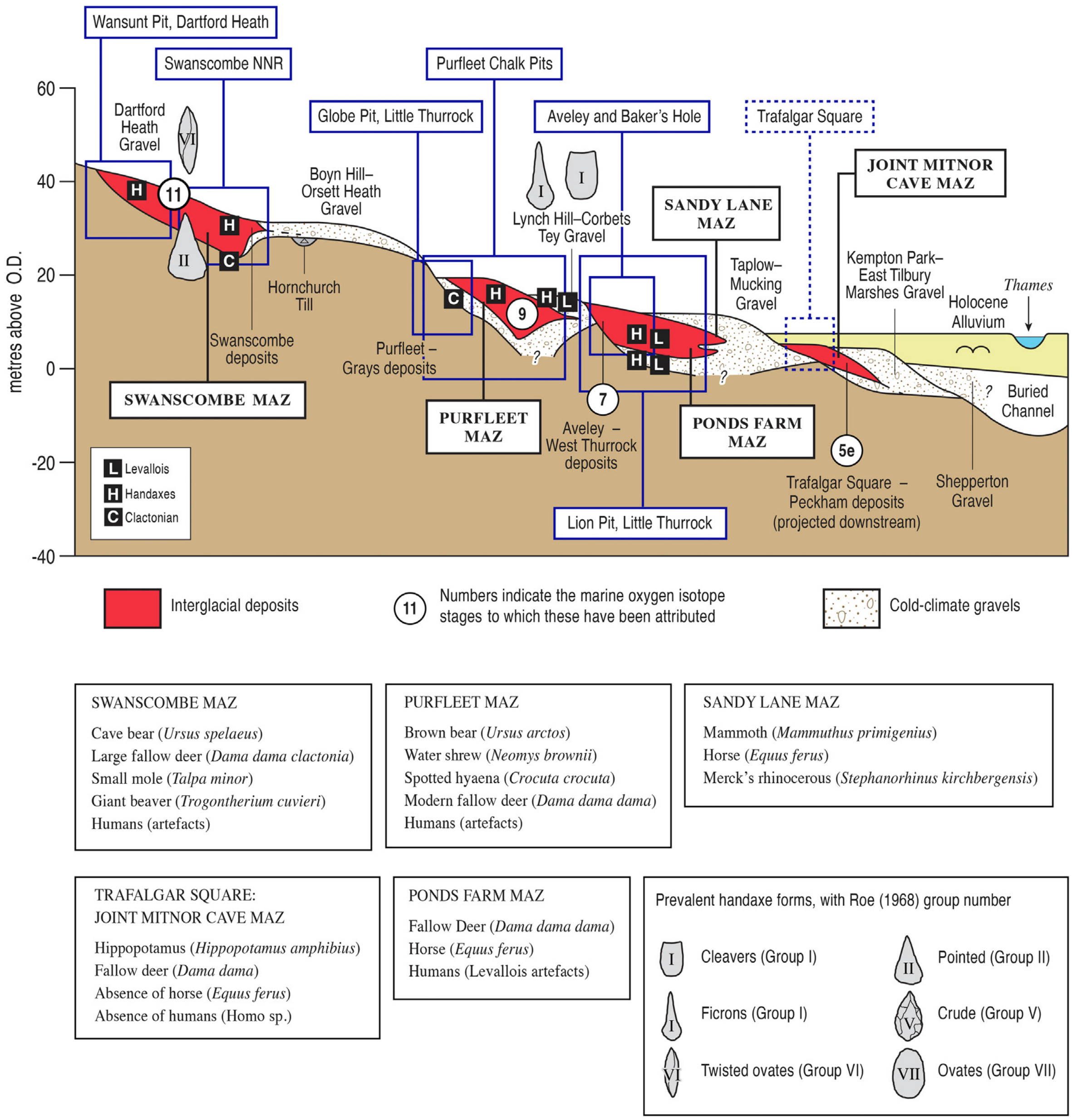


Fig. 5. Terrace staircase of the Lower Thames, showing the stratigraphical positions of key geosites (these are GCR sites/Sites of Scientific Interest, with the exception of Trafalgar Square, which is built over and is therefore known only from temporary exposures created during building) and the distribution of Palaeolithic and palaeontological components of interest. Mammal Assemblage Zones after Schreve (2001). Handaxe groups after Roe (1968), as reinterpreted by Bridgland and White (2014, 2015). It is worth noting that the recognition within this sequence of the last four Croll–Milankovitch climate cycles was important in establishing a correlation between the terrestrial record and the oceanic global template of marine isotope stages (Bridgland, 1994, 2006).

2015) and it is now protected by two natural parks, one in each country. Furthermore, this area belongs to the Naturtejo Geopark Meseta Meridional, which is a UNESCO Global Geopark within the Beira Baixa region, comprising the municipalities of Oleiros, Proença-a-Nova, Nisa, Vila Velha de Ródão, Castelo Branco, Idanha-a-Nova, and Penamacor (Neto de Carvalho and Rodrigues, 2020).

2.1.2. Main viewpoints in the Tejo

In the Tejo valley, there are four points that provide panoramic views that are of considerable value for understanding the geology and geomorphology of the valley and its region (see Fig. 1).

2.1.2.1. The 'Castelo do Rei Vamba'. The 'Castelo do Rei Vamba' is a viewpoint on the right flank of the 'Portas de Ródão' (see above, Section 2.1.1.5) from where it is possible to see the resistant quartzite ridges, the epigenic incised valley, the river terraces (including those with Palaeolithic sites, such as Foz do Enxarrique and Vilas Ruivas), the 'Conhal do Arneiro' Roman gold mine and the built heritage of Vila Velha de Ródão (for illustration, see Supplement 1, online; Figs. S1.6 and S1.7).

2.1.2.2. The viewpoint of the Nossa Senhora do Pranto chapel. This viewpoint, built into the north wall of the Chapel of Nossa Senhora do Pranto (Our Lady of Pranto) in the village of Chamusca, on the left bank of the Lower Tejo, provides a panoramic view over the Tejo valley (for illustration, see Supplement 1, online; Fig. S1.8).

2.1.2.3. The viewpoint of the 'Portas do Sol'. This viewpoint, located on the right bank of the Tejo in Santarém, provides views to the south and east across the ancient town walls to the Tejo, the wider Lezíria Ribatejana province and farmland, whereas to the north and south it provides

Fig. 6. The Museum of the Portuguese Centre of Geo-History and Prehistory, in a redundant school building at São Caetano.

upstream and downstream views (respectively) of the river and its surroundings (for illustration, see Supplement 1, online; Fig. S1.9).

2.1.2.4. The viewpoint of the Monte Gordo geodetic landmark. This viewpoint provides a magnificent view of the Tejo estuary from the top of the escarpment on the right bank of the river at Vila Franca de Xira (Fig. 7). Here can be seen the limit of urban expansion of the city of Vila Franca de Xira (constricted by the escarpment on the right bank of the Tejo), the protected area of the estuary on the left bank and the highway that links the city of Lisbon with the north of the country (A1).

2.1.3. Main Tejo Palaeolithic sites and collections

The Tejo has numerous valuable Lower–Middle Palaeolithic sites (Fig. 1), documenting human occupation during the Middle Pleistocene and found within the middle and lower terraces (T4 to T6), with the main sites located at Vila Velha de Ródão, Vila Nova da Barquinha, Golegã, Chamusca, Alpiarça, Alcochete and Loures (Cunha et al., 2008, 2012, 2017a, 2017b, 2019). This archaeological heritage, consisting of various lithic industries and some faunal remains, is deposited in national and local museums and a few private collections. The archaeological site of Foz do Enxarrique is notable, having uniquely been transformed into a site museum, albeit that material from there is mainly deposited in the National Archaeological Museum in Lisbon and in the CIART (in Vila Velha de Ródão). It is intended to excavate part of the intact area at this site to expose the archaeological level for public viewing. Also worthy of further mention is the complex of old quarries at Alpiarça, located in adjacent left-bank tributary valleys of the Tejo but exploiting deposits of the main river: its T4 terrace. The sections in the smaller and more northerly Vale do Forno yielded the most abundant Palaeolithic assemblages (Mozzi et al., 2000; Cunha et al., 2017a) but are generally no longer accessible, the valley having been developed for recreation purposes, including a large fishing lake. In the larger and better established Vale de Atela tributary, which has its own set of terraces (dating its existence back to at least the mid-Middle Pleistocene), there has been minimal development thus far and valuable exposures remain; they have been used for University of Durham undergraduate training fieldwork since 2012 and continue to yield occasional artefacts, although there has been some recent landscaping and loss of this amenity (for further information and illustration, see Supplement 1, online; Figs. S1.11 to S.16), which might have been prevented had formal conservation status been established.

