Europe's Lost Frontiers

General Editor
Vincent Gaffney

Volume 1

Context and Methodology

edited by

Vincent Gaffney and Simon Fitch

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Cover: Eleanor Ramsey

Landing by Ava Grauls (Duncan of Jordanstone College of Art & Design).
Oil and watercolour on Japanese shōji (障子) paper. 413 x 244cm

Landing is about location, ownership, shifting land and shifting borders. The painting was conceived after talking to academics about the space between Britain and Europe, and asking the question: 'How do you paint a forgotten landscape?' Landing was made to travel and interact with different environments and can be folded up and packed away into four boxes.
Ava Grauls 11/08/2021

Dedicated to our Families
For putting up with Doggerland for longer than any families since the Mesolithic

November 2021

Europe's Lost Frontiers

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Chapter 3

A description of palaeolandscape features in the southern North Sea

Simon Fitch, Vincent Gaffney, Rachel Harding, James Walker, Richard Bates, Martin Bates and Andrew Fraser

Introduction

The northwest European continental shelf retains, arguably, the most comprehensive record of a late Quaternary and Holocene landscape in Europe. The landscape was extensively populated by prehistoric communities and may have been a core habitat during several periods of prehistory, but was finally and rapidly inundated during the Mesolithic as a consequence of rising sea levels (Mithen 2003: 154-157; Walker *et al.* this volume). In response to the lack of a substantive archaeological context for the period of inundation, the North Sea Palaeolandscape Project (NSPP) undertook extensive mapping of the southern sector of the North Sea in 2007 (Fitch *et al.* 2005; Gaffney *et al.* 2007). This project derived mapping from seismic geophysical data rather than the bathymetric mapping used by earlier studies. As such, the results reflected the presence of buried landscape features which were not necessarily expressed within the current seabed surface (Fitch *et al.* 2005). In 2011 funding was provided by the National Oceanographic and Atmospheric Administration (NOAA) to undertake research on the Dutch sector of the North Sea, using a mega-merge dataset provided by PGS UK Ltd. Combined, these surveys covered *c.* 57,000km^2, located over some of the longest-lived areas of the Mesolithic landscape. Building on this research, the *Europe's Lost Frontiers* Project study area now includes a larger proportion of the southern North Sea, from Northern England across to Denmark in the north and the Dover Strait in the south. This represents an area of over 188,000km^2 (Figure 3.1).

Background

Before considering the results of mapping within the area in detail, it is useful to examine some of the background regarding the nature of the deposits associated with the landscape. Within the *Europe's Lost Frontiers* study area, the Holocene deposits under discussion are on average located between 40 and 80 milliseconds (ms) within the seismic data, with the deepest incised fluvial systems being located *c.* 30m below the seabed. However, it is also important to note that there are more substantial features associated with major fluvial systems and/or reused glacial tunnel valleys within the data. For example, within Figure 3.2 a Holocene channel can clearly be seen to cut into late Pleistocene deposits (Dogger Bank Formation) to a local depth of 75ms. For the purposes of this project, analysis generally did not include features or deposits which were not directly relevant to the project goals. For example, the Outer Silver Pit Formation (Lower Pleistocene) may be up to 80m deep locally, whilst the Markham's Hole Formation achieves 150m (Cameron *et al.* 1992; Lumsden 1986). For this reason, the Lost Frontier's dataset slices are usually derived from between 40ms to 72ms. Additional slices, between 60ms and 72ms, were used specifically to visualise local features with deeper incision but were not generally applied for the purposes of broader landscape interpretation.

Validation of this approach can be demonstrated through the integration of 2D data within the 3D framework and associated core data. For example, in the north of the study area, data from the Gauss survey (e.g. Salomonsen and Jensen 1994) was cross-correlated with the 3D survey data. The palaeochannels visualised in the Salomonsen and Jensen's (1994) survey were cored, dated and determined to be of Holocene date. More recently work by the BRITICE project, working to constrain the extents of the last glaciation, has recovered cores and materials which have also provided evidence for the Holocene landscape (Roberts *et al.* 2018). Dates of 9934 +/- 188 cal BP (SUERC-72886) obtained by BRITICE core 176VC (Roberts *et al.* 2018) evidence the emergence of the landscape during the Holocene and the presence of channel activity within the area of Doggerland. The information derived from recent work is consistent with previous mapping of Holocene formations (e.g. Cameron *et al.* 1992). Consequently, there can be confidence that the derived landscape mapping reflects data relating to the Holocene.

Broad area description of the southern North Sea

Here we will provide broad descriptions for the mapped area of the southern North Sea (Figure 3.3). These supplement the published data for the English sector of the southern North Sea provided in Gaffney *et al.* 2007, and, where overlaps exist, the version here represents a revision beyond that previously published. Further

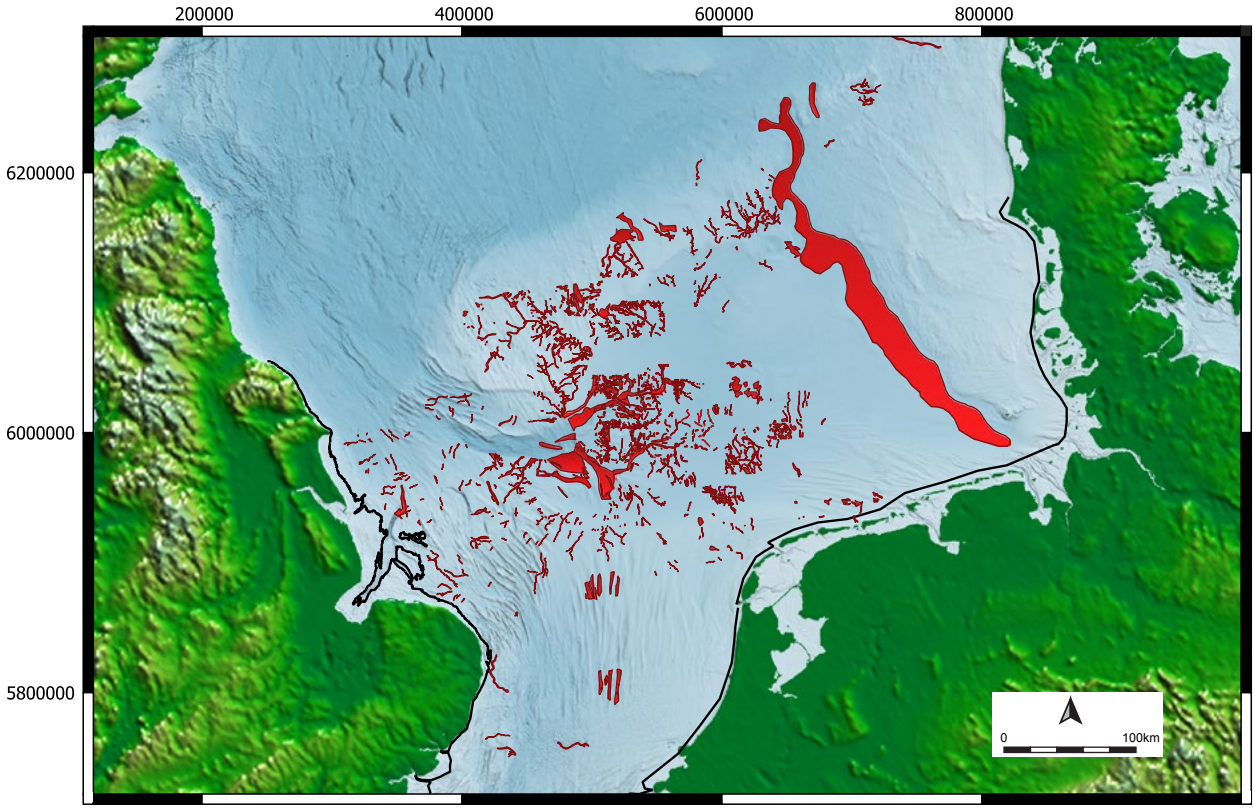

Figure 3.1 GIS Mapping of the features recorded by the Europe's Lost Frontiers project.

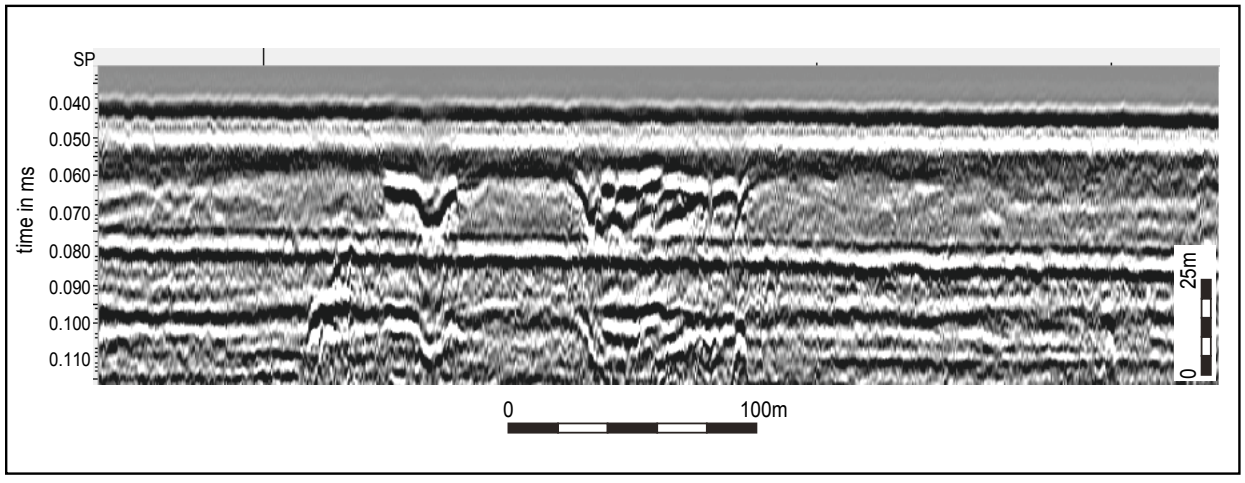

Figure 3.2 Seismic line from 'Gauss 159B' survey acquired in 1990 by the RGD and BGS over the Dogger Bank. A Holocene channel can clearly be seen to be incised into the underlying late Pleistocene deposits (Dogger Bank Formation).

detail on the areas studied by *Europe's Lost Frontiers* will be presented in later project publications.

