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Neanderthals at the frontier? Geological potential of southwestern South Scandinavia as archive of Pleistocene human occupation

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Abstract

Conservation and exposure of sediments is a prerequisite for finding archaeological traces. Regional geological history plays a significant and potentially biasing role in the reconstruction of the biogeographical distribution of Pleistocene hominins, particularly in previously glaciated regions. Here we present a digital geoarchaeological approach to a qualitative assessment of this archaeological bias in southwestern South Scandinavia. First, we identify time periods where the region was accessible and suitable for past humans. Our results show that only the longer Pleistocene interstadials offered terrestrial access in combination with potentially suitable habitats. Second, we present an extended digital geoarchaeological prospection of lacustrine, fluvial and palaeosols deposits and relict
landscape features. This review guides the identification of preserved sediments of Pleistocene origin and confirms that Pleistocene deposits and landscape features are present in the study area, however, generally in a poor state and low quantity/quality. Third, we map the modern occurrence of sediment exposure through natural processes and anthropogenic activities. Triangulating the cumulated results of these three steps we identify three target areas which offer promising combinations of these factors: A) the Holsted and Rødding hill islands in Central South Jutland; B) the moraine landscape of Central East Jutland, and C) the intersections of buried valleys on the east coast of Jutland. To test the robustness of our prediction, it is necessary to regularly survey open quarries and exposures in these target areas. This should be the aim of future studies, ideally conducted, we suggest, using citizen science approaches that include relevant stakeholders.
**Introduction**

Humans were present in parts of northern Europe already in the early Pleistocene (Roebroeks and Soressi, 2016), but the spread into southwestern South Scandinavia (henceforth swSS) seems to only have occurred much later (Riede, 2014). It is possible that this biogeographical pattern corresponds to past human dispersal, but it is also possible that this pattern is shaped, or at least highly accentuated, by taphonomy and glacial geology. This paper evaluates this bias by reviewing the Pleistocene geological features of swSS with a focus on identifying potential geological archives of Pleistocene human occupation. Such a baseline study represents a major advancement towards understanding the current absence of human taxa apart from anatomically modern humans (AMH, e.g. Neanderthals) in Scandinavia sensu lato.

Regarding evidence of human occupation throughout the entire Lower-, Middle-, and early Upper Pleistocene, the archaeological record of Scandinavia is scarce and highly ambiguous, controversial even (Donner, 2008; Holm and Larsson, 1995; Johansen and Stapert, 1995; Nielsen et al., 2017; Pettitt and Niskanen, 2005; Schulz et al., 2010). Much of this controversy can be accounted for by a patchy research history characterised by only few research projects specifically targeting the Neanderthal occupation in Scandinavia (see reviews in Holm and Larsson, 1995; Nielsen and Riede, 2018). In addition, the rarity of securely dated sedimentary archives with unambiguous traces of human presence has added strength to the notion that high northern latitudes (55°N – 70°N) were not inhabited by any human taxa prior to the Last Glacial Maximum (LGM, ~ 20 ka BP), but see discussion by e.g. Rolland (2010; 2014). Since extensive glacial erosion of interglacial/interstadial surfaces during the Pleistocene glaciations has affected present-day landforms, this lack of secure pre-LGM archaeological evidence can be the result of poor preservation of past landscapes with the potential to serve as archives of hominin activities. In addition, palaeo-landscapes with the potential to carry hominin traces have to be exposed in today’s landscape in order for these traces to be discovered, for example, through exposure by natural erosion or quarrying activities. This absence of extinct hominin taxa at higher latitudes is, however, challenged by...
the recent discovery that early modern humans already 30-40,000 years ago was adapted to harsh environment of altitudes above 4500 m (Zhang et al., 2018) and the finding that Denisovan-related DNA may have played a role in enabling modern-day Tibetans to live at the high plateau (Huerta-Sanchez et al., 2014). Therefore, the archaeological potential and current perception of any high-latitude region is closely aligned with both the de facto geological preservation of past landscapes and the way in which these past landscapes are exposed. Many aspects of Pleistocene geology of South Scandinavia have been studied (e.g. Bennike et al., 2007; Björck et al., 2000; Donner, 1995; Houmark-Nielsen, 2007, 2010; Knudsen and Larsen, 2009; Kuneš et al., 2013; Larsen et al., 2009; Sandersen et al., 2009; Svendsen et al., 2004), yet, with exception of the very late Upper Pleistocene, none of these have been explicitly framed within an archaeological perspective. To address this situation this study seeks, for the first time, to review the evidence of archaeologically relevant palaeo-landscape features in swSS and to discuss their potential for yielding late Middle and early Upper Pleistocene archaeological sites. Firstly, the relevance of the different palaeo-landscape deposits and features are narrowed down through the identification of times of opportunity, during which suitable local habitats and geographical links to the potential European hominin source-populations were in place. Secondly, and using publicly available geological data from a large number of cores and geophysical studies, the Pleistocene archaeological potential as a function of geomorphological conditions is evaluated by A) assessing the occurrence and preservation of relevant palaeo-landscape deposits and features, and by B) recognising places of active exposures of these sediments. These considerations together yield places of opportunity. Triangulating between these times and places of opportunity allows us to identify a number of target areas representing places where potentially interesting deposits are preserved at accessible depths in areas where exposure is expected. We then discuss the implications of the findings and address ways of prospectively testing the de facto archaeological potential of the identified target areas through initiatives such as active archaeological survey and citizen-driven monitoring networks.
Spatiotemporal scope

Recent ecological modelling indicates that at least part of swSS was within the habitat suitability of Neanderthals (Benito et al., 2017), prompting a closer look at the reasons for the current absence of Neanderthals here. The study area is the Jutland Peninsula *senso lato* in southwestern South Scandinavia encompassing present-day Schleswig-Holstein in Germany and Jutland in west Denmark (Figure 1). In this study, and owing to the availability of geological databases, there is an empirical emphasis on the Danish part of the peninsula. Habitual presence of hominins in temperate latitudes occurred in the late Middle and early Upper Pleistocene (Roebroeks, 2014) and provide the broad temporal frame for this study. Based on the Northwest European Stages from the global chronostratigraphic climate chart (Cohen and Gibbard, 2011) this is defined as the time period between 424,000 years Before Present (ka BP) and 29 ka BP; from the start of marine isotope stage (MIS) 11 to the end of MIS 3. The direct correlation of the Eemian Interglacial to the MIS stage 5e has recently been questioned by the identification of an asynchronous onset of the warming across Europe, specifically pointing to a late onset in Central Europe (Sier et al., 2011; Sier et al., 2015a; Sier et al., 2015b). This means that the Eemian *sensu stricto* probably does not correspond exactly to MIS 5e in the study area.
Figure 1. Map of the study area in southwestern South Scandinavia and its location in northwestern Eurasia. Coastline basemap © 2018 GADM and shaded relief basemap © 2009 - 2019 Natural Earth.
Material and methods

Materials used for this paper include a thorough literature review in combination with mapped data from the Geological Surveys of Denmark and Greenland (GEUS) available at their website (https://www.geus.dk/produkter-vdelser-og-faciliteter/data-og-kort/), including extracted data from the *Jupiter database*, which is a coring archive containing all geotechnical coring records conducted in the Danish region of the study area for ground water prospection (PC- *Jupiter*, 2001, data accessed in 2016). Additionally, the *Gerda* and *Marta* databases, containing information on geophysical data and marine resources respectively, were used as additional information sources when necessary. Maps accessed via GEUS WMS-service include:

- Ice advance map (“Israndslinjer og afsmeltning” published by Nordisk Ministerråd 1998, Andersen and Pedersen, 1998);

Buried valley data was obtained from the buried valleys project (“Begravede Dale”, http://www.begravede-dale.dk/, Jørgensen and Sandersen, 2007-2009a, b) for the Danish region of the study area and from the literature for the German and offshore part of the study area (Andersen et al., 2012; Gabriel, 2006; Gabriel et al., 2003; Huuse and Lykke-Andersen, 2000; Kluiving et al., 2003; Piotrowski, 1994; Sandersen et al., 2009). Digital elevation model (DEM) of Denmark was obtained from © Geodatastyrelsen: "Digital Højdemodel" 10m (DHM/Terræn 2007, UTM32, accessed via kortforsyningen.dk in 2016). Basemaps were obtained from the following licensed open sources: World shaded relief and oceans were obtained from © 2009 - 2019 Natural Earth; World coastline and stream maps were obtained from © OpenStreetMaps; individual countries coastlines were obtained from © 2018 GADM. For the identification and location of quarries, the website grusgrave.dk and satellite imagery (via Google Earth) was used. The maps are produced using QGIS (3.6.3 Noosa) and ArcGIS (10.5.1).
Climatic constraints and geo-environmental boundaries

Global climate oscillations and their geo-environmental effects on the study area pose physical limitations and ecological restrictions regarding the possible timing of hominin presence in swSS during the Pleistocene. Due to, on the one hand, expansion of ice sheets and, on the other hand, rising sea levels, both glacial as well as interglacial phases are associated with conditions temporarily impeding the northwards expansion of plants and animals to swSS.