Fig. 7. The Tejo Estuary seen from the Monte Gordo geodetic landmark, right bank of the Tejo River. In the foreground is the city of Vila Franca de Xira.
Photo: Fluvial Archives Group field trip, September 2010.

2.2. Thames

The Quaternary history of the Thames provides an important context for consideration and organization of geoconservation (and related Lower and Middle Palaeolithic) initiatives, given that it has led to distinctive regional distribution patterns of sediments of different ages and types. There is thus an admirable network of Thames Quaternary geosites, including several that underpin the Lower and Middle Palaeolithic record in southern Britain (Wymer, 1968; Bridgland, 1994; Bridgland and White, 2014, 2015; White et al., 2018, 2019; Shipton and White, 2020). A recent brief summary is available in the field guide (Bridgland et al., 2019) for an excursion visit associated with the Dublin INQUA Congress from which this present special issue has arisen (Bridgland, 2019). Prior to the Anglian (MIS 12) ice advance, the Thames flowed across Hertfordshire and central Essex, receiving south-bank tributaries from Surrey and Kent, the most prominent being the early River Medway, flowing from Kent across eastern Essex. After blockage and diversion by the Anglian ice sheet, the Thames was diverted into its present valley to join the Medway in the Southend area and flow (in Thames–Medway form) through eastern Essex, parallel with the present coast, to the Clacton area, where it rejoined its pre-Anglian course (Fig. 3; Fig S2.1 in Supplement 2, online). Earlier Thames courses (older than the early Middle Pleistocene) extend across Suffolk and Norfolk and are represented within the coverage of East Anglian Quaternary geoconservation interests (Allen et al., 2022). These include the celebrated early Palaeolithic site at Happisburgh, north Norfolk, where gravel composition indicates a Thames signature (Parfitt et al., 2010; see Fig. S2.1, in Online Supplement).

Geoconservation measures in the Thames have been described in some detail in earlier publications (Bridgland, 1994, 2013; Brown, 2019; https://www.essexfieldclub.org.uk/resource/Thames%20trail-FFC.pdf; see also White et al., this issue) and so will be merely outlined here to serve as a comparison with the Tejo (more detail is available in Supplement 2, online). There is a wide spread of statutory Thames Quaternary geoconservation sites (a single National Nature Reserve and 34 SSSIs or prospective SSSIs: *cf*. Bridgland, 1994; Fig. 3). In the Lower Thames (Greater London, Essex and Kent), these are supplemented with 51 non- statutory local/regional sites that relate to both the pre- and post-diversion courses. These sit within a wealth of sites distributed throughout the wider Thames system, including representation of the earlier pre-diversion route to Suffolk and Norfolk (Hey, 1980; Allen et al., 2022). It is in the post-diversion Lower Thames, however, that the greatest density of geosites exists, reflecting the plethora of interglacial evidence represented amongst the post-MIS 12 sequence in the valley within and downstream from London (Bridgland, 1994, 2013, 2014, 2019; Bridgland et al., 1995; Figs. 3 and 5).

2.2.1. National geosites (National Nature Reserve and Sites of Special Scientific Interest)

Excellent coverage of the Lower Thames terraces was achieved in the earliest listings of SSSIs drawn up following the initiation of statutory geosite notification under the 1949 National Parks and Access to the Countryside Act, with each terrace represented by multiple sites. Incorporated within this coverage is a National Nature Reserve (NNR), at Swanscombe, on the southern (Kentish) side of the river. Although already known for several decades as a locality rich in fossils (vertebrates and molluscs) and Lower Palaeolithic artefacts (Smith and Dewey, 1913, 1914; Chandler, 1929, 1931, 1932), the elevated status came about in 1954 following the discovery of fragments of a hominin skull in a gravel mid-way through the stratigraphy of the Boyn Hill Terrace at Swanscombe (Ovey, 1964; Duff, 1985; Bridgland, 1994; Conway et al., 1996; Dale et al., this issue; Fig. 8).

A network of 15 SSSIs covers the Thames downstream of London, including its pre-Anglian course, as follows (in downstream order):

(Note that a more complete list, with tributary sites (including some outside the Thames GCR block) and further details, appears in Supplement 2, online)

Pre-Anglian Thames: Newney Green, Ardleigh, Wivenhoe, St Osyth

Post-Anglian Thames: Hornchurch Railway Cutting, Aveley (Purfleet Road), Purfleet Chalk Pits (Bluelands, Greenlands and Botany Pits; former Esso Sports Ground; former Esso Storage Depot), Lion Pit Tramway Cutting, Little Thurrock (Globe Pit), Wansunt Pit, Swanscombe (NNR and associated SSSIs)

Confluent Thames–Medway: Goldsands Pit (Southminster), Clacton Cliffs and Foreshore (including the pre-diversion Holland Gravels and the post-diversion Clacton Channel), Holland-on-Sea, Little Oakley.

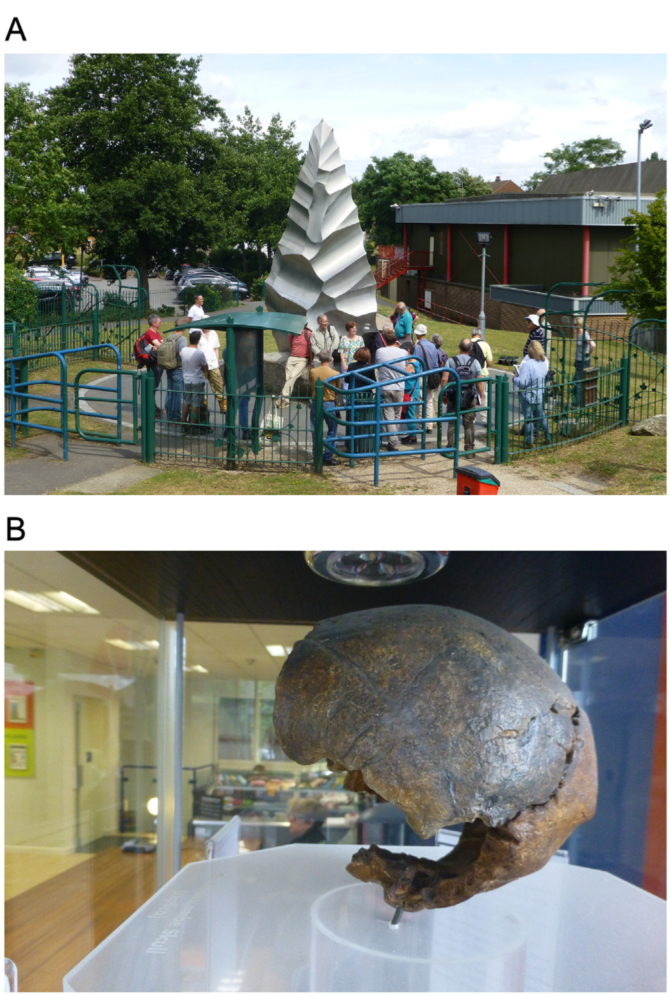


Fig. 8. Swanscombe: A – The site entrance to the NNR at Swanscombe is embellished with this stainless-steel handaxe statue, seen on the occasion of the 2019 pre-INQUA excursion visit. In the right background is the Swanscombe Centre (see B). B – a replica of the skull fossil (conjoined) is on display in the Swanscombe Centre.
Photos: Ian Mercer.

These sites were described in detail by Bridgland (1994) and many appear in various Quaternary Research Association (QRA) field guides (Bridgland et al., 1995, 2014, 2019).

Each site has a management plan, drawn up by Natural England (or its predecessor, English Nature). In most cases, the geomorphological setting can be readily appreciated, but all the sites are on or in soft rock and so their condition deteriorates rapidly. A few retain accessible faces naturally but still require superficial cleaning; some are periodically cleared of major vegetation cover and left in a state requiring further clearance of lesser vegetation before a visit, whereas some require major re-excavation before a visit and others are designated, but unexposed, to give protection for later investigation for research purposes. Sadly, a small number have deteriorated to an extent that they are no longer accessible.