Area 1 – Northern Sector

The landscape of the Area 1 displays the influence of the underlying late Pleistocene deposits which create an area of higher relief that gently descends into the lower lying areas surrounding the Outer Silver Pit (Figure 3.1). On the northwest and central area of the Dogger Bank, the predominant trend of the early Holocene fluvial systems is to the south/southeast (Figure 3.8, Shotton River and A), converging on a major channel system running east/west towards the Outer Silver Pit (Figure 3.6 and Figure 3.8, B). The north/south orientation of the channels on the Dogger Bank is thought to be a relic of the late Pleistocene drainage systems of the area (Emery 2020). In the extreme north of the Dogger Bank,

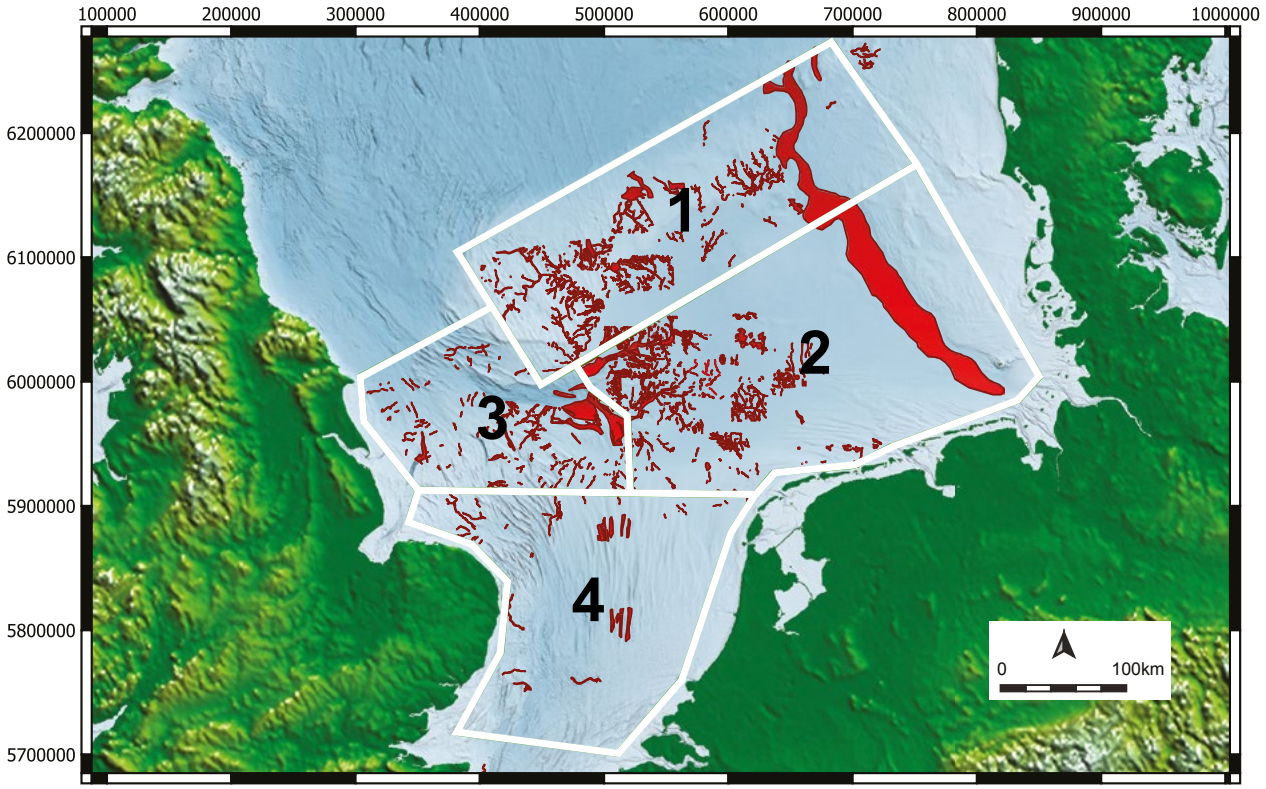

Figure 3.3 Areas divisions of landscape features within the study area.

however, one main channel runs north (Figure 3.8, C), and it is suggested that this may be a later feature with a watershed being located on the top of the Dogger Bank (Figure 3.1).

In the northeast of the Dogger Bank, the drainage directions changes. Here the channels drain from west to east into the Elbe palaeovalley. Running east of the Dogger Bank and west of Denmark, the Elbe channel was clearly a significant feature in this landscape. It has a width of 1.5km and 15m depth and can be seen clearly on seismic lines that cross the region (Hjelstuen *et al.* 2017). Smaller channels in the area were recorded by Andresen *et al.* 2019, and the wider *Europe's Lost Frontiers* data reveals these channels to be lesser tributaries of the Elbe (Figure 3.8, D). Andresen notes that these channels were formed during the Last Glacial Maximum and later morphed into sub-aerial channels. A few small channels can also be seen on the eastern side of the Elbe palaeovalley (Figure 3.18, E). These channel fragments flow to the west and towards the Elbe palaeovalley, although no data currently exists that could allow a visualisation of any junction between these channels and the Elbe itself. The exact age of these features is undetermined but, given the shallow nature of these features, they are thought to be late Pleistocene to early Holocene. As inundation progressed, these small channels would have turned into tidal channels before finally being submerged.

The Holocene fluvial features on the Dogger Bank incise the underlying late Pleistocene deposits (see Figure 3.4) and suggest that the earlier channels were active during the late Pleistocene or early Holocene, and post-date glacial activity in this area. Channel activity during this period can be divided into three main phases of activity. The first stage is seen in the formation of relatively linear channel features and is often associated with the larger features in the area. These features are of late Pleistocene age, associated with deglaciation and represent pro-glacial channels (*c.* 24,000 to 23,000 BP). These indicate the first stage of channel activity and end with the removal of meltwater as a source following glacial retreat. This, coupled with aridity during the period 23,000 to 17,000 BP, low temperatures and tundra conditions, caused the channels to become relict.

The second stage of channel activity in the area occurs, initially, with the reuse of earlier pro-glacial channel structures. These smaller channel systems are incised into the topographic lows associated with pre-existing structures (Figure 3.5). Aside from channel reactivation, the development of new feeders and the formation of new channel systems occurs during this period. These channels (*c.* 17,000 to 10,000 BP) represent an increase in channel activity due to rising precipitation after the end of glaciation (Emery 2020).

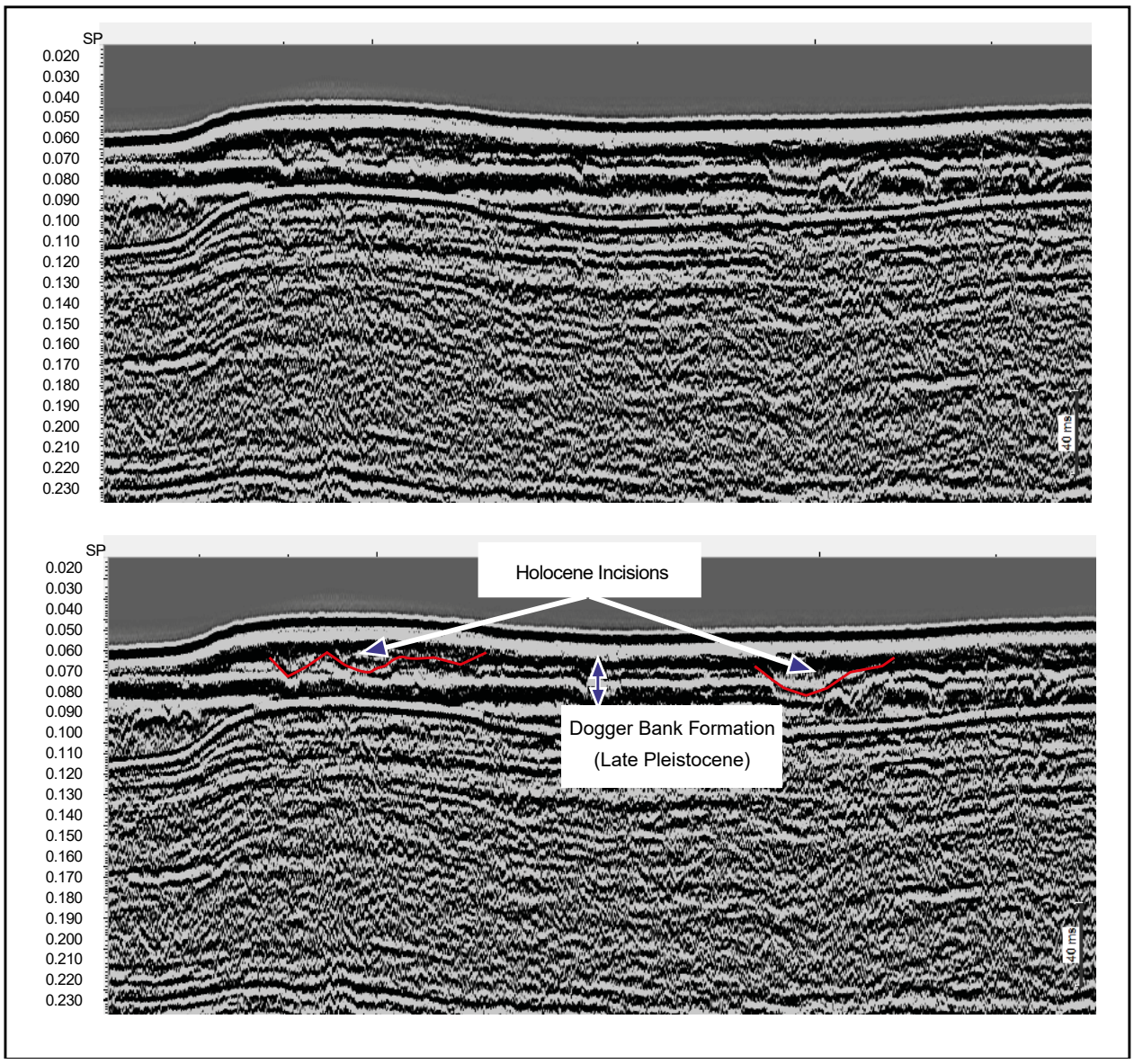

Figure 3.4 Cross section across the southern flank of the Dogger Bank. The Holocene features can be seen to incise into the underlying late Pleistocene deposits.

The geographic location of the fluvial systems on the topographic high of the Dogger Bank suggests they were sub-aerially exposed for a longer period than is evident for most of the survey area, and consequently that the systems are better developed. Roberts *et al.* 2018 suggests that the ice had retreated from this area by 23,000 BP and despite aridity during the period, a period of *c.* 11,000 years was available for channel development before they were inundated *c.* 8000 BP (Emery 2020). Most of the channels are sinuous systems with a high stream order. The channels on the Dogger Bank flow down south into a major east to west flowing channel of considerable size, located within the Oyster ground (see Figure 3.6). A vibrocore, fortuitously taken from one of the feeder tributaries of this system by the BRITICE project, provided a date of (12,629 +/- 90 cal BP SUERC-72883, Roberts *et al.* 2018: 195) which confirms the period of activity for this channel.

A third phase of channel development is evident in the area marked 'A' in Figure 3.6. Although separation of the features is difficult within the seismic data, it is clear that these later channels directly overlie the channels of the previous two stages. In addition, later channels are linked to a coastline which is related to the submergence of the landscape at around 8000 BP (Emery 2020; Shennan and Horton 2002), and therefore likely to have been formed as a response to the break-up of the landscape and a change in river base levels. Given that the channel (Figure 3.6, A) drains the top of the Dogger Bank, later channels are therefore likely to be associated with the final stages of the emergence of the Dogger Bank itself (see Figure 3.8). Zones of 'mottling' in the seismic data are associated with the flooding of the landscape and are thought to relate to peat formation (Emery 2020; Hepp *et al.*2017). These correspond to a different seismic response in the areas

Figure 3.5 Example of the later Holocene reuse of pro-glacial channels. This is evidenced by smaller (black) channels cut within the main valley and the formation of dendritic feeders on the side of the valley.