During the Pleistocene global cooling events of the Elsterian-, Saalian- and Weichselian Glaciations, swSS was fully or partly covered by the Scandinavian Ice Sheet (SIS) (Houmark-Nielsen, 1987, 2007; Svendsen et al., 2004). Within these cold phases, the SIS advanced and contracted multiple times along various trajectories. When not directly covered by ice, swSS was frequently located at the immediate glacier-rim and exposed to the accompanying perennial cold temperatures, low biomass productivity, and generally harsh periglacial conditions (Figure 2A). During these periods of full and partly glacial cover as well as while severe periglacial glacial conditions persisted – swSS was not habitable for any larger mammals, including hominins. This broadly restricts the times for human dispersal into swSS to global warm phases where the successional migration of flora and fauna could have included hominins. The longest and warmest of these are conventionally referred to as the Holstein and Eemian Interglacials, the former corresponding with MIS 11 or MIS 9 (see for example discussion in Nitychoruk et al., 2006), and the latter to MIS 5e, although regional differences in its onset have been observed (Sier et al., 2015b). On a global scale, these warmer and wetter periods are associated with hominin range expansions linked to the increase in suitable habitats triggered by intense climate amelioration (Asmerom et al., 2018; Hosfield and Cole, 2018; Scerri et al., 2018).
A number of interglacial pollen records are known from swSS and are useful for evaluating the vegetation history of the region (Figure 2B). At least two separate full interglacials are identified in the pollen record of swSS, but only the assignment of the Eemian pollen succession is chronostratigraphically robust, since this has been verified by a larger number of records with chronometric constrains. A pre-Eemian interglacial, possibly corresponding to the Holstein Interglacial, is known from the pollen record observed at Trelde Klint, located north of Fredericia in Denmark (Figure 2B, Hartz and Østrup, 1899; Kuneš et al., 2013). Here, the interglacial (PZ 1-2) starts with the colonisation of pioneer trees – pine (*Pinus*) and birch (*Betula*) – and is followed by a spread of temperate and broadleaved forests dominated by hazel (*Corylus*) and alder (*Alnus*). The oligocratic phase (PZ 3) is characterised by the spread of dense coniferous forest dominated by spruce (*Picea*) and alder with some temperate tress such as oak (*Quercus*), elm (*Ulmus*) and lime (*Tilia*). The termination of the interglacial (PZ 4-6) is characterised by a reduction in temperate...
trees leading to an opening of the forest and a return of pine and birch, spruce and larch (*Larix*). The forest is slowly replaced by an open tundra landscape with sporadic conifers, which gradually becomes more open still until it is characterised by low shrub vegetation (e.g. cypress, juniper) marking the onset of cold conditions. The climate deterioration at the end of the interglacial is shortly interrupted by a climatic amelioration in PZ 6a allowing an open coniferous forest to return. The only faunal evidence from the Middle Pleistocene from Jutland is a horse (*Equus ferus*) radius, which was discovered at Vejlby, Denmark. Although its exact age is uncertain, Aaris-Sørensen (1998) assigns it to the Holsteinian Interglacial using a MIS 9 correlation.

A well-dated pollen profile from Hollerup, northern Jutland, Denmark (Figure 2B), indicates the succession of seven pollen-zones during the Eemian Interglacial in swSS. These attest to a very warm, humid and oceanic climate during its optimum (Andersen, 1965; Björck et al., 2000; Israelson et al., 1998). The interglacial onset is characterised by the colonisation of pioneer vegetation of pine and birch (PZ 1-2), followed in PZ 3-4 by a spread of a forest with elm (*Ulmus*), oak (*Quercus*), ash (*Fraxinus*), hazel (*Corylus*) and yew (*Taxus*) (Andersen, 1965). Pollen zones 3 and 4 – in particular PZ 4 – are considered the interglacial optimum (Björck et al., 2000; Streif, 2004). In PZ 5 there is a marked increase in hornbeam (*Carpinus*) and spruce (*Picea*) as well as an abundance of alder (*Alnus*), birch (*Betula*) and bracken fern (*Pteridium*). This period is generally referred to as the *Carpinus* phase, but Menke and Tynni (1984) include this phase in the climatic optimum. The end of the interglacial (PZ 6-7) is increasingly more arid, open and accompanied by an increase in pine pollen (Andersen, 1965; Björck et al., 2000). The humid and mild conditions in the interglacial optimum in swSS is confirmed by the presence of fallow deer (*Dama dama*) (Møhl-Hansen, 1955). Other faunal remains dated to the Eemian Interglacial include straight-tusked elephant (*Palaeoloxodon antiquus*), Merck's rhinoceros (*Stephanorhinus kirchbergensis*), steppe bison (*Bison priscus*), red deer (*Cervus elaphus*), elk (*Alces alces*) and possibly also giant deer (*Megaloceros giganteus*) (Aaris-Sørensen, 1998, 2010).
The local floral and faunal signal from these interglacial phases confirm that warm and humid conditions were present in swSS during the interglacials’ optima. Productive and mixed closed as well as open resource-rich forests, similar to the Holocene’ pre-agricultural northwestern Europe suitable for large mammals (Svenning, 2002), including potentially humans, existed. Yet, accompanying these climate ameliorations is the melting of the continental glaciers and subsequent sea-level rise. This is important because ephemeral marine transgressions in swSS owing to these dynamics may temporarily have hindered direct terrestrial access to the Jutland Peninsula precisely during times of warmth. Interglacial marine transgressions in swSS occurred when the rate of eustatic sea-level rise caused by the melting of continental glaciers exceeded the rate of land uplift caused by the shrinking terrestrial glacial mass during the warming. The rate of isostatic uplift is usually more rapid immediately after the glacial retreat because the degree of rebound decreases with increasing distance to the centre of the ice sheet (Eronen et al., 2001). Equilibrium conditions between eustatic sea-level rise and the isostatic uplift are, however, dependent on many, and often unknown, factors, e.g. weight, thickness, direction, number of re-advances and centre of the receding ice sheet (Lambeck et al., 2006). The exact depth and extent of the marine transgressions in swSS is therefore associated with uncertainty and scenarios cannot be readily transferred from one interglacial to another. Yet, based on the presence of stratified marine sediments in terrestrial cores in, for example, Schleswig-Holstein and the southern part of the Jutland Peninsula the approximate location of the Holstein and Eemian Interglacial transgressions have been tentatively reconstructed (Knudsen, 1980, 1985, 1993; Knudsen, 1988a, b; Konradi, 2001; Streif, 2004). These are shown in Figure 3.
The timing and rate of the inundations are not well known, but it has been suggested that the Eemian transgression coincided with the interglacial optimum (Konradi et al., 2005). Although the depth of the waterbodies are also unknown, small islands in the relatively protected estuaries may have made crossings possible through (Konradi, 2001). The presence of large terrestrial fauna north of the proposed inundated areas during the Eemian does support that crossings were possible, but it is difficult to
determine whether these animals colonised the Jutland Peninsula prior to, during, or after the inundation took place, or whether land-bridges or fords allowed crossings. Taken at face value, the mammalian community represented in the fossil record of South Scandinavia is impoverished compared to regions further to the south or west (Table 1).

These interglacial inundations are a reminder that climate amelioration is not the only parameter controlling dispersal opportunities into high northern latitudes. The warmest interglacials may therefore not be the most appropriate times for hominin expansion into swSS because of potentially risky crossings and/or an overall negative balance between socio-ecological push and pull factors owing to likely latitudinal differences in primary productivity – and with it carrying capacity – and the technological and social challenges of moving into higher latitudes (cf. Hosfield, 2016). The shorter and less pronounced interstadial warmings of the late Middle and early Upper Pleistocene, for instance during the late Saalian and early Weichselian Glaciations, should therefore also be considered. These may have presented suitable climatic and ecological conditions along with extended times of unimpeded terrestrial access.