Some management schemes are supplemented by visual plans indicating areas where actions are required. As examples of such visual management plans (VMPs), those for Swanscombe (Swanscombe and Greenhithe Town Council) and Wansunt Pit, Dartford Heath (Greater London Authority: GLA) appear in Supplement 2 (online). The importance of VMPs was discussed by Flower et al. (2019).

2.2.2. Local geosites

To support and enhance the SSSI coverage, 51 complementary non-statutory sites of geological, geomorphological or geoarchaeological significance have been identified, together representing an important reinforcement of the geoconservation network. These sites have been identified and designated largely from the literature and local knowledge by voluntary geoconservation groups: the London Geodiversity Partnership (LGP), GeoEssex and GeoConservation Kent. Each group has different procedures, although with a common aim. The site selection process is based on clearly defined criteria and includes scientific, educational, historical and aesthetic values. The support of landowners is sought whenever possible. The majority of the sites are on private land and site selection does not infer any right of access.

In Greater London, selected non-statutory sites fall into two tiers: Regionally Important Geological Sites (RIGS) that are relevant to the whole of London and Locally Important Geological Sites (LIGS) that are local to a particular borough. These have been notified to boroughs for inclusion in their Local Plans. This provides some protection, but not all the sites have been recognized in this way as yet, given delays with revisions of plans. A third category of non-statutory sites has been termed Sites of Geological Interest (SGI). These include sites of historical importance such as the 'Fossils of Trafalgar Square' (SGI 28) and the 'Ilford Mammoth' (SGI 21). The RIGS and LIGS are on the GiGL (Greenspace Information for Greater London) website, where they are available for partners, developers and the public to consult.

In 2009 the Greater London Authority published the first 'London's Foundations' as Supplementary Planning Guidance to the 'London Plan' of 2004. This was largely informed by the LGP's first Action Plan (http://londongeopartnership.org.uk/actionplans/), which sought to show the importance and value of geodiversity in the planning system and its sustainable use, as well as to provide a framework for the conservation, enhancement and promotion of the capital's geodiversity, of which the Thames terrace sites form an important element.

In 2012, 'London's Foundations' was significantly revised and updated; further updates of the sites continue through the LGP's Action Plan, which is regularly revised. A site description and location map are provided for every SSSI, RIGS and LIGS in London's Foundations (http://londongeopartnership.org.uk/londonsfoundations/), with revised Site Assessments for London's Foundations in 2021 (http://londongeopartnership.org.uk/wp/wp-content/uploads/2023/01/Londons-Foundations-Site-Assessments-2021_web.pdf) and within the LGP's more accessible Guide (http://londongeopartnership.org.uk/guide-to-londons-sites/). The Guide on the LGP website has an interactive map of all the sites, which is linked to a listing that includes site maps and photographs as well as text. The information is also available through the GiGL website for landowners, developers and the public.

For Essex, both regionally and locally important sites are designated as Local Geological Sites (LoGS) or potential LoGS; sites of lesser importance are also noted. The significance of these, and their context, are described in the Essex Local Geodiversity Action Plan (Essex LGAP). Essex is divided into 14 administrative districts, with a LoGS Report being produced for each district, listing and describing the SSSIs, LoGS and sites of lesser importance. Details of these are lodged on the websites of the Essex Field Club (EFC) and GeoEssex (see Online Supplement 2). The proposed LoGS, as for Local Wildlife Sites, are presented to the Local Sites Partnership for endorsement and inclusion on its website, to be available to local authorities for inclusion in their Local Plans. Local authorities receive a citation and boundary map. Developers and landowners are recommended to consult the Local Sites Partnership and the EFC Datasearch Service if any development is proposed that would affect a LoGS or other types of geosite.

Kent, although having several important SSSIs, does not have any significant local geosites relating to the Thames. An important MIS 11 site, that of the Ebbsfleet Elephant, was discovered during the building of the rail link (HS1) from London to the Channel Tunnel; this could not be conserved and, regrettably, was completely removed during the building of the Ebbsfleet International Station complex. Nonetheless, the discovery of the elephant led to an additional rescue fund being obtained and the developer was supportive in giving extra time and making machinery available to complete an extensive excavation and detailed recording of the fossil and its context (Wenban-Smith et al., 2006; Wenban-Smith, 2013; see https://historicengland.org.uk/images-books/publications/curating-the-palaeolithic/cs-hs1-ebbsfleet-elephant/), an important example of last-resort 'conservation by record'. Furthermore, equivalent deposits to those at the southern end of the elephant site are thought to survive in the area to the west and have been preserved through the planning process as Area N10 within the Ebbsfleet Green development.

Within the Lower Thames there are on record 38 (currently 13 in Greater London, 25 in Essex) sites of local geological importance relating to the pre- and post-glacial Thames. These are listed, with references, on the websites of the LGP, GeoEssex and the EFC (see also Supplement 2). Information on all the Essex geosites is accessible to the public through the EFC and GeoEssex websites. Brief descriptions of the LoGS are given in the various district LoGS Reports and, within the EFC and GeoEssex websites, a location map is provided, available in various formats (*e.g.*, aerial photograph, Ordnance Survey map, Bing map), and a written description (see Supplement 2, online).

2.2.3. Planning responses

Much supplementary knowledge of the Lower Thames sequence has come about through the system of funding for archaeological assessment and rescue excavation, as established by Government Planning Policy Guidance 16 (PPG 16) and, briefly, by Planning Policy Statement 5 (PPS 5), now superseded by the National Planning Policy Framework (https://www.gov.uk/government/publications/national-planning-policy-framework–2; *cf.*, Last et al., 2013). The last-mentioned has brought the protection of archaeological and geological interests under the same guidance for the first time; its influence on Earth-science conservation was summarized by Prosser (2012). It is clear that Quaternary geological interests have benefitted significantly from their overlap with the Lower and Middle Palaeolithic, there having been considerable research undertaken on Thames terrace sediments under PPG 16 and its successors on grounds of investigating the context for archaeological materials, in particular at Purfleet (Bridgland et al., 2013) and Southfleet Road, Swanscombe (Wenban-Smith and Bridgland, 2001; Wenban-Smith et al., 2006). Areas of significant Quaternary sequences are regularly preserved through the planning process because they contain or have potential to contain important Palaeolithic archaeology; such sites could in future be reviewed to see if they merit identification as RIGS or LIGS (see above).

Information on geosites should be included in the local authorities' Local Plans. For planning applications, the London Plan provides the location of each SSSI and RIGS with the aim that, together with LIGS, detailed descriptions will be available within each local authority, indicating a level of protection for potential developers to consider within their planning applications. In Essex, the County Council and District Council planning departments advise that developers must be informed by the results of a search for geological data from a 'local environmental records centre', *i.e.,* to consult the EFC database, which includes details of any SSSI, LoGS and other geosites, before making a formal planning application. In certain cases, applications affecting LoGS are referred to GeoEssex.

For more detailed consideration of protection *via* planning and of related and helpful publications, see Supplement 2 (online).

2.2.4. Outreach

Outreach and public information related to the Thames interests covered in this paper represents an area of expansion in recent years, from a somewhat low starting point and with considerable potential for further initiatives. The display at the Earth-science NNR at Swanscombe has already been illustrated (Fig. 8), although this is a rather modest exhibition in comparison, for example, with that in the Town Hall at Mauer, Germany, in celebration of the discovery of the *Homo heidelbergenis* mandible there (Bridgland, 2013). The present situation is described in detail in Supplement 2 (online), with highlights provided here.

The Museum of London had a permanent exhibition: 'London before London', covering 450,000 BC to AD 50 with illustrations of artefacts from the Thames. The Museum is temporarily closed until 2026 for relocation; it is hoped that there will be similar displays in its new home. The MIS 7 Ilford Mammoth skull and the Aveley Elephant are both on permanent display in the Natural History Museum, which also has numerous other animal fossils from the Thames terraces in its collections. A number of local museums in East London, Essex and Kent have relevant material, usually comprising a display of locally found geological or archaeological material as well as collections. These are described in more detail in Online Supplement 2.