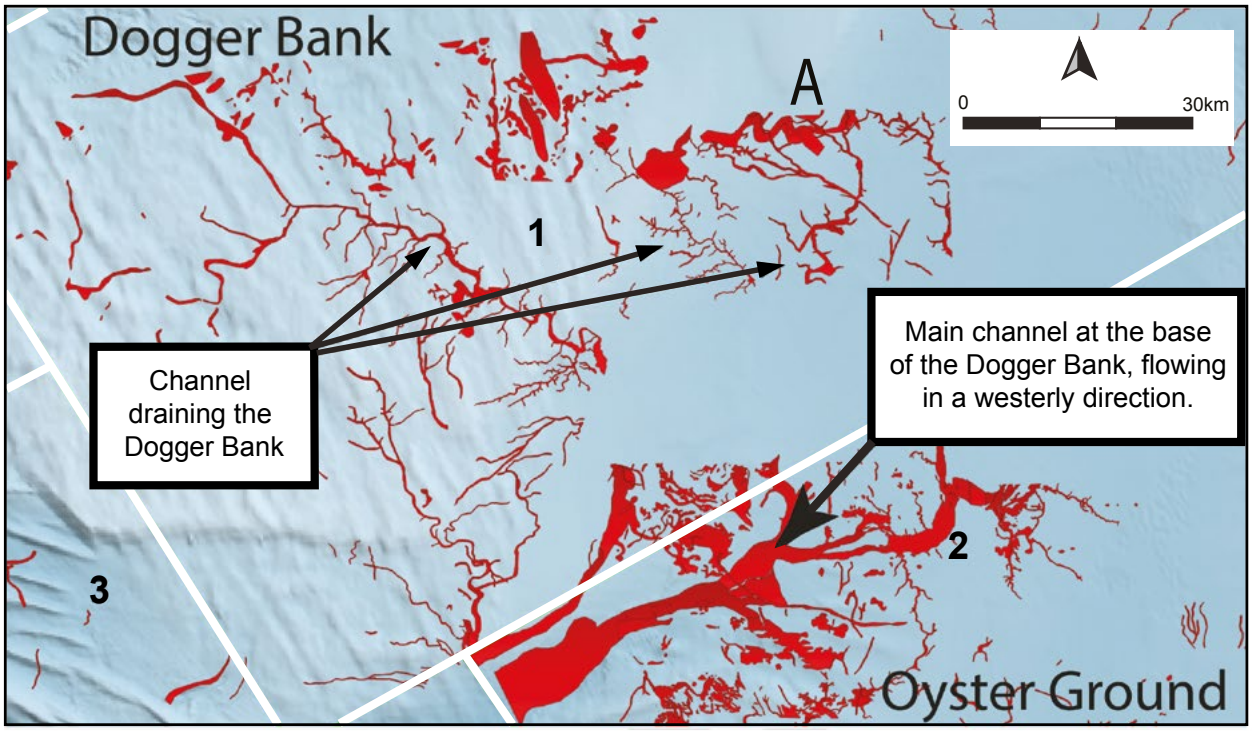

Figure 3.6 The main drainage channels of the Dogger Bank drain south into a major channel located at the foot of the bank and in the area of the Oyster Ground, eventually flowing to the west and into the Outer Silver Pit.

between the channels (Figure 3.7). This is indicative of intertidal/wetland deposits associated with inundation in this area (Hepp *et al.* 2017). The deposits are therefore likely to comprise organic muds and silts similar to deposits in the offshore Humber area (Gearey *et al.* 2017; Tappin *et al.* 2011), and thought to be of a similar Holocene age to those features dated by the Humber REC (Fitch *et al.* 2011). Within the sector, the Elbe flowed through a valley that extended across Doggerland, and is substantial enough to retain a bathymetric expression to the present day, cutting through the high ground formed by the Dogger Bank and Danish shelf. At the extreme northeast of the sector, the mouth of the Elbe palaeovalley valley can be seen clearly (Figure 3.8, F).

Seismic lines acquired across this feature show the channel relating to the Holocene to be incised some 15m below the seabed with a channel width of 3km (Hjelstuen 2017). A study by Özmaral (2017) demonstrates that the Elbe palaeovalley was almost completely devoid of pre-transgressional deposits, with the exception of sediments from a south/north trending channel network within the valley. The seismic profiles from this south/north trending channel is comparable to some of the larger channels studied by *Europe's Lost Frontiers* and suggests a similar sequence. Given the mouth of the Elbe palaeovalley is at a depth of *c.* 56m, which is similar to the late Pleistocene/early Holocene sea level, it is highly likely that parts of this area of the valley were starting to be flooded at that time (Vink *et al.* 2007) and that these channel sediments relate to the brief period following deglaciation and immediately prior to submergence. Özmaral (2017) demonstrates that after inundation was initiated, the valley experienced at least three phases of sedimentary infill due to changes in sea level. This is supported by research in the Palaeo-Ems, which fed into the Elbe Palaeovalley (Hepp *et al.* 2019), which also records these three phases and suggests the onset of fully marine conditions after 9300 cal BP. This, therefore, provides a date at which the majority of the associated Elbe palaeovalley would have also been submerged.

Area 2 – Eastern Sector

There is significant striping evident in the 3D seismic data from the southeast of Area 2. Data quality is, however, reasonable elsewhere, and 2D seismic is available to supplement the 3D data. Analysis reveals the area is largely a gently sloping, emergent plain, cut by the Elbe palaeovalley. This landscape reflects the presence of deep, late Pleistocene sediments which effectively mask any topographic expression from geological movement, such as salt swells (Holford *et al.* 2007). A topographic high is evident near the modern Dutch coastline, descending towards the lower plain of the Oyster Ground, to the south of the Dogger Bank (Figure 3.9, A). However, the dominant feature in the area is the topographic low associated with the Elbe

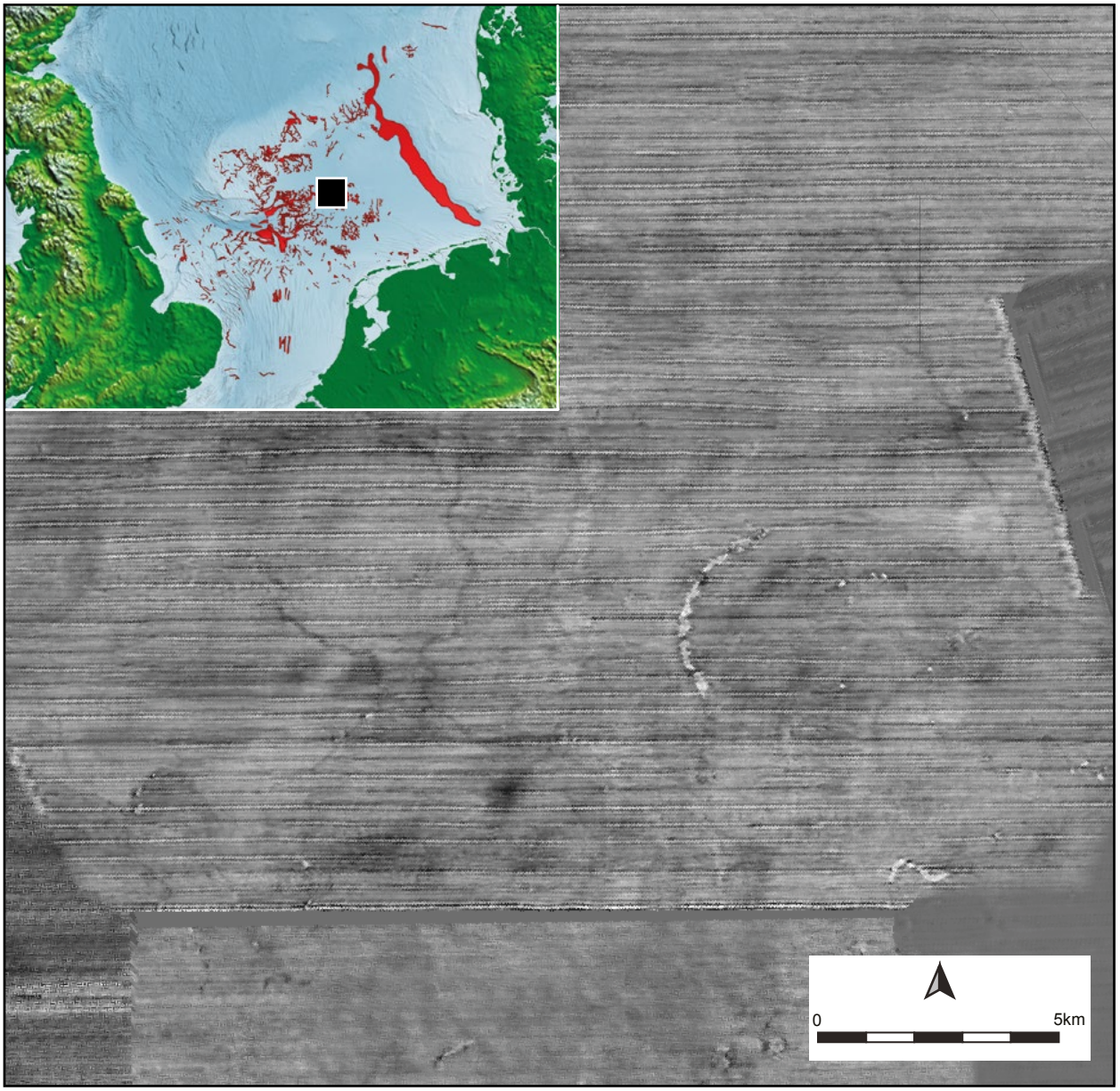

Figure 3.7 Mottling of the seismic data within the Oyster ground can clearly be seen in this image. A number of small palaeochannels can also be seen through the mottling.

palaeovalley, which forms a significant depression in the north-eastern quarter of Area 2 (Figure 3.9, B).

The majority of the fluvial features within the Oyster Ground are oriented to the west, towards the Outer Silver Pit depression and across the large and relatively flat plain (Figure 3.10). The seismic signal generates a 'mottled' appearance (Figure 3.10), the origin of which is uncertain but is thought to relate to peat formation in wetlands prior to inundation (Hepp *et al.* 2017). Several small fluvial channels can be observed within this mottled zone (Figure 3.9, C). Although data striping prevents detailed description of these features, they can be seen to flow into a larger channel system which runs along the base of the Dogger Bank. High resolution 2D seismic survey, undertaken as part of the BRITICE project (Roberts *et al.* 2018; 190), crosses this channel and reveals it to be incised up to 20m below the seabed (Figure 3.11). 3D analysis of this channel was undertaken by the authors and TNO staff (Fitch 2011; Van Heteren *et al.* 2014). These revealed phases of development, which are broadly similar to the sequence outlined by Emery (2020: 113 and 165). Proglacial channels are formed, then abandoned and eventually evolve dendritic tributaries as meltwater is replaced by precipitation. They are then transgressed as sea levels rise during the Holocene.

Analysis further reveals the presence of a large channel valley containing evidence for reuse by a small channel

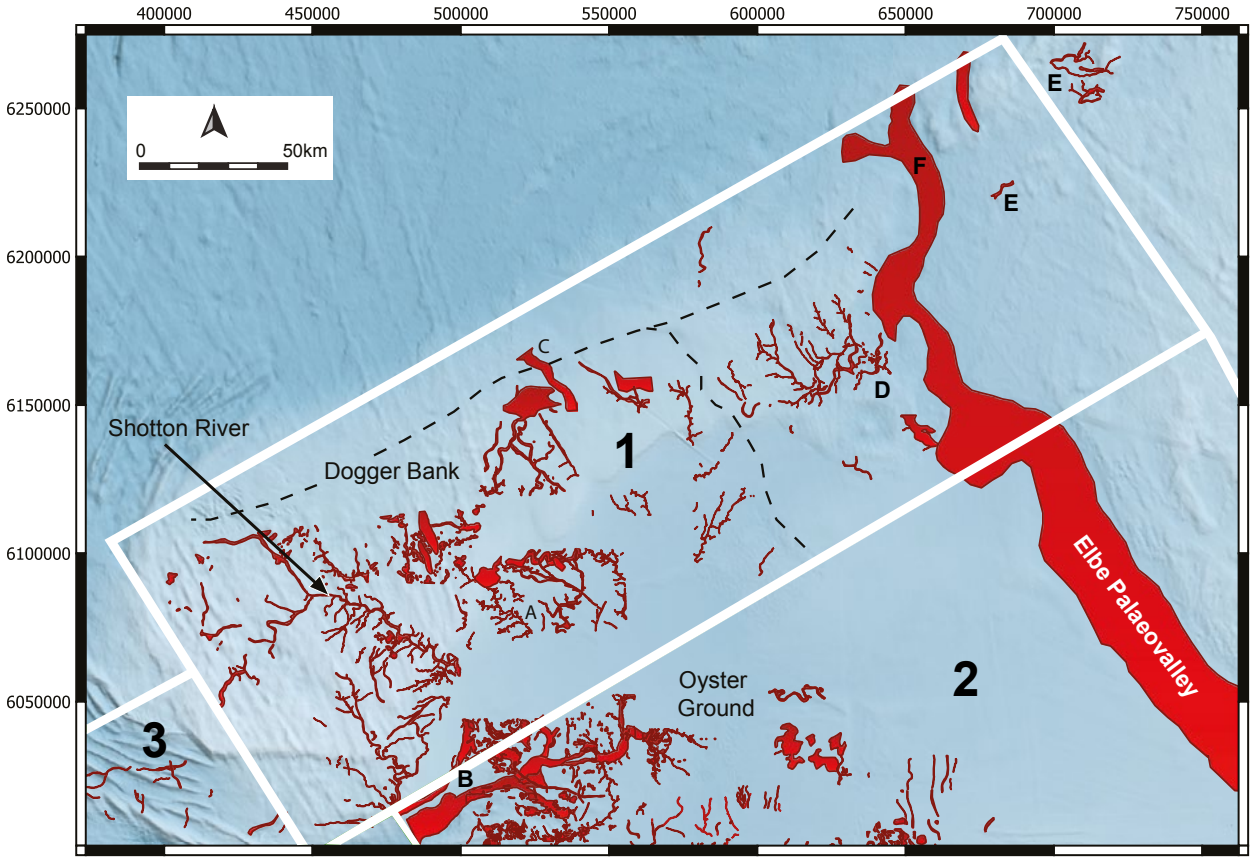

Figure 3.8 Area 1, early Holocene features of the Dogger Bank. The main watersheds are shown as dashed black lines, the features in the southwest of Area 1, including the Shotton River, would have been the longest-lived structures on the Dogger Bank.