A number of interstadial pollen records are known from swSS (Andersen, 1965; Foged, 1962; Kuneš et al., 2013). The pollen profile from Vejlby, located west of Fredericia in Denmark (Figure 2B) contains three successive interstadials, two of which (Vejlby I and Vejlby II) are tentatively considered to represent climate ameliorations (e.g. MIS 7) during the Saalian Glaciation (Andersen, 1965). Both the Vejlby I and II Interstadials are characterised by juniper shrub vegetation interspersed with open pine and birch forest. More warmth-dependant tree species did not recolonise the region in either of these interstadials (Andersen, 1965). Pollen data from the Leck core from northern Schleswig-Holstein in Germany (Figure 2B, Stephan and Menke, 1993; Urban et al., 2011) reveal a very warm interstadial with mixed oak forest which has been tentatively placed in MIS 7 and may correspond to the Reinsdorf Interstadial also identified at the eponymous archaeological site (Urban and Bigga, 2015). If the signals from Vejlby I or II and Leck respectively refer to the same MIS 7 warming, it shows that the boundary between southern boreal open forest with deciduous trees such as hazel (*Corylus*) and boreal forest with
pine, birch and spruce was located in northern Schleswig-Holstein during MIS 7, just like during the MIS 5c Brørup Interstadial described below (Emontspohl, 1995).

The early Weichselian Glaciation in swSS is dominated by a cooling tendency, interrupted by a couple of relatively mild interstadial events. In the pollen record from Brørup in Jutland, Denmark (Figure 2B, Hartz, 1909) – the type site of the Brørup Interstadial (corresponding to MIS 5c) – the first Weichselian Interstadial is characterised by the re-colonisation of birch (*Betula*), followed by larch (*Larix*), pine (*Pinus*) and spruce (*Picea*) (Andersen, 1961; Jessen et al., 1918; Jessen and Milthers, 1928). Like the potential scenario reconstructed for MIS 7 above, the transition from the southern to the middle boreal forest vegetation zones was situated in Schleswig-Holstein during this interstadial (Donner, 1995; Emontspohl, 1995). Pollen data from the Oerel core, Germany, indicates that the second Weichselian Interstadial, the Odderade Interstadial (MIS 5a), was more or less analogous to the Brørup Interstadial in northern Germany, albeit with colder winters and with larch appearing before spruce and alder and hazel appearing in the early middle part of the interstadial (Averdieck, 1967; Behre, 1989; Behre and van der Plicht, 1992; Behre and Lade, 1986; Donner, 1995; Helmens, 2014).

For the Middle Weichselian, the number of available terrestrial/lacustrine records decreases substantially in the study area. The northern German Oerel core provides indications of two interstadials during MIS 4. First the Oerel Interstadial, followed by the Glinde Interstadial (Helmens, 2014), but how these short ameliorations affected the vegetation in the study area remains unresolved.

MIS 3 in swSS is generally assumed to include first the Moershoofd Interstadial, followed by the Hengelo and Denekamp Interstadials, but they are all relatively weakly documented in the archives of the study area (Donner, 1995). The poor preservation of organic deposits dated to MIS 3 in itself suggests colder environments with a decrease in bioactive wetlands. Only one terrestrial record, identified on the Danish island of Sejerø in the Kattegat Sea, reveals a botanical record from the Hengelo Interstadial (Bennike et al., 2007; Houmark-Nielsen and Kolstrup, 1981). It contains ~90% non-arboreal pollen and is dominated by sedges and grasses (*Cyperaceae* and *Gramineae*). This indicates a treeless arctic environment with
dwarf shrubs (*Salix polaris*), herbs and wetland mosses. Mean July temperature is estimated to have been around 8 to 10°C (Bennike et al., 2007).

With the exception of giant deer (*Megaloceros giganteus*), the Weichselian faunal evidence from swSS is dominated by cold-adapted species such as mammoth (*Mammuthus primigenius*), woolly rhinoceros (*Coelodonta antiquitatis*), reindeer (*Rangifer tarandus*), Saiga antelope (*Saiga tatarica*), muskox (*Ovibos moschatus*) and steppe bison (*Bison priscus*) (Table 1, Aaris-Sørensen et al., 1990). However, few of these have been absolutely dated and thus likely reflect different periods within the Weichselian.

**Times of opportunity**

The above overview of the existing knowledge about the climatic constraints and geo-environmental boundaries of the study area offers a suitable frame for identifying potential *times of opportunity* for human occupation. Two observations are crucial for narrowing the temporal focus in the search for possible Neanderthal sites in swSS:

First – and contrary to previous work in the region that has focused on the Eemian Interglacial as the most likely period of hominin presence – we argue for a more critical view on the potential of these warm periods. With marine transgressions functioning as a physical barrier during parts of the full interglacials, strong push and/or pull factors are necessary to drive dispersals across and beyond inundated areas. While Neanderthals certainly were attracted to water bodies and coastlines (Cohen et al. 2012), evidence of sea crossings are very weak (but see counter arguments in Ferentinos et al., 2012); although we do not in principle discount the possibility that human taxa different from AMH had the capacity to make major sea crossings (for Wallacea see e.g. Ingicco et al., 2018; van den Bergh et al., 2016a; van den Bergh et al., 2016b). With the recent discovery of early *Homo sapiens* in the Apidima Cave in Greece – even predating a Neanderthal presence in the region – the complexity of the earliest human migration patterns continuously grows (Harvati et al., 2019). Yet, the notion of a deserted island Scandinavia finds a clear parallel in the significantly better investigated British Isles, where decades of targeted research have
failed to produce robust evidence for Neanderthal presence during MIS 5e (Ashton and Scott, 2016).

Although the swSS water-barrier was surely crossable in principle, as evidenced by the presence of large animals, high human population density was not a significant push factor in these scarcely inhabited northern latitudes during the Middle and early Upper Pleistocene (Jöris, 2014; Prüfer et al., 2017). Furthermore, the scarcity of MIS 5e faunal remains listed above hints at low mammalian biomass and diversity and hence a lack of subsistence-related pull factors in interglacial swSS. No large carnivore remains have been found in the context of the Jutland Peninsula from the interglacials (or indeed any of the pre-LGM periods), although indirect evidence of bite and gnaw marks point to the presence of at least smaller carnivores (Egeland et al., 2014; Riede et al., 2013). This might be significant for the presence/absence of hominins, as they are considered part of the larger carnivore guild of the Pleistocene landscape (Pettitt, 2012). During the Eemian, we find the nearest Neanderthal groups to swSS on the North European Plain, e.g. at the site of Neumark-Nord, where it seems that Neanderthals were successfully exploiting mosaic and humid interglacial forest environments (Pop and Bakels, 2015). Combined, these observations suggest little incentive for Neanderthals on the North European Plain to push or pull beyond significant barriers such as extended waterbodies during the Holstein or Eemian Interglacials.

Table 1: Schematic temporal overview of swSS and the geo-environmental parameters influencing the times of opportunity as discussed in the text.

<table>
<thead>
<tr>
<th>Glacial/Interstadial</th>
<th>Faunal remains</th>
<th>Palynological records</th>
<th>Reconstructed environment</th>
<th>Ice advances (expansion from)</th>
<th>Island condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weichselian Glaciation</td>
<td>Oerel (MIS 3)</td>
<td><em>Mammuthus primigenius</em>, <em>Megaloceros giganteus</em>, <em>Rangifer tarandus</em>, <em>Saiga tatarica</em>,</td>
<td>Oerel (DE)</td>
<td>Boreal forest</td>
<td>Main advance (E/N), Klintholm (E), Ristinge</td>
</tr>
<tr>
<td>Odderade (MIS 5 a)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>no</td>
</tr>
<tr>
<td>Glacial/Interglacial</td>
<td>Site</td>
<td>Fauna</td>
<td>Vegetation</td>
<td>Climate</td>
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<tr>
<td><strong>Eemian Interglacial</strong></td>
<td>Brørup (MIS 5c)</td>
<td><em>Ovibos moschatus</em>, <em>Bison priscus</em>, <em>Coelodonta antiquitatis</em>, <em>Lagomys hyperboreus</em></td>
<td>Shrubs, herbaceous vegetation</td>
<td>(E), Sundsøre (N)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>Castor fiber</em>, <em>Palaeoloxodon antiquus</em>, <em>Stephanorhinus kirchbergensis</em>, <em>Bison priscus</em>, <em>Cervus elaphus</em>, <em>Dama dama</em>, <em>Alces alces</em>, <em>Megaloceros giganteus</em></td>
<td>Herning, Hollerup (DK)</td>
<td>Coniferous forest, humid and oceanic</td>
<td>yes</td>
</tr>
<tr>
<td><strong>Saalian Glaciation</strong></td>
<td>Reinsdorf (MIS 7?)</td>
<td>Equus ferus</td>
<td>Mixed oak forest</td>
<td>Warthe (E), Drenthe (NE), Norwegian (N) no</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Wacken (MIS 9?)</td>
<td></td>
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<tr>
<td><strong>Holstein Interglacial</strong></td>
<td></td>
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<td></td>
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<tr>
<td>Tornskov, Kås Hoved, Trelde Klint (DK)</td>
<td>Coniferous forest, wet and warm</td>
<td>Temperate broadleaf forest</td>
<td>yes</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Elsterian Glaciation</strong></td>
<td>Lind, Ølgod I &amp; II, Harreskov (DK)</td>
<td>Cervus elaphus</td>
<td>Warm oceanic</td>
<td>Baltic (E), Middle (NE), Norwegian (N) no</td>
<td></td>
</tr>
</tbody>
</table>