Several geosites have information boards, with more planned (currently there are no boards at Trafalgar Square or Wansunt Pit, but both are on the LGP 'wish-list', working in conjunction with the QRA and other interested parties). Information boards are in place at several sites; that at Erith Park is illustrated in Supplement 2 (online; Fig. S2.7) by way of example. A newly installed information board at Purfleet Commercial Park (formerly Bluelands Pit, part of the Purfleet Chalk Pits SSSI) includes a QR code that leads to further information about the site online. Copies of the further information will also be lodged on the websites of GeoEssex and the EFC. There are interpretation boards within Swanscombe Heritage Park, along the access path to the Skull Site NNR. The nearby discovery of the Ebbsfleet elephant (see above) has been commemorated in a mural at Ebbsfleet International Station and a life-sized sculpture of a straight-tusked elephant and calf has been erected within newly redeveloped quarried land at Castle Hill, ~350 m from the discovery site (see Supplement 2, online, Fig. S2.8).

In addition there are various 'geotrails', of relevance in that they incorporate information related to the evolution of the Thames and make use of some of the documented geosites (*e.g.*, https://www.

essexfieldclub.org.uk/resource/Thames%20trail-FFC.pdf; see also Supplement 2, online). The LGP has devised some geowalks as audiotrails, one of which includes the Holocene peat bed ('submerged forest') at Erith (londongeopartnership.org.uk/wp/wp-content/uploads/2021/07/3.Submerged_Forest.mp3).

3. Discussion

In both Portugal and Britain there is a strong desire to promote the conservation of sites involving the geology (and Palaeolithic archaeology) of the terraces of the Tejo and Thames (respectively), using statutory and non-statutory administrative measures and by raising public interest and support through outreach. Each country has its own mechanisms, with varying degrees of effectiveness and success, the different approaches being somewhat predicated by contrasts between the areas concerned, especially in relation to issues such as population density and pressure for development. In both countries, archaeological localities have greater statutory protection than geological sites, although in Britain it is not possible to designate sites that lack built structures, ruling out all Lower–Middle Palaeolithic localities (*cf.*, Last et al., 2013). As many Palaeolithic archives coincide with important Quaternary geosites, there is in any case a fortuitous commensurate benefit to geoconservation interests from this overlap between archaeology and geology, particularly when the principles of developer-funded assessment and rescue excavation are applied. In addition, the Thames record is well covered by a network of statutory geosites (NNR and SSSIs), confirmed and enhanced by the GCR and seeing regular use for research and field trips and excursions (see above).

At the national level, Portugal has protection for geological sites through the classification of Natural Monuments, administered by the Institute for the Conservation of Nature and Forests, or by the attribution of legal protection status to geosites, which must comply with the creation of a protected area; for archaeological sites a variety of strategies includes 'Regulation of Archaeological Works' (Decree Law No. 164/2014), administered by the Directorate of Cultural Heritage (DGPC). In Britain, the equivalents are the SSSI network administered by Natural England and the embedding of archaeological interests within planning (PPG 16 and its successors). In the case of Portuguese protected areas of regional or local scope, the classification may be carried out by municipalities or associations of municipalities, subject to the legal conditions and terms. In Britain local sites are dealt with by County Councils and a lower tier of District Councils. For the most part, geosites are identified by local geological groups, such as the London Geodiversity Partnership, GeoEssex and GeoConservation Kent, and passed on to the County and District Councils for acceptance and inclusion in their development plans. In Portugal there are sporadic local initiatives at various scales, such as has been reported above, but no systematic organization comparable with that in Britain.

In England, the effectiveness of these various systems has been somewhat inconsistent, reflective of levels of government funding and the engagement of local planning authorities. Natural England administers both biological and geological SSSIs and is a statutory consultee for planning applications on SSSIs. In the most part, appropriate representations have been made either to safeguard SSSIs from development in the Lower Thames or to ensure that rescue and recording have been carried out (*cf.*, Bridgland et al., 2013; Evans et al., 2023), with one or two notable exceptions further back in time (*cf.*, Bridgland et al., 2003). However, in recent years Natural England's resources have been more constrained as regards site monitoring and grants for site management, although site monitoring surveys have now resumed and are a target under the government Environment Improvement Plan, which requires Natural England to report on the condition of geological SSSIs. Success at the local level depends on the engagement of local geodiversity groups and the support of the local planning authority. There is a significant role here for 'citizen science', with interested and well-informed local people monitoring geosites, especially those in settings where exposures are naturally 'freshened up', such as eroding coastal sections (*cf.*, Allen et al., 2022).

Citizen Science also has a role in the Tejo, focusing on general geological and archaeological themes, of relevance here being Quaternary topics (river and landscape evolution), Palaeolithic and Neolithic artefacts as records of the evolution of primitive human communities, as well as the fossil record. There is citizen-scientist assistance and interaction in connection with presentations in municipal auditoriums (for the general public) and schools (for students and teachers), the creation of temporary thematic exhibitions and museum displays, guiding thematic field trips (for public participation), providing press releases and media interviews about new findings with societal relevance, citizen discoveries (lithic artefacts or fossils) and protection of relevant sites, as well as dissemination by using social media (webpages, Instagram, Facebook, *etc.,*) and other videos and literature.

In the Lower Thames area, where the special interest of the Quaternary river-terrace deposits is enhanced by the occurrence of significant fossils and archaeological components, there have been many successes, as illustrated above, but there have also been disappointments. Archaeology is very well catered for by its consideration within the planning system, as well as the employment of county archaeologists, which partly compensates for the near impossibility in applying archaeological designation to Lower–Middle Palaeolithic (Pleistocene) find-spots or even occupation sites because of the absence of built structures (see above; *cf.*, Last et al., 2013). However, significant impact can be caused by infrastructure that is outside the planning process, such as utilities, some highways works and development for which planning consent is not required. Furthermore, not all county planning departments have Lower–Middle Palaeolithic specialists, although these interests have been well covered in the Lower Thames area (Kent, Essex and Greater London); to enhance the general situation, and raise the profile of the geoarchaeological conservation amongst developers and planners, Historic England has championed training aimed at promoting awareness (Last et al., 2013). Nonetheless, it could be argued that for important Palaeolithic sites a change in the criteria for designating scheduled monuments is needed.

Outreach has been more successful in Portugal in terms of visual experiences. Significant displays are available in several museums, such as the Portuguese Centre of Geo-History and Prehistory [CPGP], Centro de Interpretação de Arte Rupestre do Vale do Tejo, Museum of Prehistoric Art and of the Sacred Tagus Valley [Mação], and the archaeological site of Foz do Enxarrique is being developed as a permanent display for the general public. In Britain, there are permanent displays at the Natural History Museum of specific interest (Ilford Mammoth skull, Aveley elephants) rather than a more comprehensive treatment of the geology and archaeology of the river. There is a wider brief for the 'London before London' display at the Museum of London, describing London 450,000 BC to AD 50, but localized to the city. There are minor displays (see Online Supplement 2), permanent and temporary, at various museums (*e.g.*, Redbridge, Chelmsford) and visitor centres (Swanscombe, Pitsea).

Because the Tejo is partly in a hard-rock area of high relief, there are splendid views of the river and its terraces (see above, Section 2.1.2). In Britain, the Lower Thames is in a soft-rock area of subdued relief. An impression of the terrace sequence can be obtained by a north to south traverse in the London Borough of Barking and Dagenham from Marks Gate (TQ 905485) to Dagenham Dock (TQ 820489), encompassing the Boyn Hill, Lynch Hill and Taplow Terraces and on to the current floodplain. Similarly, on the Tendring Peninsula, this can be illustrated by a transect from Lamb Corner (TM 046316) to Clacton (TM 179148), traversing the terrace flats corresponding to the Ardleigh, Wivenhoe and Holland gravels (Allen et al., 2022).

Visual outreach in the form of information boards is available at the major Portuguese viewpoints and is in position at many of the Lower Thames sites, with more planned. Outreach in the form of publications, both in the Lower Tejo and in the Lower Thames, has been expressed by the production of booklets, field guides and pamphlets, but mostly these have had limited circulation and lifespans. In summary, outreach has improved significantly in both countries over the last decade and is set to continue expansion into the future.