(Fitch this volume: Figure 3.5 and 3.9, E). This may suggest such features are the product of proglacial drainage at *c.* 23,000 BP, after the retreat of the ice sheets, and then modified and reused by fluvial channels between *c.* 17,000 to 9000 BP. Later modification is indicated by the formation of tributaries and peat deposits associated with the channels. Dates acquired from nearby cores taken by the BRITICE project (e.g. 175VC Roberts *et al.* 2018) provided early Holocene dates (*c.* 9900 to 9700 BP) but also reveal underlying peat deposits of late Pleistocene age (SUERC-72885, 20,190 +/- 229 cal BP). Fortuitously, one BRITICE core, 147VC, sampled a peat from the Oyster Ground (Figure 3.10), near a likely tributary channel mapped by *Europe's Lost Frontiers*. This provided a C14 date of 12,629 +/-90 cal BP (SUERC-72883) which clearly indicates the period during which this landscape feature was emergent.

Towards the east of the Oyster ground, a slight topographic high forms a watershed (Figure 3.9, D and Figure 3.12). Holocene palaeochannels flowing east of this rise can be seen in the *Europe's Lost Frontiers* data. These have been independently verified by surveys undertaken in the German sector (Hepp *et al.* 2019) and the Danish Sector (Prins *et al.* 2019). As the *Europe's Lost Frontiers* data extends beyond these datasets, these channels can be confirmed as flowing into the Elbe palaeovalley. The Elbe remains a significant feature in Area 2 and is represented by a major depression in the bathymetry extending up to the modern coastline and the modern river Elbe.

Small palaeochannels can be observed flowing into the Elbe on both the eastern and western sides of the valley (Hepp *et al.* 2019) and form a significant drainage system within the Doggerland landscape. A study by Papenmeier and Hass (2020), nearer the modern shore, shows this valley to be partially filled with 16m of sediments. In this section of the channel flooding started around 9600 BP and continued to be tidally dominated until *c.* 5000 BP (Papenmeir and Hass 2020).

The Elbe palaeovalley represents an additional *c.* 400km of river length which, combined with the modern Elbe would give the late Pleistocene/early Holocene river a total length of *c.* 1500km. This is, in comparison, greater than the modern length of the Rhine. The size of the valley also reflects the large volumes of water flowing through the extensive drainage system. The channel would have possessed an extremely large catchment, draining parts of Germany, Poland and the Czech Republic. If the submerged section is included, then

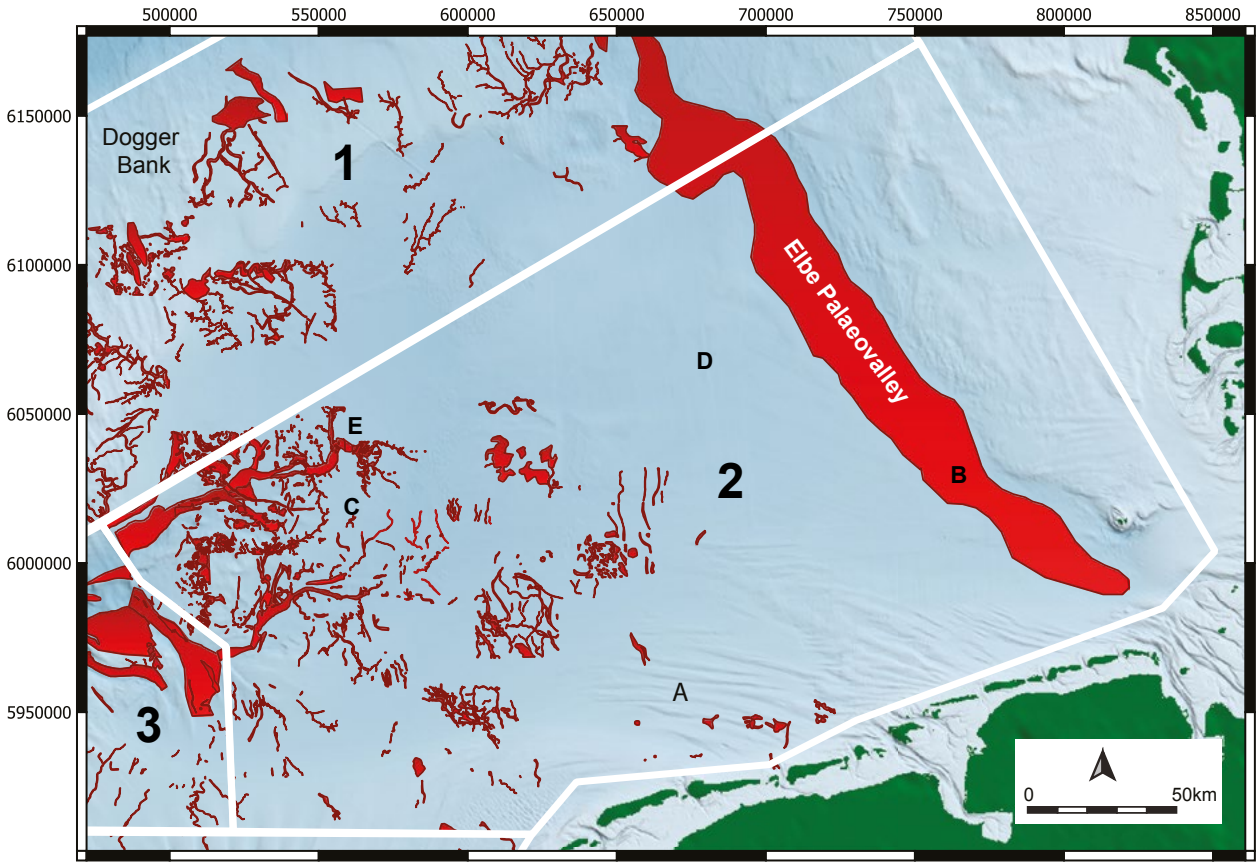

Figure 3.9 Map of the Eastern Sector/Area 2.

this drainage contains parts of Denmark, Netherlands and the Dogger Hills.

Previous researchers have proposed the existence of a palaeolake in the area of the Oyster Ground, formed following glacial melt at approximately 18,700 BP (e.g. Emery 2020; Hijma *et al* 2012; Hjelstuen 2017). This idea originates with Hjelstuen (2017) who suggested that the 12m deep and 3km wide incision at the northeast of the Dogger Bank formed the outflow of such a feature. Hjelstuen's study, however, had no access to seismic data from the area of the hypothesised lake or the Oyster Ground more generally. The suggestion relies on core data from the Ling Bank, which is many kilometres to the north, and well away from the Oyster Ground. Whilst Hjelstuen does acknowledged that there were significant issues in such an interpretation, his work remains the basis for later references to such a feature (e.g., Emery 2020: 119 Fig 4.11).

The 3D and 2D seismic data examined through *Europe's Lost Frontiers*, along with published core data, provides an opportunity to resolve the Oyster ground lake issue. Whilst the data will be discussed in detail in a forthcoming *Europe's Lost Frontiers* volume, no lake deposits were visible within the available seismic data in this area. It is also clear that there are considerable drainage systems present in the Oyster Ground that would have been able to provide drainage, and these trend to the west and into the Outer Silver Pit. The presence and direction of these channels strongly suggest that the hypothesis that a lake formed in this area, at least, is incorrect. Given that the Outer Silver Pit drains in a different direction, west as opposed to northern outflow proposed by Hjelstuen, it is therefore unlikely that the Oyster ground channels, nor the Outer Silver Pit outflow, is likely to be the source of the delta sediments at Ling Bank identified by Hjelstuen (2017). Indeed, given the presence of a ribbon lake between the ice and the northern edge of Dogger Bank at *c.* 23,000 to 21,000 BP (Roberts et at. 2018), it is possible that this may be the source of the Ling Bank delta material, rather than the Oyster ground. Indeed, Hjelstuen (2017: 16) notes that seismic correlation with sediments from the Ling Bank Delta and shallow bore holes (Hjelstuen 2017: 16) suggests that it was related to the Last Glacial Maximum and therefore could be related to the drainage of the lake observed by Roberts *et al.* (2018: 203) at *c.* 21,000 BP. It is important to note however that Hjelstuen provides no absolute dating for the Ling Bank sediments and thus the possibility of any correlation remains tentative.