Secondly, we argue for a less dismissive view on the potential of the longer and most pronounced interstadials. These warmings coincided with low global sea-level as continental ice sheets were confined to the polar region, meaning that swSS and adjacent submerged parts of the North Sea became an extended part of the North European Plain which accommodated large mammals including occasionally
Neanderthals. As verified by the vegetation signal in swSS, the longer interstadials in MIS 9 (~Wacken), MIS 7 (~ Reinsdorf) and MIS 5 (~ Brørup) could have offered suitable open forests of the middle boreal type. Although our knowledge of Neanderthal habitat preference is still incomplete – and these may have varied over time –, their attested presence in boreal-type habitats during times of global cooling provides at least indirect evidence for their ability to cope with such environments (Aldhouse-Green et al., 2012; Gaudzinski and Roebroeks, 2000; Green, 1984; Schild, 2006; Turner, 1998). Explicit push or pull factors are pertinent to evaluate if swSS could have been exploited in a similar fashion during the longer Pleistocene interstadials. But without significant barriers in the landscape, discrete pull factors may have included access to high quality Scandinavian flint (both erratic and primary) and hunting of seasonally migrating game. In sum, we argue that interstadials offered the most attractive and likely times of hominin presence in the study area and, therefore, that palaeo-surfaces from these periods offer the highest potential for finding evidence of human exploitation along this northern frontier.

**Geological prospection of swSS**

Setting off from this temporal baseline, geoarchaeological prospection aimed at locating sediments and geological features with a maximal probability of preserving traces of hominin presence is required to test and potentially verify and/or reject Middle-Upper Pleistocene hominin activity in swSS.

**Preservation and exposure**

Issues of preservation are particularly relevant for our study area because of substantial modifications to pre-glacial landscapes in lowlands as well as on higher plateaus by the repeated covering of the Scandinavian Ice Sheet (SIS) (Andersen et al., 2018). This intense glacial history has a negative impact on the expected preservation of any material, palaeontological or archaeological, embedded in these Pleistocene deposits, although more moderate views on glacial destruction of the subglacial landscapes also exist (Holm and Larsson, 1995; Kleman, 1994). In these moderate views, survival of relict landscapes has been linked to dry-bed glacial systems where the overlying ice sheet stays continuously
frozen and forms a protective shield over the landscape. Under these circumstances there is little subglacial meltwater, which is considered the main erosional force (Kleman, 1994). Archaeological and palaeontological finds emerging today along the edges of rapidly melting glaciers and thawing of permafrost do suggest that ice sheets, under certain conditions, may act protectively vis-à-vis organic layers, artefacts and ecofacts, albeit only as long as they are embedded in stable cold environments since deterioration starts immediately when thawing sets in (Andrews and MacKay, 2012; Dixon et al., 2014; Rechlin, 2013). Such conditions, however, were probably not present across most, if any, of the Pleistocene glacial/interglacial transitions in swSS, making it unlikely that subglacial preservation occurred to any appreciable extent.

Issues of exposure and accessibility of Pleistocene deposits are also relevant in the study area and are similarly related to glacial modifications of the landscape. Due to glacial deposition of thick moraine- and till deposits, Pleistocene deposits are usually buried deeply, sometimes below more than 100 meters of combined Holocene topsoil and Weichselian glacial moraine. Since the maximum depth of aggregate exploitation in at least Danish quarries is 25 meters (Ditlefsen et al., 2015), there is often little chance to encounter Pleistocene deposits in such places. Despite these caveats, careful triangulation between available geological prospection data and the previously identified temporal windows of interest provides the best and perhaps only way of systematically searching for traces of hominin presence prior to the LGM in swSS. In the following, we present such an approach, where we have mined available datasets reflecting the presence and accessibility of dated sediment packages from the relevant period. We then analyse and rank these with regard to their potential for yielding traces of hominin presence in order to assess spaces of opportunity for discovery.

General characteristics of the study area

The study area of swSS is dominated by unconsolidated or weakly consolidated sediments. No outcrops of hard bedrock are found. The exact order, direction, timing, duration and extent of the numerous ice
sheet pulses that occurred throughout the Middle and Late Pleistocene is subject to some uncertainty, especially for the older Elsterian and Saalian Glaciations (but see suggestion in Table 1, Houmark-Nielsen, 1987; Larsen et al., 2009; Svendsen et al., 2004). This is because swSS was at the outer perimeter of these glaciations, with repeated advances partly or wholly erasing and obscuring traces of previous glacial advances through glaciotectonic deformation, subglacial erosion and periglacial dynamics. The current landscape of the study area is characterised by a flat outwash plain in the west and an irregular moraine landscape in the east and north, separated by the small hills of the Jutland Ridge, which marks the so-called Main Stationary Line (MSL) of the Last Glacial Maximum (LGM). A number of pre-LGM landforms are preserved on the flat outwash plain – so-called hill islands or bakkeøer in Danish – which are raised topographic features that avoided major fluvio-glacial erosion and burial below meltwater sediments, but experienced severe periglacial nivation processes (Christiansen, 1996). The Jutland Peninsula is comparatively flat with a topography ranging between 7.5 and 170 meter above sea level (asl). The following geological overview is based on a comprehensive collection of data from geotechnical databases and repositories, geological reports, field surveys and a systematic literature study.

**Lacustrine deposits**

The majority of the swSS Pleistocene deposits have a glaciogenic origin and therefore have low organic contents. Low-energy freshwater paleolakes provide good climatic and environmental as well as, in principle, archaeological archives as they offer stratified lacustrine sediments. The lacustrine deposits are of particular interest because they represent deposition in basins within an otherwise terrestrial ecosystem. The surrounding flora, fauna and possibly hominin interaction with the lakeshore environment could therefore be represented in these basins through preserved micro- or macrofossils, bones and artefacts. Lake shores are known hotspots of large mammal, and by extension hominin, activity. The importance of lacustrine deposits as archaeological archives is widely acknowledged and attested by, for instance, the Eemian sites Lehringen and Gröbern in North Germany; and from Denmark, the Late
Clustering of interglacial lacustrine deposits have historically been documented around the towns of Herning in Central Jutland and Brørup in the northern part of South Jutland (Hartz and Østrup, 1899; Jessen et al., 1918; Jessen and Milthers, 1928). Both Herning and Brørup are placed on relict hill island features, which is likely also a contributing factor in the preservation of the lacustrine deposit. Other well-documented lacustrine deposits are known primarily from coastal exposures such as Emmerlev Klev and Stensigmose Klint near Als and Trelde Klint near Vejle, all in Southeast Jutland. In a lacustrine deposit identified in connection with railway construction at Ejstrup Station, near Kolding in Southeast Jutland, skeletal remains of a fallow deer and forest elephant have been uncovered (Nordmann, 1944). Although many of these sequences were initially discovered and most of them studied around 100 years ago, they still provide an important frame of reference for understanding the climatic and ecological development of the Pleistocene warm-phases in Denmark. There is also major untapped potential in the growing number of data repositories produced by the aggregate industries and activities related to groundwater prospection.

A targeted inspection of the Danish publicly available National Borehole Database (named Jupiter) shows that the well-known and published localities outlined above represent only a fraction of the total number of buried lacustrine deposits in Denmark. Jupiter is a national repository of all geotechnical boreholes (n >280,000) made in the context of official prospecting in Denmark (e.g. groundwater screening) and is continuously managed and updated by the Geological Survey of Denmark and Greenland (GEUS). Basic information on the stratigraphy and pedology of the cores is digitally available, making it possible to extract a relatively complete dataset of all the occurrences of preserved lacustrine deposits in the study area (PC-Jupiter, 2001). The stratigraphic descriptions and interpretations in the geotechnical reports are not as extensive and detailed as stratigraphic profiles studied for research purposes, yet the Jupiter database is entry-rich and geographically comprehensive. Another advantage is that the boreholes are
usually very deep (~100-150 meters), which means that the entire Quaternary is likely to be represented in the cores, except in the very north of Jutland (Vendsyssel) where deposits from the Eemian Interglacial have not been found above 125 m below current terrain as a result of glacioisostatic processes (Knudsen and Larsen, 2009).