4. Conclusions

The Tejo (Lower Tagus) and the Lower Thames both have important Quaternary records that have benefitted from a variety of geoconservation measures, as described and discussed in this paper. Both have terrace staircases with rich assemblages of Lower–Middle Palaeolithic artefacts, revealing human occupation histories in the Middle and Late Pleistocene. The Thames also has an exemplary palaeontological record, something not found to any great extent in the Tejo. In the studied areas of these two rivers, significant geoconservation initiatives have been developed, although there are differences in approach. Whereas Thames Quaternary interests are well covered by a network of statutory site designations, outreach is to the fore in the Lower Tejo. The Thames has relatively few examples of physical outreach provision and limited formal protection for Pleistocene archaeological sites outside the geological network, although extensive informal protection is provided by interaction between local geo-groups and county and local authority administrations. There is also a considerable difference in the degree of threat, with the Lower Tejo above Lisbon a relatively undeveloped valley, albeit with sporadic quarrying for aggregate, whereas the Lower Thames is a designated area for infrastructure development, lying to the east of London and close to its orbital motorway.

The Alpiarça case study suggests that formal geosite protection, as benefits the NNR and SSSIs in the Thames, might be valuable in preventing further unnecessary loss of valuable geological exposures in Portugal, whereas the success of outreach and dissemination in the Tejo, as well as the museum initiatives there, provide exemplars for future improvement in the Thames. In both countries the work of volunteers is of great importance and is likely to become more so in the future.

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Declaration of competing interest

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References

Allen, P., Bain, D.R., Bridgland, D.R., Buisson, P., Buylaert, J.-P., Bynoe, R., George, W.H., Haggart, B.A., Horne, D.J., Littlewood, E.-M., Lord, A., March, A.C., Mercer, I., Mercer, R., Murray, A.S., Penkman, K.E.H., Preece, R.C., Ratford, J., Schreve, D.C., Snelling, A.J. R., Sohar, K., Whittaker, J., White, M.J., White, T.S., 2022. Mid–late Quaternary fluvial archives near the margin of MIS 12 glaciation in southern East Anglia, UK; amalgamation of multi-disciplinary and citizen-science data sources. Quaternary 5, 37. https://doi.org/10.3390/quat5030037.

Bates, M.R., Keen, D.H., Lautridou, J.-P., 2003. Pleistocene marine and periglacial deposits of the English Channel. Journal of Quaternary Science 18, 319–337.

Breuil, H., 1932. Les Industries à éclats du Palaéolithique ancien, I: Le Clactonien. Préhistoire, Paris 1, 148–157.

Breuil, H., Koslowski, L., 1932. Études de stratigraphie paléolithique dans le nord de la France, la Belgique, et l'Angleterre. L'Anthropologie 42 (27–47), 291–314.

Breuil, H., Zbyszewski, G., 1942. Contribution à l'étude des industries Paléolithiques du Portugal et de leurs rapports avec la géologie du Quaternaire. Les principaux gisements des deux rives de l'ancien estuaire du Tage. Comunicações dos Serviços Geológicos de Portugal XXIII, Lisboa (369 pp.).

Breuil, H., Zbyszewski, G., 1945. Contribution à l'étude des industries Paléolithiques du Portugal et de leurs rapports avec la géologie du Quaternaire. Les principaux gisements des plages quaternaires du littoral d'Estremadura et des terrasses fluviales de la basse vallée du Tage. Comunicações dos Serviços Geológicos de Portugal XXVI, Lisboa (678 pp.).

Bridgland, D.R., 1994. Quaternary of the Thames. Geological Conservation Review Series, 7. Chapman & Hall, London, p. 441.

Bridgland, D.R., 2006. The Middle and Upper Pleistocene sequence in the Lower Thames; a record of Milankovitch climatic fluctuation and early human occupation of southern Britain. Henry Stopes Memorial Lecture. Proceedings of the Geologists' Association 117, 281–305.

Bridgland, D.R., 2010. The record from British Quaternary river systems within the context of global fluvial archives. Journal of Quaternary Science 25, 433–446.

Bridgland, D.R., 2013. Geoconservation of Quaternary sites and interests. Proceedings of the Geologists' Association 124, 612–624.

Bridgland, D.R., 2014. Lower Thames terrace stratigraphy: latest views. In: Bridgland, D.R., Allen, P., White, T.S. (Eds.), The Quaternary of the Lower Thames and Eastern Essex: Field Guide. Quaternary Research Association, London, pp. 1–8.

Bridgland, D.R., 2019. Quaternary fluvial archives of the River Thames. In: Bridgland, D.R., Briant, R.M., Allen, P., Brown, E.J., White, T.S. (Eds.), The Quaternary Fluvial Archives of the Major English Rivers: Field Guide. Quaternary Research Association, London, pp. 49–59.

Bridgland, D.R., Westaway, R., 2014. Quaternary fluvial archives and landscape evolution: a global synthesis. Proceedings of the Geologists' Association 125, 600–629.

Bridgland, D.R., White, M.J., 2014. Fluvial archives as a framework for the Lower and Middle Palaeolithic: patterns of British artefact distribution and potential chronological implications. Boreas 43, 543–555.

Bridgland, D.R., White, M.J., 2015. Chronological variations in handaxes: patterns detected from fluvial archives in NW Europe. Journal of Quaternary Science 30, 623–638.

Bridgland, D.R., White, M.J., 2018. The Farnham river terrace staircase: an optimal record of the Thames Palaeolithic. Earth Heritage 49, 51–53.

Bridgland, D.R., Allen, P., Haggart, B.A. (Eds.), 1995. The Quaternary of the Lower Reaches of the Thames. Field Guide. Quaternary Research Association, Durham (372 pp.).

Bridgland, D.R., Field, M.H., Holmes, J.A., McNabb, J., Preece, R.C., Selby, I., Wymer, J.J., Boreham, S., Irving, B.G., Parfitt, S.A., Stuart, A.J., 1999. Middle Pleistocene interglacial Thames–Medway deposits at Clacton-on-Sea, England: reconsideration of the biostratigraphical and environmental context of the type Clactonian Palaeolithic industry. Quaternary Science Reviews 18, 109–146.

Bridgland, D.R., Schreve, D.C., Allen, P., Keen, D.H., 2003. Key Middle Pleistocene localities of the Lower Thames: site conservation issues, recent research and report of a Geologists' Association excursion, July 8, 2000. Proceedings of the Geologists' Association 114, 211–222.

Bridgland, D.R., Antoine, P., Limondin-Lozouet, N., Santisteban, J.I., Westaway, R., White, M.J., 2006. The Palaeolithic occupation of Europe as revealed by evidence from the rivers: data from IGCP 449. Journal of Quaternary Science 21, 437–455.

Bridgland, D.R., Harding, P., Allen, P., Candy, I., Cherry, C., George, W., Horne, D., Keen, D.H., Penkman, K.E.H., Preece, R.C., Rhodes, E.J., Scaife, R., Schreve, D.C., Schwenninger, J.-L., Slipper, I., Ward, G., White, M.J., White, T.S., Whittaker, J.E., 2013. An enhanced record of MIS 9 geoarchaeology: data from construction of the High Speed 1 (London–Channel Tunnel) rail-link and other recent investigations at Purfleet, Essex, UK. Proceedings of the Geologists' Association 124, 417–476.

Bridgland, D.R., Allen, P., White, T.S. (Eds.), 2014. The Quaternary of the Lower Thames and Eastern Essex. Field Guide. Quaternary Research Association, London.

Bridgland, D.R., Briant, R.M., Allen, P., Brown, E.J., White, T.S. (Eds.), 2019. The Quaternary Fluvial Archives of the Major English Rivers. INQUA Field Guide. Quaternary Research Association, London.

Bridgland, D.R., Westaway, R., Hu, Z., 2020. Basin inversion: a worldwide Late Cenozoic phenomenon. Global and Planetary Change 193, 103260.

Brilha, J., Andrade, C., Azerêdo, A., Barriga, F.J.A.S., Cachão, M., Couto, H., Cunha, P.P., Crispim, J.A., Dantas, P., Duarte, L.V., Freitas, M.C., Granja, M.H., Henriques, M.H., Henriques, P., Lopes, L., Madeira, J., Matos, J.M.X., Noronha, F., Pais, J., Piçarra, J., Ramalho, M.M., Relvas, J.M.R.S., Ribeiro, A., Santos, A., Santos, V., Terrinha, P., 2005. Definition of the Portuguese frameworks with international relevance as an input for the European geological heritage characterisation. Episodes 28, 177–186.