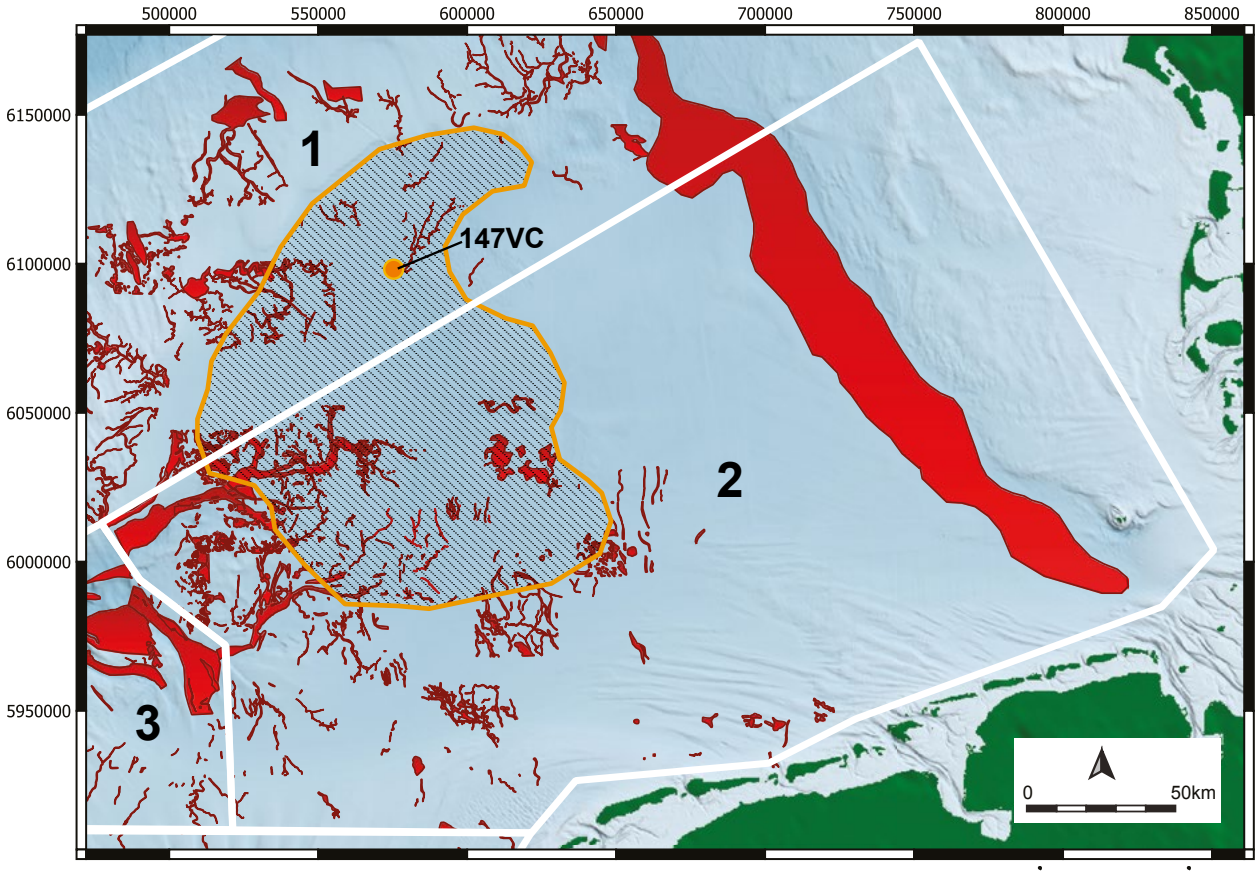

Figure 3.10 The extent of wetland response is outlined within the red hashed area. The location of BRITICE core 147VC is marked in orange.

Other explanations are available for these data. A bathymetric depression (near the area marked 'F' on Figure 3.8) is identified by Hjelstuen as the location of the outflowing of a meltwater burst. However, it must be recognised that this channel cut is the substantial channel associated with the Elbe palaeovalley. There may, therefore, be no need to invoke a lake outburst to explain this depression, indeed, the seismic line presented in the paper (Hjelstuen 2017: Figure 11a) shows the channel to be 15m deep and 3000m wide (Hjelstuen 2017: 14) which is consistent with nearer shore submerged sections of Elbe itself (Papenmeier and Hass 2020), which would not have been affected by a meltwater outburst. It should also be noted that these dimensions are also consistent with other major fluvially derived features within the projects study area that have been recorded by *Europe's Lost Frontiers*.

Finally, it is also important to note that the link to an oxygen isotope anomaly in foraminifera on the Norwegian continental margin, which is dated to *c.* 18,700 cal BP, and was used by Hjelstuen (2017) to infer the presence of a lake, only indicates the possibility of a meltwater plume near the Norwegian continental margin (Lekens *et al.* 2005). This information does not provide evidence of direction and is not sufficient to tie any possible plume to the Oyster ground area. Indeed, this plume has previously been identified as coming from the Norwegian Ice Sheet (Lekens *et al.* 2005). Consequently, there is little need to invoke a glacial meltwater palaeolake in the Oyster ground region.

Although the data on the Ling Bank sediments would benefit from further, detailed consideration and dating, the presence of the channel systems in the Oyster ground observed by *Europe's Lost Frontiers* suggest that any palaeolake in the Oyster Grounds is substantially smaller and shallower than suggested, and thus not visible in the data available, or more probably is absent.

Area 3: Western Sector

This area is largely characterised as a relatively gentle plain sloping to the north and down from the modern British coastline (Figure 3.13). The dominant topographic feature within this area is the Outer Silver Pit, which forms a significant depression in the northwest of the area. The Outer Silver Pit is a distinct east-west trending bathymetric deep and is the largest of a series of depressions in the southern North Sea. This feature is up to 80m deep in places and is thought to result either from quaternary sub glacial processes (Praeg 2003), or a catastrophic drainage event

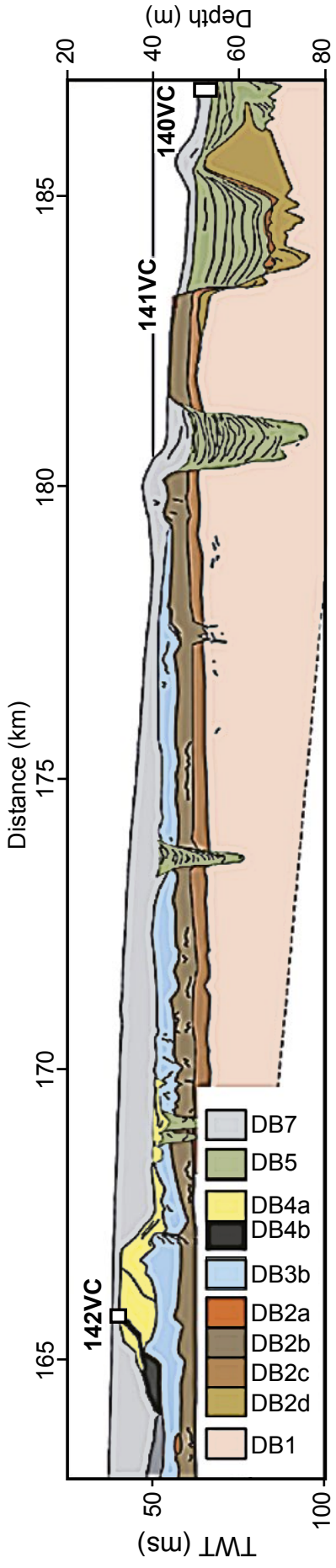

Figure 3.11 Interpretation of a seismic line crossing the base of the Dogger Bank area (near the area marked B in Figure 3.8) clearly shows a large channel running at the base of Dogger Bank (shown here as the DB5 unit between 141VC and 140VC) (Roberts *et al.* 2018: Figure 6).

(Wingfield 1990). This Outer Silver Pit dominates the landscape, with channels from the Oyster Ground (Area 2) flowing into this feature.

The Outer Silver Pit was investigated by the NSPP and thought to have been modified during the Late Palaeolithic/Early Mesolithic by macro tidal processes during marine inundation (Briggs *et al.* 2007: Figure 3.13, A). The Outer Silver Pit was eventually flooded by the sea around 10,000 BP (Shennan *et al.* 2000; Sturt *et al.* 2013). A distinctive zone, characterised by a palimpsest of small channels which cross an area of 5823km^2, can be seen adjacent to the Outer Silver Pit (Figure 3.13, B). In addition, the area contains several small depressions within which the seismic data is 'mottled'. This mottled signal is thought to indicate peatland/wetland and, consequently, the area, along with the small channels, is thought to represent an extensive wetland area close to the edge of the Outer Silver Pit, which formed an estuary during this period (Briggs *et al.* 2007; Gaffney *et al.* 2007). It is assumed that this wetland environment was continuously active from the end of the Pleistocene until the early Holocene. Recent cores from the area, taken by the BRITICE project (Roberts *et al.* 2018), have recovered peat which dates to 9801 +/- 171 cal BP (SUERC-72162) supporting this hypothesis.

In the centre of Area 3 (Figure 3.13, C), are a series of large anastomosing channels flowing from the southeast and into the Outer Silver Pit. Several of the larger channel features have been associated with the Botney Cut formation and dated to the late Pleistocene to early Holocene (Cameron *et al.* 1992). Detailed survey during the Humber REC over one of the smaller features has revealed that these were active during the Holocene (Fitch this volume; Tappin *et al.* 2011) although coring failed to reach the base of the feature.

A significant outflow channel is partially visible in the southeast corner of the Outer Silver Pit (Figure 3.13, D). This appears to drain the Outer Silver Pit to the south and is of a sufficient size for the channel to have a contemporary bathymetric expression. Imaging this feature using 3D seismic data suggests that the channel must have been formed following a considerable outflow, and that it extends much further south than is visible on the bathymetry. Although no dating evidence from this feature is currently available, the presence of a small number of re-use channels suggests that the feature is of pre-Holocene age. The current models for the last glaciation suggest two possible points of origin for this feature (Roberts *et al.* 2018). The first requires an outflow from the lake in the Outer Silverpit (referred to as 'Dogger Lake' by Roberts *et al.* 2018: Fig 17), and which may have occurred a short time prior to 30,000 BP. Roberts *et al.* (2018) note that sometime between 30,000 to 25,000 BP, following an ice advance, a separate glacial lake was moved eastwards by the ice from the

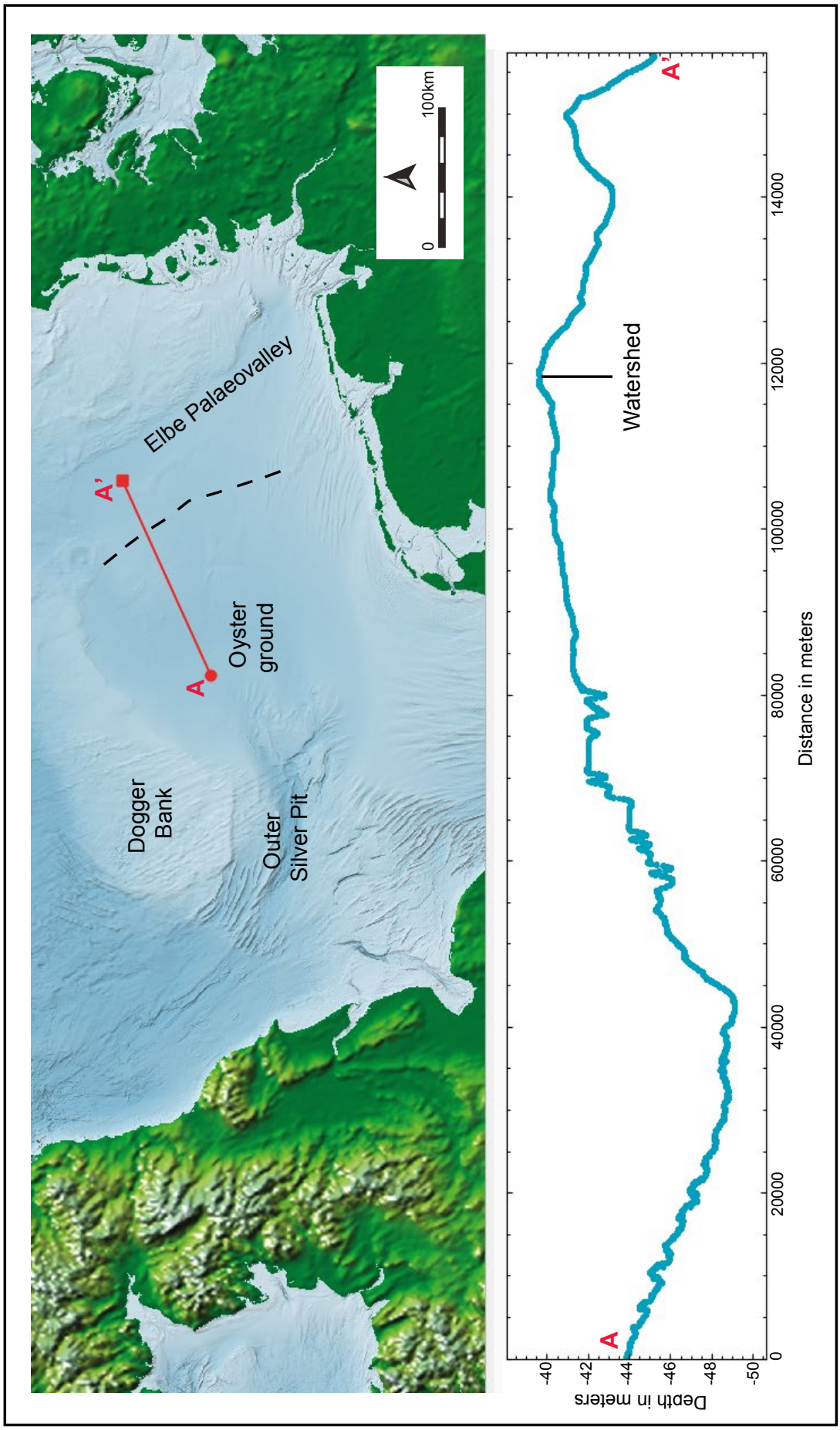

Figure 3.12 Cross section across the east of the Oyster ground. The topographic rise which forms the watershed is apparent.