A drawback of the database is the rarity of absolute dates associated to the cores; the Pleistocene part of most sequences is defined on the basis of relative stratigraphy alone. Also, Holocene lacustrine development is likely to be well-represented in the data, while soil surfaces likely are under-represented due to modern drilling methods that fragment pedogenic evidence. Importantly for this study, the distinction between interglacial and interstadial lacustrine deposits is not available in the data, and the term interglacial is used to define sedimentation during warm conditions as opposed to cold condition, rather than for the identification of specific depositional events. It is therefore likely that what is entered as interglacial lacustrine deposits in the dataset, also includes interstadial deposition events. At the level of individual borehole samples and based on the local stratigraphy, it is possible to make informed interpretations regarding the chronological attribution of the lacustrine deposits. For example, if the lacustrine deposit is covered by glacial moraine or glaciofluvial gravel, it must at least predate the Weichselian Glaciation. On a regional scale, the depth of the deposit can be used as a general guideline to suggest a pre- or post-Weichselian attribution of the lacustrine deposit. These data therefore allow a general discussion of the geographical spread and density of Pleistocene deposits with high organic preservation potential in Denmark (Nielsen, 2016).

Figure 4 shows the distribution of all the lacustrine deposits registered in Jupiter according to depth of the layer under present-day terrain and in relation to the advances of the Weichselian Glaciation. The number of observations is higher in South Denmark compared to the rest of Denmark and are particular abundant in the southern part of Jutland and on the island of Funen. As a result of Weichselian soil deposition and periglacial processes, lacustrine deposits are generally found deeper in the cores east of the MSL and higher in the cores west of the MSL.
Figure 4. Distribution and depth of interglacial lacustrine deposits identified in geotechnical boreholes. Colours refer to the depths in ranges in meters below the current surface independent of elevation. Several boreholes contain more than one lacustrine deposit at various depths, that is for example the case for most of the boreholes from North Jutland, but in these instances the highest deposit in the stratigraphy defines the colour of the dot. Borehole data from the GEUS Jupiter database (PC-Jupiter, 2001). The full extent of the Weichselian glaciation is shown in light blue, with red dotted lines indicating the marginal pulse of glacial advances before/after the maximum extent (“Israndslinjer og afsmeltning” published by Nordisk Ministerråd 1998, Andersen and Pedersen, 1998).
The distribution shown in Figure 4 indicates that despite swSS having been exposed to extensive and repeated Pleistocene geological erosion from advancing ice sheets, regional marine transgressions and aeolian soil removal, lacustrine deposits are frequently found in South Jutland. Of these, the most accessible ones (<10 m) are located west of the MSL, although given the general correlation between depth and chronology the deeper layers may be of greater interest vis-à-vis Pleistocene palaeontology and archaeology.

Combined with the other proxies discussed below, the borehole information can guide the strategic identification of archaeological target areas. The following discussions of geological deposits (fluvial and palaeosols) and relict landscape features (buried valleys, hill islands, submerged landscapes and lignite basins) also draw on information available in the Jupiter database.

**Fluvial deposits**

Fluvial sedimentation is characterised by (often) high-energy deposition of large amounts of material such as sand silt, clay and gravel. There is therefore a high degree of re-deposition and long-distance transport associated with this type of sedimentation. The potential of fluvial gravel deposits as archaeological repositories has been well-documented in the river terraces of NW Europe (Antoine et al., 2003a; Basell et al., 2011; Bridgland, 1995, 2000; Hosfield, 2011; Howard et al., 2007; Schreve and Bridgland, 2002), i.e., at the fossil-bearing sites Swanscombe in Britain (Stringer and Hublin, 1999) and Steinheim in Germany (Adam, 1988; Orschiedt, 1996). The formation of large-scale terraces along palaeo-rivers is driven by climate fluctuations, enabled by gradual isostatic uplift and are primarily preserved beyond the area covered by Quaternary glaciations (Bridgland, 2000; Bridgland, 2006). Absolute dating of intermittent layers of fossiliferous deposits has provided evidence for a correlation with oceanic climate records, showing the synchronous formation of river terraces and global interglacial-glacial cycles (Bridgland, 2000).
Large-scale aggradational palaeo-river terrace-systems are not present in swSS. The area was completely covered by the Elsterian and Saalian Glaciations which remodelled the underlying, older interglacial landscape and erased the visible traces of intermittent river terrace formation. Since the last Weichselian Glaciation did not cover Denmark completely, Eemian fluvial terraces could potentially have preserved, but the proximity to the ice margin may also have caused these to have been largely or entirely destroyed by periglacial erosion. Furthermore, swSS does not have river systems with a deep Pleistocene origin (cf. Gibbard, 1988). The largest Danish river systems, Skjern Å and Gudenåen, only formed after the Weichselian glaciation (Larsen and Kronborg, 1994). Although smaller- and larger-scale interglacial fluvial sedimentation and terrace built-up would have taken place along paleo-rivers within, for instance, now buried tunnel valleys, the size of these palaeo-rivers, the amount of sediment-deposition and the level of subsequent subglacial erosion make these deposits comparably small and deeply buried – and hence of comparatively low potential as artefact- or fossil-bearers.

Most of the known fluvial deposits in swSS are of glaciofluvial origin related to recurrent glacial meltwater activities. This fact principally renders them an unlikely source of archaeological material, except in a scenario where meltwater picked up archaeological material from the preceding interglacial. In this case, the archaeological material would be in heavily altered secondary contexts, embedded within glaciofluvial deposits, and would have been exposed to a dynamic environment causing e.g. rolling, weathering, and splintering. Artefacts from such contexts can provide valuable information (cf. Hosfield, 2011) but are far from ideal for establishing robust baselines of human presence.

Glaciofluvial gravel- and sand-deposits are abundant in the Danish subsoils. The larger pockets are primarily located in Central Jutland, along the MSL, and on the western outwash plain (Ditlefsen et al., 2015). In many places these deposits are mined by the aggregate industry for gravel and sand. With flagship sites such as Maastricht-Belvédère in the Netherlands (De Loecker, 2006; Roebroeks et al., 1992; Roebroeks et al., 2012) and Boxgrove in Britain (Roberts and Parfitt, 1999), quarries are widely recognised for their potential to expose archaeological material and sites. Unfortunately, the highly
industrialised extraction methods used today including digging below the groundwater table has reduced discovery rates in these contexts. Finds are usually only recognised after mechanic sorting and therefore lack stratigraphic information. Another issue is that weathered artefacts require highly specialised training to be identified. Furthermore, the recognition of artefacts is also dependent on the willingness of quarry workers/owner and/or stable collaborations with amateur archaeologists.

**Palaeosols**

Palaeosols are intact former surfaces preserved within a sequence of deposits (Catt, 1990; Valentine and Dalrymple, 1976). Here the main focus is on intact and in situ terrestrial surfaces. Palaeosol horizons are often preserved below aeolian deposits owing to rapid and non-destructive burial. Rapid burial caused by a mudslides or periglacial solifluction can also lead to intact preservation of a palaeosol. Palaeosols present ideal circumstances for preservation of in situ open-air archaeological sites, and several localities in the loess-covered region of northwestern Europe (Antoine et al., 2003b), eastern Europe (Iovita et al., 2014; Łanczont et al., 2015) and Central Asia (Chlachula, 1999) are known.

Because of glacial history, palaeosols are generally rare in northern latitudes and when found, often highly fragmented. Nonetheless, palaeosols have been discovered in Norway (Olsen, 1998) and Northern Germany (Dücker, 1965; Dücker and Menke, 1970; Stremme et al., 1982; Stremme, 1964). In Denmark, pre-Holocene palaeosols are reported from Oksbøl (Gravesen et al., 2004; Sjøring, 1977), Give (Frederiksen, 1977), Asklev (Dalsgaard, 1983; Kristiansen et al., 2009), Emmerlev Klev (Felix-Henningsen, 1979; Felix-Henningsen, 1981), Holsted, Ribe (Frederiksen and Sjøring, 1979), Helberskov (Sjøring and Skibsted, 1992), Hinnerup and Skellerup-Nygaarde (Figure 5 and Table 2). Most of these are fragments of podzols, which have preserved within protective sub-moraine depressions and have later become exposed in quarries. The robusticity of the proposed chronological attribution of these podzols is varying, and in the case of the Helberskov podzol, its pre-Weschelian attribution is very weakly supported by geomorphological evidence. Podzolisation occurs in temperate nutrient-poor sandy and highly acidic
soils. Therefore, these weathered and fragmented podzols do not offer good archaeological preservation potential compared to their counterparts in the loess sections of, for instance, Central Europe.