Brown, E.J., 2019. Geoconservation and geodiversity of Quaternary fluvial sites. In: Bridgland, D.R., Briant, R.M., Allen, P., Brown, E.J., White, T.S. (Eds.), The Quaternary

Fluvial Archives of the Major English Rivers: Field Guide. Quaternary Research Association, London, pp. 37–44.
Brugal, J.-P., Raposo, L., 1999. Foz do Enxarrique (Ródão, Portugal): preliminary results of the analysis of a bone assemblage from a Middle Palaeolithic open site. In: Gaudzinski, S., Turner, E. (Eds.), The Role of Early Humans in the Accumulation of European Lower and Middle Palaeolithic Bone Assemblages: Ergebnisse eines Kolloquiums (Romisch-Germanisches Zentralmuseum Forschungsinstitut fur Vor- und Fruhgeschichte Monographien), vol. 42, pp. 367–379.
Cameron, T.D.J., Crosby, A., Balson, P.S., Jeffery, D.H., Lott, G.K., Bulat, J., Harrison, D.J., 1992. The Geology of the Southern North Sea. HMSO, London (152 pp.).
Cardoso, J.L., 1993. Contribuição para o conhecimento dos grandes mamíferos do Plistocénico superior de Portugal. Câmara Municipal de Oeiras (567 pp.).
Chandler, R.H., 1929. On the Clactonian industry at Swanscombe. Proceedings of the Prehistoric Society of East Anglia 6, 79–116.
Chandler, R.H., 1931. On the Clactonian Industry and report of field meeting at Swanscombe. Proceedings of the Geologists' Association 42, 175–177.
Chandler, R.H., 1932. Preliminary notice: types of Clactonian implements at Swanscombe. Proceedings of the Prehistoric Society of East Anglia 6, 377–378.
Chauhan, P., Bridgland, D., Moncel, M.-H., Antoine, P., Bahain, J.-J., Briant, R., Cunha, P.P., Despriée, J., Limondin-Lozoue, N., Locht, J.-L., Martins, A., Schreve, D., Shaw, A., Voinchet, P., Westaway, R., White, M., White, T., 2017. Fluvial deposits as an archive of early human activity: progress during the 20 years of the Fluvial Archives Group. Quaternary Science Reviews, Special Issue - Fluvial Archives Group 166, 114–149. https://doi.org/10.1016/j.quascirev.2017.03.016.
Conway, B., McNabb, J., Ashton, N., 1996. Excavations at Barnfield Pit, Swanscombe, 1968–72. British Museum Occasional Paper 94, London, p. 256.
Cunha, P.P., 2019. Cenozoic basins of Western Iberia: Mondego, Lower Tejo and Alvalade basins. In: Quesada, C., Oliveira, J.T. (Eds.), The Geology of Iberia: A Geodynamic Approach, Regional Geology Reviews, vol. 4. Springer International Publishing, pp. 105–130. https://doi.org/10.1007/978-3-030-11190-8 Cenozoic Basins, Chapter 4.
Cunha, P.P., Martins, A.A., Daveau, S., Friend, P.F., 2005. Tectonic control of the Tejo River fluvial incision during the late Cenozoic, in Ródão — central Portugal (Atlantic Iberian border). Geomorphology 64, 271–298.
Cunha, P.P., Martins, A.A., Huot, S., Murray, A., Raposo, L., 2008. Dating the Tejo River lower terraces in the Ródão area (Portugal) to assess the role of tectonics and uplift. Geomorphology 102, 43–54.
Cunha, P.P., Almeida, N.A.C., Aubry, T., Martins, A.A., Murray, A.S., Buylaert, J.-P., Sohbati, R., Raposo, L., Rocha, L., 2012. Records of human occupation from Pleistocene river terrace and aeolian sediments in the Arneiro depression (Lower Tejo River, central eastern Portugal). Geomorphology 165–166, 78–90.
Cunha, P.P., Martins, A.A., Buylaert, J.-P., Murray, A.S., Raposo, L., Mozzi, P., Stokes, M., 2017a. New data on the chronology of the Vale do Forno sedimentary sequence (Lower Tejo River terrace staircase) and its relevance as fluvial archive of the Middle Pleistocene in western Iberia. Quaternary Science Reviews 166, 204–226.
Cunha, P.P., Cura, S., Cunha Ribeiro, J.P., Figueiredo, S., Martins, A.A., Raposo, L., Pereira, T., Almeida, N., 2017b. The Lower and Middle Palaeolithic industries associated with the T4 Terrace of the Lower Tejo River - archives of the human occupation during ca. 335 ka to 155 ka ago. Journal of Lithic Studies 4, 27–56. https://doi.org/10.2218/jls.v4i3.2531 (ISSN 2055-0472 (Online)).
Cunha, P.P., Martins, A.A., Buylaert, J.-P., Murray, A.S., Gouveia, M.P., Font, E., Pereira, T., Figueiredo, S., Ferreira, C., Bridgland, D., Pu, Y., Stevaux, J., Mota, R., 2019. The lowermost Tejo River Terrace at Foz do Enxarrique, Portugal: a palaeoenvironmental archive from c. 60–35 ka and its implications for the Last Neanderthals in Westernmost Iberia. Quaternary 2 (1), 3. https://doi.org/10.3390/quat2010003.
Cunha, P.P., Martins, A.A., Gomes, A., Bridgland, D.R., 2020. Landscapes and landforms of the Beira Baixa Region (Sarzedas–Monfortinho, Eastern Central Mainland Portugal). Chapter 16. In: Vieira, G., Zêzere, J.L., Mora, C. (Eds.), Landscapes and Landforms of Portugal, World Geomorphological Landscapes. Springer Nature Switzerland AG. ISBN: 978-3-319-03640-3, pp. 199–210 https://doi.org/10.1007/978-3-319-03641-0_16.
Dale, L.C., Rawlinson, A.A., Bridgland, D.R., White, M.J., 2023. The value of geoconservation sites in understanding historical collections of Lower and Middle Palaeolithic artefacts. Proceedings of the Geologists' Association https://doi.org/10.1016/j.pgeola.2021.06.008 (this issue, in press).
Daura, J., Sanz, M., Arsuaga, J.L., Hoffmann, D.L., Quam, R.M., Ortega, M.C., Santos, E., Gómez, S., Rubio, A., Villaescusa, L., Souto, P., Mauricio, J., Rodrigues, F., Ferreira, A., Godinho, P., Trinkaus, E., Zilhão, J., 2017. New Middle Pleistocene hominin cranium from Gruta da Aroeira (Portugal). Proceedings of the National Academy of Sciences of the United States of America 114, 3397–3402.
Duff, K.L., 1985. The Story of Swanscombe Man. Kent County Council and Nature Conservancy Council, Canterbury.
Ellis, N.V., 2011. The Geological Conservation Review (GCR) in Great Britain—rationale and methods. Proceedings of the Geologists' Association 122, 353–362.
Ellis, N.V., Bowen, D.Q., Campbell, S., Knill, J.L., McKirdy, A.P., Prosser, C.D., Vincent, M.A., Wilson, R.C.L., 1996. An Introduction to the Geological Conservation Review. GCR Series No. Joint Nature Conservation Committee, 1, p. 131.
Evans, D., Brown, E., Larwood, J., Prosser, C., Silva, B., Townley, H., Wetherell, A., 2023. Geoconservation: principles and practice. Natural England General Publication NE802. Natural England.
Figueiredo, S.D., 2012. The Pleistocene Elephants of Portugal, Coloquio Internacional Marfim y Elefantes en la Peninsula Iberica y el Mediterráneo Occidental, Abstract Book. pp. 37–44.