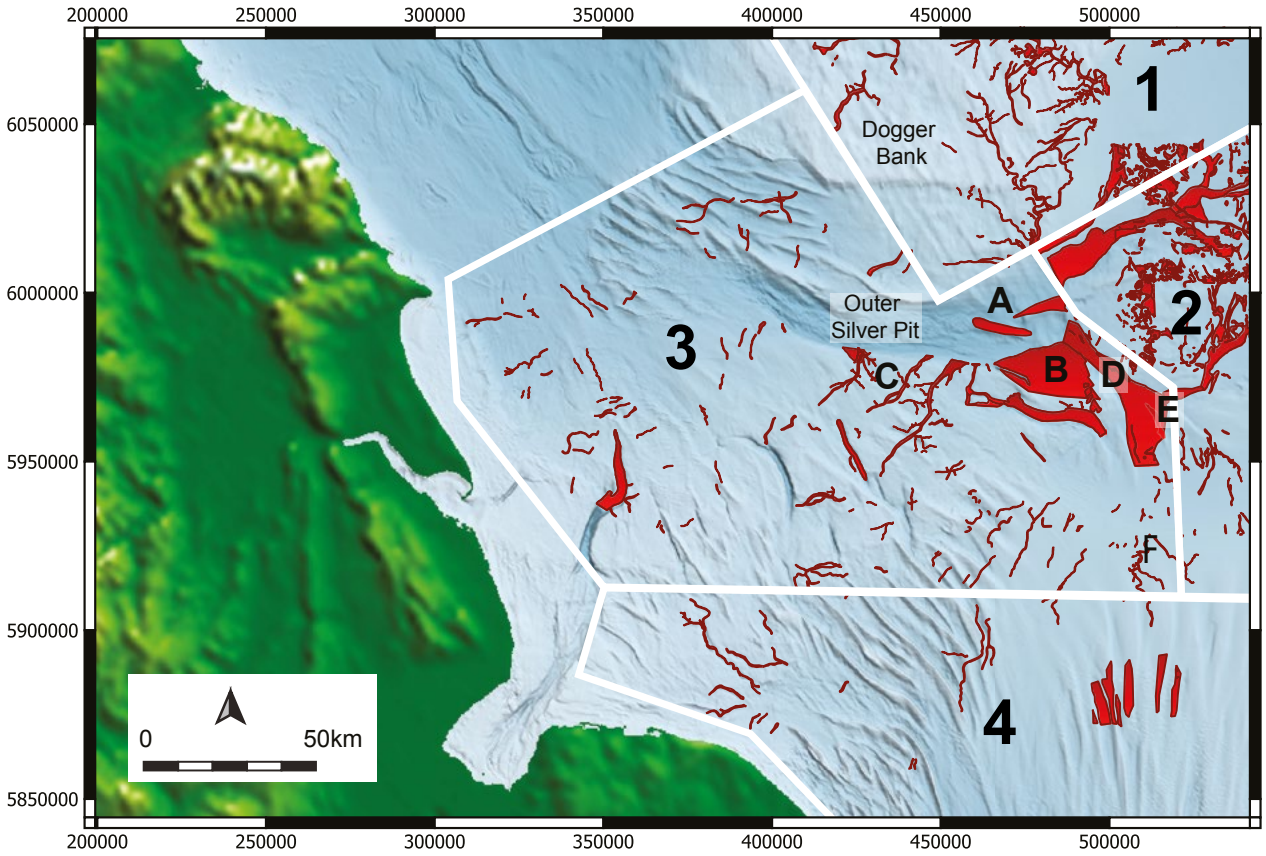

Figure 3.13 Location of mapped features within Area 3.

area around the Outer Silver Pit to the northeast of the Dogger Bank. This water movement may have provided the opportunity to breach the Outer Silver Pit banks to the south and produce a meltwater outburst that could have, feasibly, created this feature. The second point arises during the 22,000 to 21,000 BP ice advance. Around 23,000 BP, a ribbon lake had formed to the north of the Dogger Bank (Roberts *et al.* 2018), and it is possible that this feature may have extended around the Dogger Bank into the Outer Silver Pit. Ice re-advance beginning at *c.* 22,000 BP may then have pushed into the area of the ribbon lake and induced an outburst from the lake creating this feature. Whilst it is impossible currently to provide an accurate date for origin of the channel, its size, position, and the evidence for later re-use suggest that it was a significant feature within the Holocene landscape, and that it was a route for flooding from the south during final inundation.

Slightly to the east of the outburst channel, close to the boarder with Area 2, is another large, deeply incised channel system (Figure 3.13, E). This is *c.* 1400m wide and appears to drain part of the Oyster Ground (Area 2). It can be seen to flow southwest in the seismic data, before eventually meeting the large outflow channel south from the Outer Silver Pit. At this point the channel changes direction, re-uses the outflow channel, and flows south. This relationship suggests that the channel (Figure 3.13, E) is later than the outwash feature (Figure 3.13, D), and dates from a period either post *c.* 30,000 BP or *c.* 21,000 BP.

The presence of this channel is also indicated in a map of the area by Emery (2020: 119 Figure 4.11), and the feature may drain some of the European rivers prior to the formation of the Elbe palaeovalley). However, Emery emphasises the speculative nature of this interpretation, and the seismic data is unable to provide sufficient evidence of any extension to the Elbe Palaeovalley channel to support this suggestion. As the channel links with dendritic feeders where it extends into Area 2, this suggests that the feature was sub-aerially exposed during the Holocene and thus remained a feature in the landscape throughout the late Pleistocene/Holocene period.

The southwards trend of this large feature is paralleled by several smaller channels (Figure 3.13, F), one of which was recorded by Preag who suggested a Holocene date for the feature (1997). The *Europe's Lost Frontiers* 3D seismic interpretation suggests that this channel, and those nearby, have a well-developed, high sinuosity. The *Europe's Lost Frontiers* data also reveals additional features related to these features, including floodplains, bars and oxbow

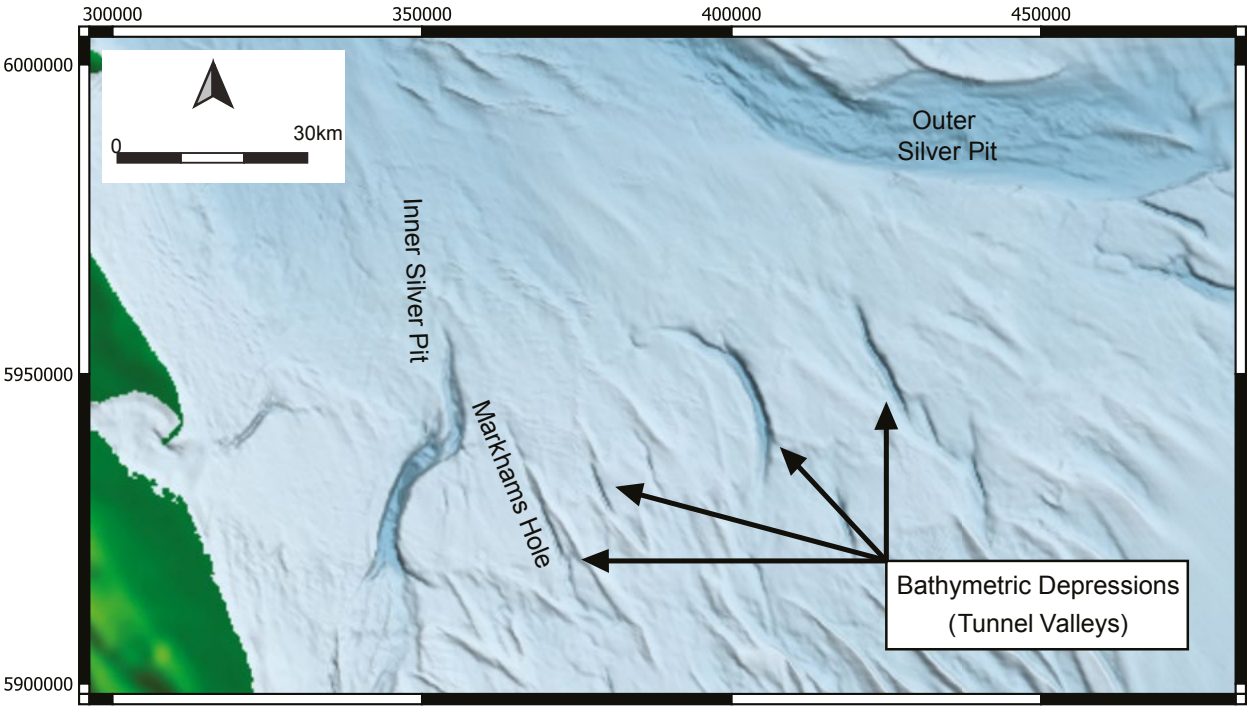

Figure 3.14 Topographic depressions southeast of the Outer Silver Pit (Area 3)

lakes, which illustrate the development of this plain. Many of the channel features recorded are comparable to those seen in the Danish sector (Prins and Andersen 2019), and presumably form at a similar time and environment. It is apparent that several of the features are well preserved and within reach of future high resolution geophysical survey and environmental sampling.

The western part of this landscape includes a number of large depressions, including Markham's Hole (Figure 3.14), which are tunnel valleys and may have contained lacustrine features during the Mesolithic. The seismic data reveal that these features are much deeper than the bathymetry suggests and contain deposits that can be directly related to the late Pleistocene, Botney Cut Formation. The late Pleistocene sediments are then directly overlain by sediments of recent origin. The sedimentary relationships therefore suggest that the valleys date from the late Pleistocene. As these features would have formed topographic features in the Holocene landscape, it is likely that these depressions may have contained lakes during the Early Holocene. This interpretation is supported by the work of the British Geological Survey (Brown 1986), who records the presence of late Weichselian to Holocene glacio-lacustrine deposits in similar features in the British sector.

Area 4: Southern Sector

Although it is suspected that Area 4 (Figure 3.16) has significant information relating to the early Mesolithic landscape, data striping and noise in the 3D seismic data hindered interpretation. Fortunately, new 2D seismic data acquired during windfarm development, and research surveys undertaken as a collaboration between *Europe's Lost Frontiers* and the Deep History Project, provides valuable supplementary information for the area (e.g., Messiaen *et al* 2020). The expansion of windfarms within this area will also offer future opportunities to significantly refine and improve the mapping for this area (Peeters *et al.* 2019).

A brief description of the area and the results of survey are provided here, more detail will be provided in a later volume (Fitch *et al.* forthcoming). Whilst the details of the majority of the channels observed are yet to be fully resolved, they do tend to be smaller in scale than those discussed in the other mapping areas of the study area.