Figure 5. Location of the palaeosols discussed in the text and listed in Table 2. Coastline basemap © 2018 GADM.

Table 2: List of palaeosols known from the Danish region of the study area, their proposed age, type and available publications.

<table>
<thead>
<tr>
<th>Palaeosol</th>
<th>Proposed age</th>
<th>Type</th>
<th>Publications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oksbøl</td>
<td>Eemian</td>
<td>Podzol</td>
<td>Sjørring 1977; Skibsted, 1992; Sjørring and Frederiksen, 1979</td>
</tr>
<tr>
<td>Asklev</td>
<td>Eemian</td>
<td>Podzol</td>
<td>Dalsgaard, 1983; Kristiansen et al., 2009</td>
</tr>
<tr>
<td>Give</td>
<td>&gt;Weichselian</td>
<td>Podzol</td>
<td>Frederiksen, 1977</td>
</tr>
</tbody>
</table>
Relict landscapes

Buried tunnel valleys

Tunnel valleys form as subglacial erosion corridors by meltwater cutting into the underlying strata at the glacial margins, either gradually over time or rapidly (Jørgensen and Sandersen, 2006; Piotrowski, 1994). The orientation of tunnel valleys therefore largely corresponds to the overall movement of the various ice advances (Jørgensen and Sandersen, 2006). Open as well as buried tunnel valleys are present in the study area. The open tunnel valleys formed during the Weichselian Glaciation and are visible in the landscape today (Smed, 1979, 1981a, b, 1982; 1998). The buried tunnel valleys that formed during the Elsterian and Saalian Glaciations are partly or completely filled with sediment, sometimes rendering them unrecognizable in the current landscape (Jørgensen and Sandersen, 2006; Milthers, 1925; Ussing, 1903). The archaeological potential of valleys is, for example, attested to by the Neanderthal hunting site at Salzgitter-Lebenstedt in the central part of North Germany (Gaudzinski and Roebroeks, 2000).

Tunnel valleys are not unique to swSS, and can be found in all previously glaciated areas (Donner, 1995; Dürst Stucki et al., 2010; Ehlers and Linke, 1989; Kluivering et al., 2003; Smed, 1998). Studies have identified open and buried tunnel valleys in Northern Germany (Gabriel et al., 2003; Piotrowski, 1994).
and offshore in the Danish North Sea (Andersen et al., 2012; Huuse and Lykke-Andersen, 2000). Here, the focus is on the valleys retaining terrestrial deposits and their function as repositories for Pleistocene sediments. The buried valleys of Denmark have recently been comprehensively reconstructed and mapped. This provides a unique framework for understanding the evolution of the Pleistocene landscape in the study area. This reconstruction is based on a combination of borehole data, Transient Electromagnetic Data (TEM) and seismic data (Jørgensen and Sandersen, 2007-2009b; Jørgensen and Sandersen, 2006; Sandersen and Jørgensen, 2003).

In Denmark, the buried valleys are most abundant in Jutland, particularly in its eastern part. There are fewer buried valleys on Funen, primarily located in its northern part. Zealand has very few buried valleys and is dominated by one large and fully buried valley which transects the northern part of the island in an ENE-WSW going direction (Figure 6). The latter’s size, direction and isolation suggest a different origin than the smaller and often overlapping systems of valleys (Jørgensen and Sandersen, 2007-2009b).

Offshore valleys are observed in the Great Belt and in the southern part of Little Belt. The Danish buried valleys are primarily filled with glacial sediment such as till, clay, gravel or sand, but according to the report associated with the dataset (Jørgensen and Sandersen, 2007-2009b), 46 valleys yielded observations of lacustrine deposits linked to either interglacial or interstadial deposition. When supplemented with the observations from the Jupiter borehole database, the distribution of buried valleys with lacustrine deposits can be refined (n = 55, marked in green in Figure 6). Also, thanks to the Jupiter data it is possible to assess the wider distribution of lacustrine deposits in a given area along with the depth of the lacustrine deposits found in each valley, which in turn reflects how likely they are to be exposed by invasive construction or aggregate activities.
Figure 6. Distribution of fully (dark grey) and partly (light grey) buried valleys in Denmark. Valleys containing observations of interglacial (Ig)/interstadial (Is) lacustrine deposits are marked in shades of green; Dark green representing fully buried valleys and light green representing partly buried valleys. Exemplary insert shows a closer look at the partly and fully buried valley system with interglacial deposits observed in connection with Horsens Fjord. Buried valleys from Jørgensen and Sandersen (2007-2009a). Coastline basemap © 2018 GADM.
The detection of interglacial lacustrine deposits is critical for identifying buried terrestrial valley systems with potential for preservation of organic remains such as fauna, flora and archaeological sites. Because the valleys are deeply buried, the best approach is to (i) focus on valleys associated with observations of interglacial deposits and to (ii) identify places where these overlap with aggregate extraction and large-scale construction activities.

**Hill islands**

In contrast to the often deeply buried valley systems discussed above, Pleistocene deposits can also be preserved in isolated remnants of relict landscapes. In the study area, this type of context is restricted to the so-called hill islands of West Jutland (bakkeøer in Danish after Dalgas, 1870). These hill islands are isolated remnants of past glacial landscapes, which avoided extensive pro- and periglacial erosion and today rises above the otherwise flat landscape (Høyer et al., 2013). Since West Jutland was last glaciated during the Saalian Glaciation, the sediment making up the hill islands are mostly likely to be, in addition to Holocene top soils, primarily of Saalian age, but moraine and till deposition from earlier glaciations (e.g. the Elsterian) may make up the lower sections (Sjørring and Frederiksen, 1979). In principal, *in situ* archaeological material could be preserved in sediments within subglacial depressions acting as traps for lacustrine or palaeosol deposits. These could become exposed through aggregate industry activities on the hill islands, or through erosion along the hill edges. Yet, in the unconsolidated sediments covering the entire study area, chances of *in situ* preservation are very low, however, as solifluction and nivation processes acting on past land surfaces have been intense throughout the entire last glaciation (Christiansen, 1996). By the same token, the preservation of Pleistocene archaeology in secondary contexts in sediment packages preserved as part of these hill islands is possible.

There are six major and numerous smaller hill islands in the study area (Figure 7). The largest hill islands (Skovbjerg, Varde, Esbjerg, Holsted, Rødding and Toftlund) follow the western coastline and decrease
slightly in size in a southward trajectory. Hill islands continue in a similar fashion in the adjoining region of Schleswig-Holstein, northern Germany (Ehlers et al., 2004). The Skovbjerg and Varde hill islands are the largest and most northerly ones (Høyer et al., 2013; Madsen, 1921; Niebe et al., 1990; Ussing, 1903). Here, a number of observations attest to the preservation and exposure of interesting geological features (most of them early Pleistocene and therefore not part of the main scope here, but see Houmark-Nielsen et al., 2006), including the Eemian/early Weichselian lacustrine deposits from Solsø lake and Herning bog mentioned in the section on lacustrine deposits (Larsen and Kronborg, 1994; Thomsen, 1999). Except for the Skovbjerg and Varde hill islands, geological studies of the individual hill islands in their entirety are not available.

Figure 7. Location and outline of the Danish hill islands on a digital elevation model shown in the hillshade (DHM/Terræn10m, ©Geodatastyrelsen). Coastline basemap © 2018 GADM.
Possible remnants of palaeo-coastlines have been occasionally been observed in on these hill islands, for instance, the suggested relicts of an Eemian shoreline on Jejsing hill island (Gravesen et al., 2004) and on the western rim of Skovbjerg hill island (Larsen and Kronborg, 1994; Thomsen, 1999). These observations suggest at least some potential for hill islands to preserve Pleistocene deposits of archaeological interest.

Submerged landscape of the Danish North Sea

Focus on the submerged palaeo-landscapes of the North Sea has grown in recent times, targeting different types of finds (van Kolfschoten and van Essen, 2004; Verhart, 2004), different timeframes (Gaffney et al., 2007; Roebroeks, 2014; White, 2006), and different offshore sectors (Antoine et al., 2003c; Glimmerveen et al., 2004; Gupta et al., 2007; Peeters and Momber, 2014). These investigations have already demonstrated the great potential of these submerged landscapes for recovering Pleistocene artefacts and fossils, including spectacular examples such the Neanderthal cranial fragment recovered in the Dutch North Sea (Amkreutz et al., 2010; Hublin et al., 2009).