Figueiredo, S.D., Raposo, L., 2018. As Aves Como Recurso Alimentar do Homem do Paleolítico Médio: interpretação tafonómica das acumulações faunísticas da Gruta Nova da Columbeira e da Foz do Enxarrique. Boletim do Centro Português de Geo-História e Pré-História 1, 57–63.
Figueiredo, S.D., Sousa, M.F., 2003. Os Elefantes Plistocénicos de Portugal. Revista Evolução 2, 5–28.
Figueiredo, S.D., Sousa, M.F., 2005. Os Elefantes Plistocénicos do Estuário do Tejo, Actas do I Seminário de Paleontologia e Arqueologia do Estuário do Tejo: 91–98. Ed. Colibri e C. M, Montijo.
Figueiredo, S., Nobre, L., Costa, J., Ruivo, P., 2005. Várzea de Loures: Um local privilegiado para a Implantação de um projecto de musegrafia e investigação. Revista da Rede de Museus Loures 2, 18–20.
Figueiredo, S.D., Coimbra, F., Antas, M., Silvério, S., Sousa, M.F., 2018. The Museum of the Portuguese Centre of Geo-History and Prehistory. Earth Heritage 50, 41–43.
Figueiredo, S., Coimbra, F., Antas, M., Carrança, A., Sousa, M.F., 2020. The Museum of the Portuguese Centre of Geo-History and Prehistory: a project for the dissemination of paleontological and prehistoric heritage. Boletim do Centro Português de Geo-História e Pré-História 2, 37–43.
Figueiredo, S., Raposo, L., Sousa, M., 2021. Upper Pleistocene fauna from the Middle Palaeolithic site of Foz do Enxarrique (Vila Velha de Ródão, Naturtejo Unesco Global Geopark). Geoconservation Research 4, 685–693.
Flower, L., Allen, P., Bridgland, D.R., Brown, E., 2019. Wansunt Pit SSSI: the importance of visual management plans in Quaternary geoconservation in England. Abstract, 20th Congress of the International Union for Quaternary Research (INQUA), Dublin . https://app.oxfordabstracts.com/events/574/program-app/submission/91891.
Gibbard, P.L., 1985. The Pleistocene History of the Middle Thames Valley. Cambridge University Press, Cambridge, p. 155.
Gibbard, P.L., 1995. Formation of the Strait of Dover. In: Preece, R.C. (Ed.), Island Britain: A Quaternary Perspective, Geological Society of London Special Publication, vol. 96, pp. 15–26.
Gouveia, J., 2009. Monumento Natural das Portas de Ródão. Açafa on-line 2, 1–78.
Gouveia, M.P., Cunha, P.P., Falguères, C., Voinchet, P., Martins, A.A., Bahain, J.-J., Pereira, A., 2020. Electron spin resonance dating of the culminant allostratigraphic unit of the Mondego and Lower Tejo Cenozoic basins (W Iberia), which predates fluvial incision into the basin-fill sediments. Global and Planetary Change 184. https://doi.org/10.1016/j.gloplacha.2019.103081.
Grimaldi, S., Rosina, P., 2001. O Plistoceno Médio final do Alto Ribatejo (Portugal central): o sítio da Ribeira da Ponte da Pedra. Arkeos 11, 89–116.
Hey, R.W., 1980. Equivalents of the Westland Green Gravels in Essex and East Anglia. Proceedings of the Geologists' Association 91, 279–290.
Karampaglidis, T., Benito-Calvo, A., Rodés, A., Braucher, R., Pérez-González, A., Pares, J., Stuart, F., Di Nicola, L., Bourles, D., 2020. Pliocene endorheic–exorheic drainage transition of the Cenozoic Madrid Basin (Central Spain). Global and Planetary Change 194. https://doi.org/10.1016/j.gloplacha.2020.103295.
Last, J., Brown, E.J., Bridgland, D.R., Harding, P., 2013. Quaternary geoconservation and Palaeolithic heritage protection in the 21st century: developing a collaborative approach. Proceedings of the Geologists' Association 124, 625–637.
Martins, A.A., Cunha, P.P., Huot, S., Murray, A., Buylaert, J.-P., 2009. Geomorphological correlation of the tectonically displaced Tejo River terraces (Gavião–Chamusca area, central Portugal) supported by luminescence dating. Quaternary International 199, 75–91.
Martins, A.A., Cunha, P.P., Rosina, P., Osterbeck, L., Cura, S., Grimaldi, S., Gomes, J., Buylaert, J.-P., Murray, A., Matos, J., 2010. Geoarchaeology of Pleistocene open air sites in the Vila Nova da Barquinha–Santa Cita area (Lower Tejo River basin, central Portugal). Proceedings of the Geologists' Association 121, 128–140.
Mishra, S., White, M.J., Beaumont, P., Antoine, P., Bridgland, D.R., Howard, A.J., Limondin-Lozouet, N., Santisteban, J.I., Schreve, D.C., Shaw, A.D., Wenban-Smith, F.F., Westaway, R.W.C., White, T., 2007. Fluvial deposits as an archive of early human activity. Quaternary Science Reviews 26, 2996–3016.
Morigi, A., Schreve, D., White, M., 2011. The Thames Through Time. The Formation and Changing Environment of the Thames Valley and Early Human Occupation to 1500 BC, Part 1: The Ice Age. English Heritage and Oxford Archaeology, Oxford.
Mozzi, P., Azevedo, T., Nunes, E., Raposo, L., 2000. Middle terrace deposits of the Tagus river in Alpiarça, Portugal, in relation to early human occupation. Quaternary Research 54, 359–371.
Neto de Carvalho, C., Rodrigues, J., 2020. Naturtejo UNESCO Global Geopark: the culture of landscape. Chapter 28. In: Vieira, G., Zêzere, J.L., Mora, C. (Eds.), Landscapes and Landforms of Portugal, World Geomorphological Landscapes. Springer Nature Switzerland AG. ISBN: 978-3-319-03640-3, pp. 359–377 https://doi.org/10.1007/978-3-319-03641-0_16 (Book ID: 319490_1_En Book).
Oosterbeek, L., 2009. Museu de Arte Pré-Histórica de Mação e Rede PACAD. Museologia. Pt. 3, 199–205.
Oosterbeek, L., Grimaldi, S., Rosina, P., Cura, S., Cunha, P.P., Martins, A.A., 2010. The earliest Pleistocene archaeological sites in western Iberia: present evidence and research prospects. Quaternary International 223–224, 399–407.
Ovey, C.D., 1964. The Swanscombe Skull. A survey of research on a Pleistocene Site, Royal Anthropological Institute Occasional Paper. 20. William Clowes and Sons, London, p. 211.
Parfitt, S.A., Ashton, N.M., Lewis, S.G., Abel, R.L., Coope, G.R., Field, M.H., Gale, R., Hoare, P. G., Larkin, N.R., Lewis, M.D., Karloukovski, V., Maher, B.A., Peglar, S.M., Preece, R.C., Whittakker, J.E., Stringer, C.B., 2010. Early Pleistocene human occupation at the edge of the boreal zone in northwest Europe. Nature 466, 229–233.
Penkman, K.E.H., Preece, R.C., Bridgland, D.R., Keen, D.H., Meijer, T., Parfitt, S.A., White, T.S., Collins, M.J., 2011. A chronological framework for the British Quaternary based on *Bithynia* opercula. Nature 476, 446–449.
Penkman, K.E.H., Preece, R.C., Bridgland, D.R., Keen, D.H., Meijer, T., Parfitt, S.A., White, T.S., Collins, M.J., 2013. An aminostratigraphy for the British Quaternary based on *Bithynia* opercula. Quaternary Science Reviews 61, 111–134.