The lack of palaeochannels within this area is striking (Figure 3.15). The central zone within Area 4 is totally devoid of these features (Figure 3.15, A). Those that do exist (e.g. the Southern River, Figure 3.15, B) are scattered toward the periphery of the area, but appear to flow towards the central axial area between East Anglia and the Netherlands (Figure 3.16) and seem to terminate at or near the 40m meter bathymetric contour. This dearth of landscape features in the central zone is probably explained by the presence of a large marine embayment infilling during the Mesolithic. Isostatic models (e.g. Sturt *et al.* 2013), and more recent models utilising improved core data from the region (Ch'ng *et al.* forthcoming), suggest that flooding of this area was initiated by 10,500 BP. This is supported

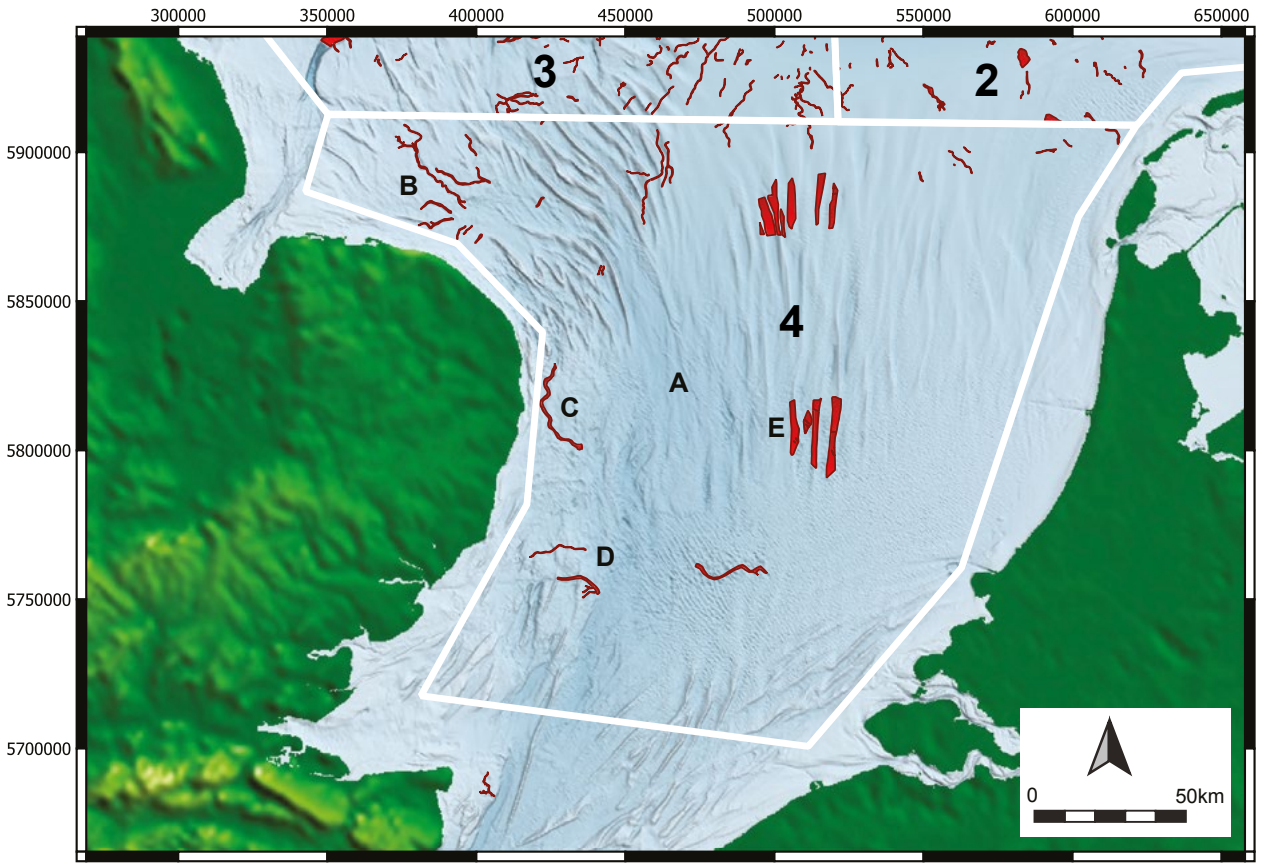

Figure 3.15 Early Holocene landscape features in Area 4.

by core data from the Belgian continental shelf which indicates marine influence in the area at 10,000 BP and possibly earlier (De Clercq 2018). A core (VC39), taken by the TNO in 2019 near the Brown Bank, also provides a sea-level index point at 10,280 +/- 77.5 cal BP (Busschers pers. comm.). This information, combined with radiocarbon dates from the estuary of Southern River (VC51: 8827 +/- 30 cal BP, SUERC-85716), strongly support the existence of a marine inlet in this area during the Mesolithic.

Of the palaeochannels that are visible, the majority are situated on the western flank on the East Anglian shelf (Figure 3.15, C and D). These channels are characterised by broad, but shallow, meanders, suggestive of a gentle water flow. The channels can be seen to widen as they progress towards the marine inlet, indicating the direction of flow. Mapping of these features suggest that the heads of the channels are filled with fine grained sediment and organic material (possibly peats) as the channels approach the contemporary coastline, the seismic signal suggests this material then progresses into silts and clays. This sequence of sediments is similar to those seen in other channels in the southern North Sea (e.g., Missiaien *et al.* 2020, Fitch *et al.* this volume) and a description is provided by the East Coast Regional Environmental Characterisation (ECREC, Limpenny *et al.* 2011). A single vibrocore acquired from one channel (Figure 3.15, C) recovered peats dated at 10,670-10,250 cal BC (SUERC 11978) at 30.80m deep and 7530-7350 cal BC (SUERC 11975) at 30.05m deep (Limpenny *et al.* 2011: 131). These dates are broadly comparable to those from near the Brown Bank on the eastern bank of the embayment (8,716-8,566 cal BC (SUERC 89491)), and Southern River (ELF051 (2.84m): 7844-7606 cal BC (SUERC 85724), ELF051 (3.78m): 11,080-10,854 cal BC (SUERC 85725)). The termination of these palaeochannels at or near the *c.* 40m meter bathymetric contour, suggests a period of coastal stability. However, it may also be true that subsequent flooding did not result in erosive conditions comparable to those during the initial formation of the central marine inlet, possibly because the widening channel may have induced lower current speeds.

Fewer channels are observed within the available 3D seismic data on the eastern flank of the marine inlet. However, high resolution survey, undertaken as part of the Deep Sea History collective, combined with data from recent windfarm projects, has demonstrated that there are Holocene deposits in the region, and those channels which have been cored are sand filled, and often have organic rich and occasionally peat layers (Harding *et al.* forthcoming, Missiaen *et al.* 2020, Plets *et*

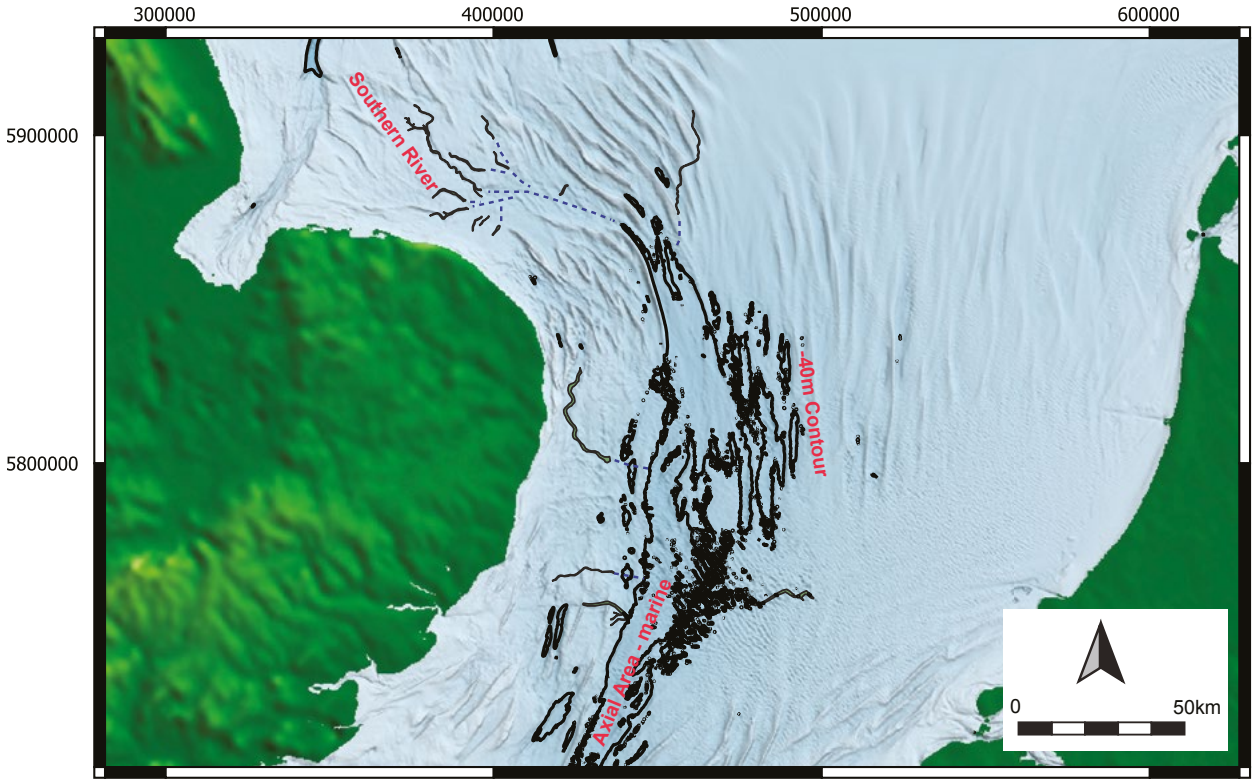

Figure 3.16 Mapped palaeochannels in Area 2 flow towards the -40m bathymetric contour, below this line virtually no features are mapped. This supports the hypothesis that the axial area was a marine inlet during the Holocene/Mesolithic.

al. forthcoming, Thal 2019). Aside from palaeochannels, land surfaces are occasionally visible (Harding *et al.* forthcoming: Figure 3.15, E), which are overlain by organic layers, intertidal deposits and frequently buried under sandbanks. These surveys have also provided a clear, acoustically strong high amplitude signal in the seismic data which has been identified as the top of the Naaldwijk Formation and associated with the marine inundation of the area. Landsurfaces associated with the Naaldwijk Formation may provide responses characterised by a coherent negative, flat parallel reflection. These are often regarded as indicative of peat layers (e.g. Plets *et al.* 2007). These peats are thought to have formed as the post-glacial soils were impacted by higher levels of salinity, sedimentary accretion and flooding (Andrews *et al.* 2000). The base of the Naaldwijk Formation is poorly resolved further east, possibly due to a lack of signal penetration resulting from the increasing thickness of the overlying sand banks.

Any palaeochannels that may have existed in the central zone in the Late Palaeolithic (pre-10,000 BP) were presumably impacted by marine erosion following formation of a marine inlet. As the area of the inlet was inundated and exposed to marine erosion at a relatively early date, the chances of such features surviving is presumably significantly lower.

Area 2 also possesses significant surface topography and modern (less than 4000 BP) seafloor features including sand waves. These structures are imaged in the bathymetry as north-south-trending peaks and troughs. The modern sediments have an erosional contact with the Holocene. Several modern sandbanks also directly overly and preserve areas of Holocene landscape (e.g. the Brown Bank Missiaen *et al* 2020: Figure 3.15, E). Consequently, the modern bathymetry does not necessarily reflect the Holocene landscape morphology in this area. Additionally, the size of many of these sandbanks can render the underlying Holocene landscape relatively inaccessible to archaeological sampling. However, where topographic or erosional conditions allow, it is possible to recover sediment samples, as has been successfully demonstrated near Brown Bank (Missiaen *et al* 2020).

An archaeological narrative of landscape development from the Late Palaeolithic to the Mesolithic

Having provided a general description of landscape features identified during recent study, it is useful to support this with a summary chronological and archaeological overview.