The eastern part of North Sea, including the Danish and German territories, is relatively unexplored when it comes to the potential of Pleistocene archaeology, although as part of the increasing attention on submerged landscape, this issue is being addressed for the Late Glacial and Holocene periods (Flemming et al., 2014). Few if any verified remains of Pleistocene fauna from submerged contexts are known from the Danish North Sea sector (Kim Aaris-Sørensen, pers. comm. 15.12.2015). This lacuna can be a result of a combination of aspects, including poor preservation caused by glacial erosion, palaeoclimatic conditions unsuitable for hominins as well as fauna, lack of research attention and lack of collaboration with active stakeholders.

The seafloor of the eastern North Sea became part of the wider terrestrial landscape of northwestern Europe during glacial periods. The thickness of the Quaternary sedimentation is c. 1000 m in the central and deepest part of the Danish North Sea basin (Central Graben) and decreases towards the margins of the
basin due to uplift and erosion (Huuse and Lykke-Andersen, 2000). A number of fully buried Pleistocene valley systems have been identified below the current seafloor off the west coast of Jutland (Huuse and Lykke-Andersen, 2000). These are invisible in the current geomorphological landscape of the basin, but visible from seismic and borehole data (Andersen et al., 2012; Huuse and Lykke-Andersen, 2000). Most of these buried valley systems are between 100 and 350 meters deep, run in a N-S trajectory and their shoulders usually lie 10-50 m below the current sea bottom terrain. This suggests that they are relatively deeply buried and probably of an Elsterian or possibly Saalian age (Huuse and Lykke-Andersen, 2000). Just as their terrestrial counterparts, these valleys served as sedimentation traps and, hence, hold some potential as archaeological archives.

Licensed aggregate areas off the west coast of Denmark make up areas where potential archaeological and zoological remains could be recovered during dredging. In the North Sea, these are primarily located in the Jyske Rev off the west coast area between Ringkøbing and Thy – a map of the licensed areas can be accessed via the MARTA database curated by GEUS. The most common extraction technique used in the Danish North Sea is suction dredging, where the target deposit such as sand or gravel is sucked by vacuum into a tube and onto a boat where the water is drained. This type of dredging is usually limited to 28 m below the sea floor terrain, and therefore primarily reaches postglacial, Late Glacial or at most glacial deposits. These constraints reduce the likelihood that deposits of older Pleistocene age are exploited and, hence, reduces the potential of Pleistocene archaeological material being discovered as a result of suction dredging in the study area. Trawling provides another mode of find recovery. Disturbance of superficial marine sediment is highest when fishing for blue mussels (Gislason et al., 2013), which involves the highly destructive scraping of the sea floor. This type of fishing is mostly limited to the Limfjord area and fjords in the Inner Danish Waters. It is not practiced to any appreciable degree in the North Sea sector (Gislason et al., 2013). Other types of trawling also cause disturbance of the sea floor, such as beam trawling and bottom trawling. These methods are applied to fishing in large parts the Danish North Sea (Gislason et al., 2013) and could perhaps yield future discoveries. The
expanding offshore renewable energy initiatives, e.g. the Horns Rev windmill farm off the shore of Esbjerg, southwest Jutland, may also provide access to Pleistocene deposits through deep coring activities in connection with the establishment of new mills (Kristoffersen, 2006). The archaeological potential of the submerged North Sea landscapes is exciting, but as of yet, there is very little collaboration between the archaeological- and industrial stakeholders in swSS. There is still much more to learn about these submerged landscapes. Future research and collaborative initiatives are needed to establish the precise archaeological potential of the Danish North Sea area.  

**Lignite basins**

Lignite, or brown coal, is naturally compressed peat. The archaeological potential of lignite basins does not lie in the lignite itself, which is usually formed prior to the Pleistocene, but rather in the fact that lignite is regularly exploited by the aggregates industry. The presence of lignite often indicates stable basin conditions providing good circumstances for organic and at times archaeological preservation above or between the lignite deposits. Open-cast lignite mines such as of Schöningen, Germany (Lang et al., 2015), and Marathousa, Greece (Tourtoulakis and Karkanas, 2012), have yielded extraordinary archaeological finds. The Danish lignite is mostly found in areas with Miocene subsoil, primarily in Jutland south of the Limfjord (Rasmussen, 2004). It formed in the Neogene (Miocene, Pliocene) in warm marshland environments and is preserved within basins, channels and valleys which avoided erosion during Pleistocene glaciations (Larsson et al., 2011). The Danish lignite veins appear at varying depths from close to the surface to below 30 m. The layers’ extent range from 0.1 m to 8 m in thickness and sometimes overlay each other (Hartz, 1909; Koch, 1989; Milthers, 1941; Rasmussen, 2004). The largest basins observed in Denmark measure up to 1.5 km in diameter, but the average size is around 500-300 m in circumference. Deposits are primarily known in Central Jutland where they are present closer to the current surface (< 10 m in certain areas) due to tectonic faulting (Figure 8). These accessible lignite areas
were exploited industrially, particularly during the Second World War (Koch, 1989; Koch et al., 1973; Milthers, 1941).

Figure 8. Map of the Danish Pre-Quaternary underground showing Central Jutland where most of the historic lignite extraction took place due to the faults in the region, which improved accessibility in pre- and early industrial times. Three examples of boreholes (extracted from the Jupiter database) with lignite deposits are shown. Pre-Quaternary underground map from (Håkansson and Pedersen, 1992). Coastline basemap © 2018 GADM.

There are some important differences between the lignite basins in the study area and the general characteristics of known archaeology-bearing lignite basins in Europe. Most importantly, the basins in the study region are comparably small, shallow and highly prone to erosion, allowing only limited basin sedimentation. Secondly, the extraction of lignite, at least in Denmark, ceased in the 1970s, and there is therefore currently little opportunity to make discoveries within these basins (Koch et al., 1973; Milthers, 1941). By the same token, it is important to note that only the lignite close to the current surface has ever been exploited. These shallow basins have the lowest archaeological potential and this may partly explain the lack of archaeological discoveries from these contexts.
Results

Places of exposure

Our digital geoarchaeological prospection confirms that Pleistocene deposits and landscape features are present in the study area. They are, however, not in a general state or quantity comparable to regions of northwest Europe with well-documented Lower, Middle and Upper Pleistocene archaeological sites. It is therefore possible that the absence of pre-Weichselian archaeology in the study area is driven largely by preservation bias. Besides preservation, exposure is an important factor influencing the likelihood of archaeological discoveries. Since, as shown above, remnants of relevant palaeo-landscapes are in many places deeply buried in unexposed sediments. The combined occurrence of three criteria is therefore essential for archaeological remains to be recovered in primary or even secondary stratigraphic contexts today: 1) suitable past conditions and human presence, 2) continuous preservation, and 3) modern-day accessibility.

With the purpose of identifying explicit locations where the above criteria 2 and 3 are fulfilled, we combined the information from our digital gearchaeological prospection with information on places of active exposure. Places of active exposure include dynamic natural landscapes such as coastlines and river shores, as well as anthropogenic exposures such as quarries and mines. The distribution of quarries was mapped from aerial- and satellite image reconnaissance and field survey (Figure 9). These exposures offer different conditions. Exposure of coastal cliff profiles is strongly determined by seasonality, wave exposure and rising sea-level causing varying erosion rates. Exposures of banks along rivers and waterways are influenced by fluctuations in discharge, embankments and by efforts to mitigate nutrient export to coastal water, which have markedly lowered bank erosion in recent decades. Conversely, the rate of exposure is relatively high and stable in controlled extraction environments such as active quarries where sediment removal is constant and often very deep, albeit limited by groundwater.
Figure 9. Distribution of quarries collected from grusgrave.dk and from satellite aerial survey with
Identifying target areas

The various combinations of co-occurrence of past and present features can be ranked by their relative likelihood to serve as, and reveal, archaeological repositories. We suggest that lacustrine deposits have a particular guiding potential due to their combined preservation quality and widespread distribution. Their presence further implies minimum disturbance and thereby the possibility of making *in situ* prehistoric finds in datable contexts. When lacustrine deposits are located in buried Pleistocene valleys, they are more likely to represent Pleistocene warm phases instead of postglacial kettle-holes and lakes.