Pereira, D.I., Pereira, P., Brilha, J., Cunha, P.P., 2015. The Iberian Massif landscape and fluvial network in Portugal: a geoheritage inventory based on the scientific value. Proceedings of the Geologists' Association 126, 252–265.

Pereira, T., Cunha, P.P., Martins, A.A., Nora, D., Paixão, E., Figueiredo, O., Raposo, L., Henriques, F., Caninas, J., Moura, D., Bridgland, D.R., 2019. Geoarchaeology of the Cobrinhos site (Vila Velha de Ródão, Portugal) - a record of the earliest Mousterian in western Iberia. Journal of Archaeological Science: Reports 24, 640–654.

Pettitt, P., White, M., 2012. The British Palaeolithic: Human Societies at the Edge of the Pleistocene World. p. 616 Routledge.

Prosser, C., 2012. Reasons to be cheerful in new National Planning Policy Framework for England. Earth Heritage 38, 7–8.

Raposo, L., 1995a. O Paleolítico. In: Medina, J. (Ed.)História de Portugal, vol. 1. Clube Internacional do Livro, Lisboa, pp. 23–85.

Raposo, L., 1995b. Ambientes, territorios y subsistencia en el Paleolítico Medio de Portugal. Complutum 6, 57–77.

Raposo, L., 1996. Quartzite bifaces and cleavers in the final Acheulian assemblage of Milharós (Alpiarça, Portugal). Non-Flint Stone Tools and the Palaeolithic Occupation of the Iberian Peninsula, pp. 151–165.

Raposo, L., Cardoso, J.L., 1998. O Sítio do Paleolítico Médio da Conceição (Alcochete). Centro de Estudos e Monitorização Ambiental (74 pp.).

Raposo, L., Carreira, J., Salvador, M., 1985. A estação de Acheulense final de Milharós, Vale de Forno, Alpiarça. Actas da 1ª Reunião do Quaternário Ibérico, 2. Instituto Nacional de Investigação Científica, Lisboa, pp. 41–60.

Raposo, L., Salvador, M., Pereira, J.P., 1993. O Acheulense no Vale do Tejo, em território português. Arqueologia & História 10, 3–29.

Rasmussen, S.O., Bigler, M., Blockley, S.P., Blunier, T., Buchardt, S.A., Clausen, H.B., Cvijanovic, I., Dahl-Jensen, D., Johnsen, S.J., Fischer, H., Gkinis, V., Guillevic, M., Hoek, W.Z., Lowe, J.J., Pedro, J.G., Popp, T., Seierstad, I.K., Steffensen, J.P., Svensson, A.M., Vallelonga, P., Vinther, B.M., Walker, M.J.C., Wheatley, J.J., Winstrup, M., 2014. A stratigraphic framework for abrupt climatic changes during the Last Glacial period based on three synchronized Greenland ice-core records: refining and extending the INTIMATE event stratigraphy. Quaternary Science Reviews 106, 14–28.

Roe, D.A., 1968. British Lower and Middle Palaeolithic hand axe groups. Proceedings of the Prehistoric Society 34, 1–82.

Roe, D.A., 1981. The Lower and Middle Palaeolithic Periods in Britain. Routledge & Kegan Paul, London, p. 324.

Rose, J., 1994. Major river systems of central and southern Britain during the Early and Middle Pleistocene. Terra Nova 6, 435–443.

Rose, J., Allen, P., Hey, R.W., 1976. Middle Pleistocene stratigraphy in southern East Anglia. Nature 263, 492–494.

Rose, J., Whiteman, C.A., Allen, P., Kemp, R.A., 1999. The Kesgrave Sands and Gravels: 'pre-glacial' Quaternary deposits of the River Thames in East Anglia and the Thames Valley. Proceedings of the Geologists' Association 110, 93–116.

Rosina, P., Voinchet, P., Bahain, J.J., Cristovão, J., Falguères, C., 2014. Dating the onset of lower Tagus River terrace formation using electron spin resonance. Journal of Quaternary Science 29, 153–162.

Santisteban, J.I., Schulte, L., 2007. Fluvial networks of the Iberian Peninsula: a chronological framework. Quaternary Science Reviews 26, 2738–2757.

Santonja, M., Pérez-González, A., 2000–2001. El Paleolítico inferior en el interior de la Península Ibérica. Un punto de vista desde la geoarqueología. Zephyrus 53–54, 27–77.

Schreve, D.C., 2001. Differentiation of the British late Middle Pleistocene interglacials: the evidence from mammalian biostratigraphy. Quaternary Science Reviews 20, 1693–1705.

Shipton, C., White, M.J., 2020. Handaxe types, colonization waves, and social norms in the British Acheulean. Journal of Archaeological Science: Reports 31, 102352.

Silva, P.G., Roquero, E., López-Recio, M., Huerta, P., Martínez-Grãna, A.M., 2017. Chronology of fluvial terrace sequences for large Atlantic rivers in the Iberian Peninsula (Upper Tagus and Duero drainage basins, Central Spain). Quaternary Science Reviews 166, 188–203.

Smith, R.A., Dewey, H., 1913. Stratification at Swanscombe: report on excavation made on behalf of the British Museum and H.M. Geological Survey. Archaeologia 64, 177–204.

Smith, R.A., Dewey, H., 1914. The High Terrace of the Thames: report on investigations made on behalf of the British Museum and H.M. Geological Survey in 1913. Archaeologia 65, 187–212.

Sousa, M.F., Figueiredo, S.D., 2001. The Pleistocene elephants of Portugal. Congress La Terra degli Elefanti (Proceedings), Roma, pp. 611–616.

Voinchet, P., Moreno, D., Bahain, J.-J., Tissoux, H., Tombret, O., Falguères, C., Moncel, M.-H., Schreve, D.C., Candy, I., Antoine, P., Ashton, N., Beamish, M., Cliquet, D., Despriée, J., Lewis, S., Limondin-Lozouet, N., Locht, J.-L., Parfitt, S., Pope, M., 2015. New chronological data (ESR and ESR/U-series) for the earliest Acheulean sites of northwestern Europe. Journal of Quaternary Science 30, 610–622.

Warren, S.H., 1955. The Clacton (Essex) channel deposits. Quarterly Journal of the Geological Society of London 111, 283–307.

Wenban-Smith, F.F., 2013. The Ebbsfleet Elephant. Oxford Archaeology Monograph, 20, p. 562.

Wenban-Smith, F.F., Bridgland, D.R., 2001. Palaeolithic archaeology at the Swan Valley Community School, Swanscombe, Kent. Proceedings of the Prehistoric Society 67, 219–225.

Wenban-Smith, F.F., Allen, P., Bates, M.R., Parfitt, S.A., Preece, R.C., Stewart, J.R., Turner, C., Whittaker, J.E., 2006. The Clactonian elephant butchery site at Southfleet Road, Ebbsfleet, UK. Journal of Quaternary Science 21, 471–483.

Westaway, R., Bridgland, D.R., 2010. Causes, consequences and chronology of large-magnitude palaeoflows in Middle and Late Pleistocene river systems of northwest Europe. Earth Surface Processes and Landforms 35, 1071–1094.

White, M.J., Schreve, D.C., 2000. Island Britain–Peninsular Britain: palaeogeography, colonisation and the Earlier Palaeolithic settlement of the British Isles. Proceedings of the Prehistoric Society 66, 1–28.

White, T.S., Preece, R.C., Whittaker, J.E., 2013. Molluscan and ostracod successions from Dierden's Pit, Swanscombe: insights into the fluvial history, sea-level record and human occupation of the Hoxnian Thames. Quaternary Science Reviews 70, 73–90.

White, M.J., Bridgland, D.R., Schreve, D.C., White, T.S., Penkman, K.P., 2018. Well-dated fluvial sequences as templates for patterns of handaxe distribution: understanding the record of Acheulean activity in the Thames and its correlatives. Quaternary International 449, 23–57.

White, M.J., Ashton, N.M., Bridgland, D.R., 2019. Twisted handaxes in Middle Pleistocene Britain and their implications for regional-scale cultural variation and the deep history of Acheulean hominin groups. Proceedings of the Prehistoric Society 85, 61–81.

White, T.S., Bridgland, D.R., Allen, P., White, M.J., 2023. The Clacton-on-Sea GCR site (Clacton cliffs, foreshore and golf course): progressive enhancement of understanding at the interface between geology and archaeology. Proceedings of the Geologists' Association (this issue).

Wymer, J.J., 1968. Lower Palaeolithic Archaeology in Britain, as Represented by the Thames Valley. John Baker, London.

Wymer, J.J., 1988. Palaeolithic archaeology and the British Quaternary sequence. Quaternary Science Reviews 7, 79–98.

Wymer, J.J., 1999. The Lower Palaeolithic Occupation of Britain. Wessex Archaeology and English Heritage, Salisbury.

Zbyszewski, G., 1943. Les eléphants quaternaires au Portugal. Comunicações dos Serviços Geológicos de Portugal 24, 71–89.

Zbyszewski, G., 1946. Étude géologique de la region d'Alpiarça. Comunicações dos Serviços Geológicos de Portugal 27, 145–268.

Zbyszewski, G., 1977. Três ossos de vertebrados quaternários. Comunicações dos Serviços Geológicos de Portugal 61, 191–194.

Zeuner, F.W., 1959. he Pleistocene Period: Its Climate, Chronology and Faunal Successions. 2nd edition. Hutchinson, London, p. 447.