Furthermore, in cases where lakeshores have avoided subsequent erosion by being rapidly covered by sediments and/or avoiding destructive glacial processes (e.g. on hill islands), they represent potentially undisturbed archaeological archives, albeit often at considerable depths from the current land surface. The best means for exposing these deposits are therefore in aggregate industrial contexts where exploitation, and thus exposure, is deep and constant. Using such a deductive framework to evaluate the local overlaps of geological features and exposure potential, we identify three overall target areas with suitable conditions for holding as well as exposing Pleistocene deposits. These are:

A) Holsted and Rødding hill islands in Central South Jutland (Figure 10A). Here there is a number of fully buried valleys with interglacial lacustrine deposits (identified both in the valley infill and in the borehole data) and at least three active quarries.

B) The moraine landscape of Central East Jutland (Figure 10B). Here, there is a large number of both fully and partly buried valleys with some on them containing interglacial lacustrine deposits (mainly known from the valley infill). This area lies at the rim of the Weichselian moraine and there are numerous quarries in this area, although none of these currently overlap with buried valleys with interglacial lacustrine deposits. New quarries opened in the area or the expansion of existing quarries might hold potential in the future.
Figure 10. Triangulation of the digital geoarchaeological prospection performed in the study and the identified target areas: A) Holsted and Rødding hill islands, B) Jutland moraine landscape and C) Intersections of buried valleys and active coasts. Projected on a digital elevation model in semi-transparent hillshade (DHM/Terræn10m, ©Geodatastyrelsen). Coastline basemap © 2018 GADM.
C) The intersections of buried valleys on the east coast of Jutland (Figure 10C). Here, there is a number of fully and partly buried valleys, some of which must represent palaeofjords; these hold a large number of interglacial lacustrine deposits. The largest of these is host to at least four active quarries operating in the branches of this valley system, providing optimal conditions for future surveying.

With the identification of these target areas it is possible to direct and focus future geoarchaeological survey efforts and thereby to significantly improve the likelihood of making new observations relevant to the question of the earliest occupation of southwestern South Scandinavia.

Implications and future perspectives

The northern dispersal of early hominins is a matter of continuous and contentious debate. Most biogeographical studies suggest that North Eurasia was at the periphery of the hominin range until the very late Pleistocene or even the early Holocene. We acknowledge that the archaeological evidence at present supports a late human colonisation of high northern latitudes (above 55°N), but stress the importance of geological dynamics influencing archaeological site representation. The strongly disturbing effects of, for example, glaciers and marine inundation on surface soil integrity can be a major source of bias in macro-regional and global comparisons of human dispersal and distribution. It is therefore important to be cognisant of the degree to which local and regional circumstances can both positively and negatively affect the preservation and exposure of archaeological material. It is, however, very difficult to quantify the relative loss of archaeology due to poor preservation or lack of exposure, but local/regional studies focusing on the status of the geological baseline, like the one presented here, provides the necessary foundation for at least a qualitative assessment of this bias. Although we stress the importance of potential geological biases, these probably do not solely explain the absence of humans in swSS and across the high northern latitudes during the Middle Pleistocene. Climatically-driven ecological and adaptive constraints most likely restricted the geographical expansion of many pre-modern hominin
populations during significant portions of the Pleistocene. The advancing continental glaciers, for example, caused swSS to be partly or fully covered by ice during the most severe glacial periods. During these periods, hominins contracted or went extinct at higher latitudes.

At present, it is unclear whether swSS was consistently or just temporarily uninhabitable. Although there appears to be a tacit consensus that early hominins did not occupy periglacial areas, this is primarily based on broader sentiments of human ecology and is not as such confirmed empirically. Recent finds of Middle Pleistocene hominins in high-altitude contexts raise doubts about the categorical inability of operating in extreme environments (Zheng et al., 2018; Huartes-Sanchez et al., 2014). Furthermore, modelling of Eemian Neanderthal habitat suitability has shown that topography and summer rainfall defines habitat suitability at the local scale and that the southwestern part of the Jutland Peninsula was within at least the marginal suitability range exploited by Neanderthals at this time (Benito et al., 2017). This is further corroborated by GIS modelling of Eemian palaeoclimate zones, showing a Neanderthal preference for warm temperate and mesic climates (Nicholson, 2017). Such environs were at least temporarily in place in swSS throughout various glacial-interglacial cycles.

The discussion of whether Neanderthals or another taxa of humans of the Middle and Upper Pleistocene could have been habitual or ephemeral occupants above c. 55° northern latitude is ongoing (Hoffecker, 2005; Slimak et al., 2011; Zwyns et al., 2012). Recent focus on and increase in the number of known Pleistocene sites from other “peripheral” areas (as defined by the traditional centre-margin view of West Europe, coastal Levant and South/East Africa as cores) such as Mongolia (Zwyns et al., 2014) and Siberia (Pitulko et al., 2016), indeed shows the potential of, and need for, ongoing archaeological surveys. Added to the recently proven and offspring-bearing interaction between different archaic hominins sharing geographical territories in the Altai mountains, Russia (Slon et al., 2018), it is clear that there is still room for surprises when it comes to our understanding of the behaviour and resilience of hominin groups within the temperate latitudes of Eurasia. However, organic preservation, soil displacement and sediment exposure are important factors in the success of such surveys. Keeping with this, another important aspect
is robustness of interpretations, which has to be extraordinary for extraordinary claims. A number of sensational sites pushing the physical and adaptive boundaries of human taxa apart from AMH has surfaced in recent years, which after more rigorous scrutiny appear contentious. A good example of this is the Cerutti Mastodon site in southern California, where a recent interpretation of the site dated to the Eemian Interglacial, suggests that AMH was not the first human taxon to arrive on the North American continent (Holen et al., 2017), whereas ensuing critique questions the unambiguous presence of humans at the site (Ferraro et al., 2018; Hovers, 2017). It is therefore crucial to find the right balance between empirically-founded scepticism and open curiosity when moving beyond conceptual frontiers.

Addressing this exact problem, we have presented a digital geoarchaeological perspective aimed at formulating a robust interpretation regarding the influence of sediment preservation and exposure to the potential Pleistocene archaeology of southwestern South Scandinavia. We have identified specific areas within the case study region that should be the target of future systematic investigation. Systematic geoarchaeological survey schemes are time- and skill-demanding and require efficient documentation procedures. Citizen science has gained popularity in recent years as a bridge between the archaeological scientific community and the wider public (Gibb, 2019; Lambers et al., 2019; Metz, 2015); the involvement with stakeholders outside of the scientific community offers a potential solution to some of the challenges and constraints archaeological survey projects face (e.g. short-term, result-driven funding, lack of man-power). Due to the different character of archaeological survey activities to more traditional citizen science objectives (i.e., as counting the occurrence of certain species), it is advantageous to develop bottom-up and self-maintaining citizen science frames for such activities. This can be achieved by encouraging public interest through enthusiastic dissemination and by offering reproducible knowledge through accessible handbooks or guides. Importantly and probably most demanding, such schemes are dependent on systematic documentation and recording as well as evaluation of these data by a trained specialist. We propose that such ‘self-maintaining’ citizen science schemes are particularly relevant in regions and time-periods where formalised archaeological survey efforts are minimal;
southwestern South Scandinavia and the question of Neanderthal presence in the region represent precisely such a situation. Similar schemes have shown great promise elsewhere (Buteux et al., 2009)

Conclusion

We have here provided an in-depth review of the Middle and Upper Pleistocene geoarchaeological status and potential of southwestern South Scandinavia. Based on the combined occurrences of terrestrial passages and the broad ecological settings of the study time and area, we argue that the longest and warmest Pleistocene interstadials rather than full interglacials offer the best conditions for human presence in swSS. Drawing on suite of digital geoarchaeological sources and tools, we conclude that that Pleistocene deposits and landscape features are present in the study area, but that issues of preservation and exposure make them less suitable archaeological archives than in other regions with presently better-known Pleistocene archaeological signals. Nevertheless, we show that lacustrine deposits within relict landscapes such as buried valleys and hill islands offer the best potential for preserving archaeologically significant material within what is available in the study region, and that these should be sought in places where they overlap with deep and active exposure processes such as in quarries and along coastal cliffs. We identified three target areas where this combination of features occurs: A) the Holsted and Rødding hill islands in Central South Jutland; B) the moraine landscape of Central East Jutland, and C) the intersections of buried valleys on the east coast of Jutland. In order to verify and test the robustness of this prediction it is necessary to regularly survey open quarries and exposures in these target areas. This should be the aim of future studies, ideally conducted, we suggest, using citizen science approaches that include relevant stakeholders.

Through such a regionally based, but globally integrated, systematic and comparable study along the currently assumed frontiers of past human distribution ranges, is it possible to challenge the validity of the proposed ranges and hence to reach a better understanding of the dispersal limits and adaptive capacities of past human populations.
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