At the end of the Late Palaeolithic, the northern edge of the current Dogger Bank essentially represented

the coastline of Doggerland (Figure 3.17). Although the Outer Silver Pit and the embayment to the south, near Brown Bank, had already started to flood, research by BRITICE suggests that the coastline north of Dogger Bank had existed from *c.* 21,000 BP Roberts *et al.* 2018). This coastline remained a relatively stable component of the landscape for approximately 11,000 years prior to the start of the Mesolithic. The implications of a relatively stable northern coastline are significant. The coastline, with its rich and varied resources must have been extremely important in economic and cultural terms to the human communities in the region.

As sea levels rose there would have been impacts affecting large areas away from this coastline. The Outer Silver Pit would been become a significant marine inlet, and an outlet for major drainage systems from the Dogger Bank and East Anglia (Figure 3.17). The other main drainage basin, associated with the Elbe palaeovalley, would have experienced flooding with a significant inlet forming on the north-eastern coastline of Doggerland. Whilst these areas flooded, the Elbe palaeovalley channel would have continued to drain areas in the east of Doggerland, as well as Denmark and Germany (Figure 3.17). Inundation would also have continued in the south of Doggerland. Here, flooding would have preceded from the area of the English Channel (Figure 3.17) and created a relatively shallow marine inlet between Britain and the Netherlands (Figure 3.18). Although low lying, most of the study area remained emergent during this time and the landscape could have provided a diversity of environments that would have made the area attractive for a range of subsistence activities. The extensive river systems would have provided excellent transport corridors for both human and animals, as well as providing wetland resources. Given the connectedness of the landscape, it is reasonable to surmise that groups from what are now the Netherlands and Britain were connected through Doggerland (Reyneir 2000 citing Verhart pers. comm.). Aside from connections across the land, the boat technology of the day must have supported travel (Pedersen *et al.* 1997), supporting trade and contact between communities who lived in or visited the region (Gaffney *et al.* 2009). A number of cultural indicators are suggestive of such links. These include the rare antler head dresses, found at Bedburg-Konigshoven in Germany (Street 1989), through the Low Countries (Verhart 2008) and as far north as Star Carr (Clark 1972; Conneller 2004). Such linkages may suggest a 'northern technocomplex' centred on the great plains of the North Sea (David 2006: 139).

Between 10,000 BP and 8500 BP sea-level rise continued and large tracts of the landscape of central Doggerland must have been inundated, initially through the three main inlets in the landscape (Figure 3.18). The area around the Outer Silver Pit was submerged, allowing the inundation of large parts of the centre of Doggerland including the relatively low-lying area of the Oyster Ground.

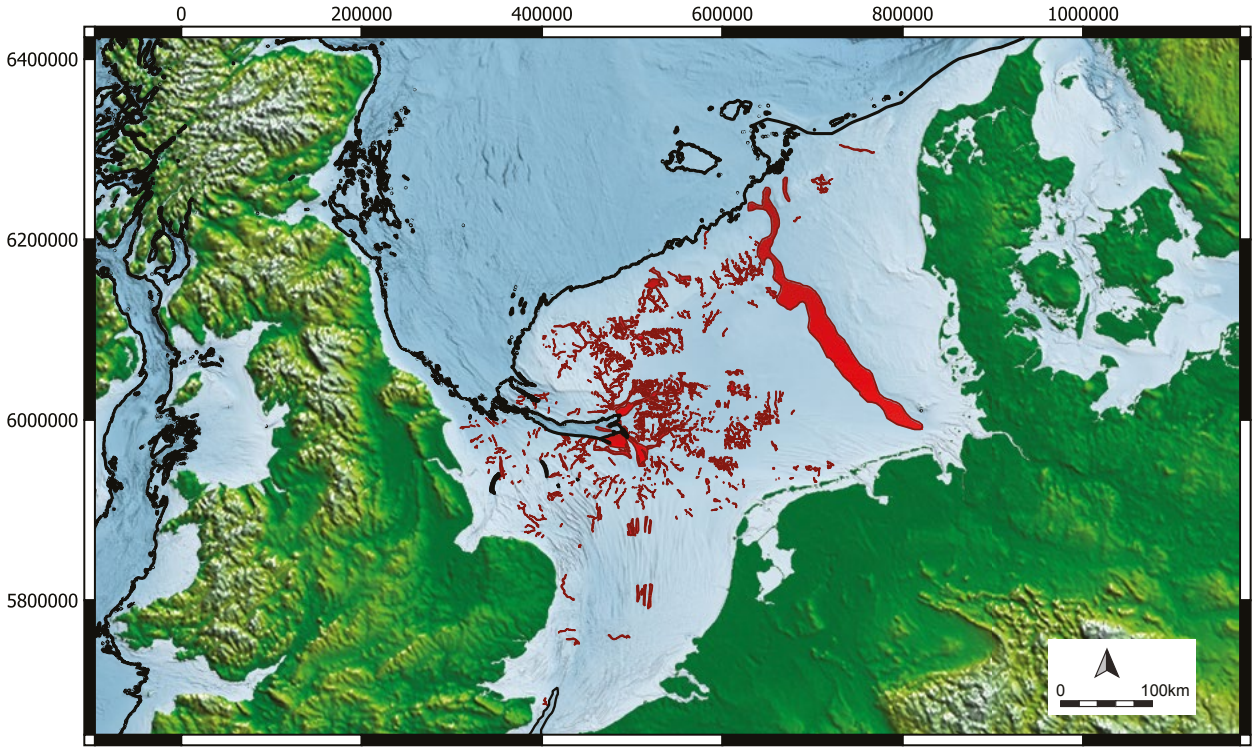

Figure 3.17 Major features, Late Palaeolithic c. 11,500 BP.

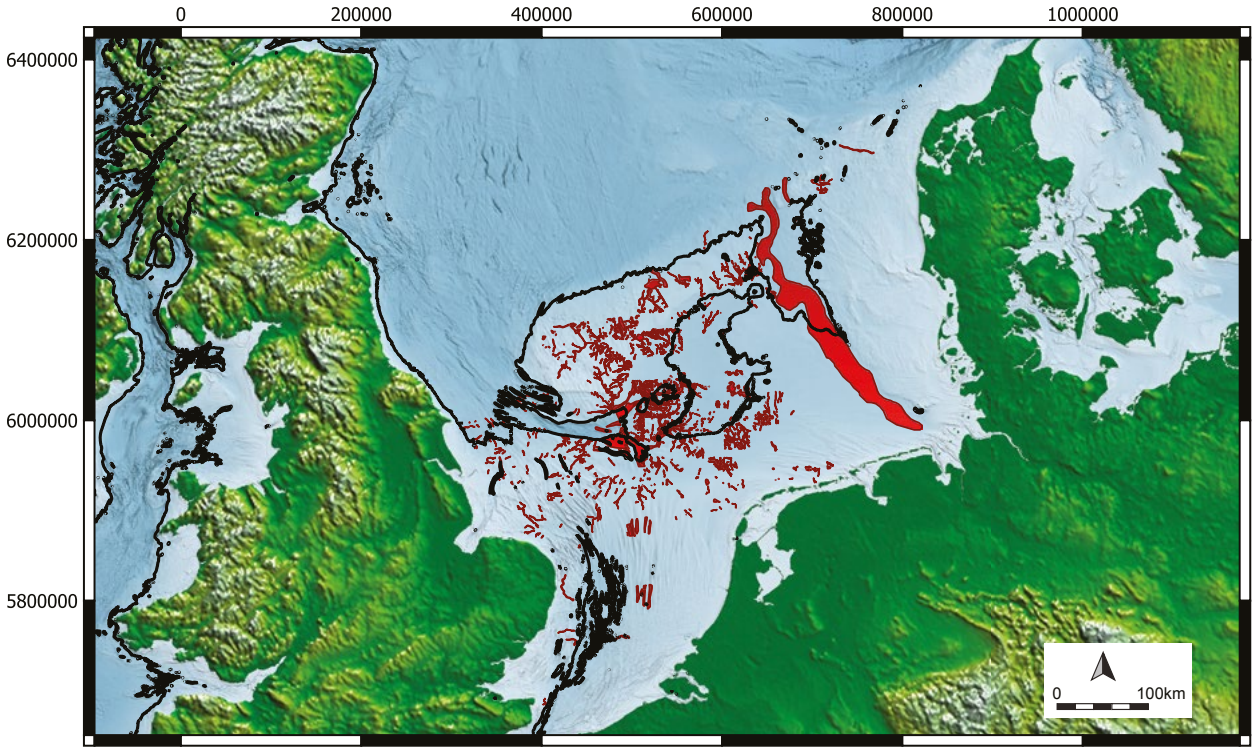

Figure 3.18 Coastlines of early Mesolithic Doggerland c. 10,000 BP.

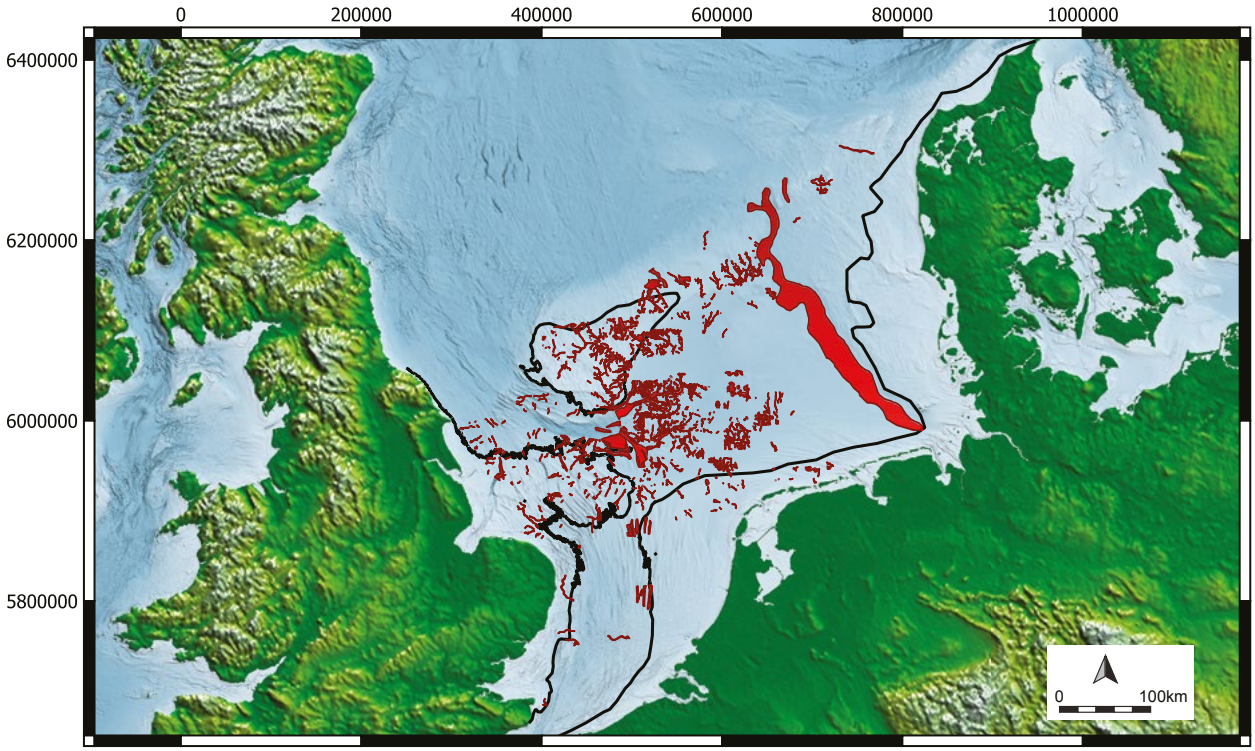

Figure 3.19 Coastlines of Mesolithic Doggerland c. 8500 BP.

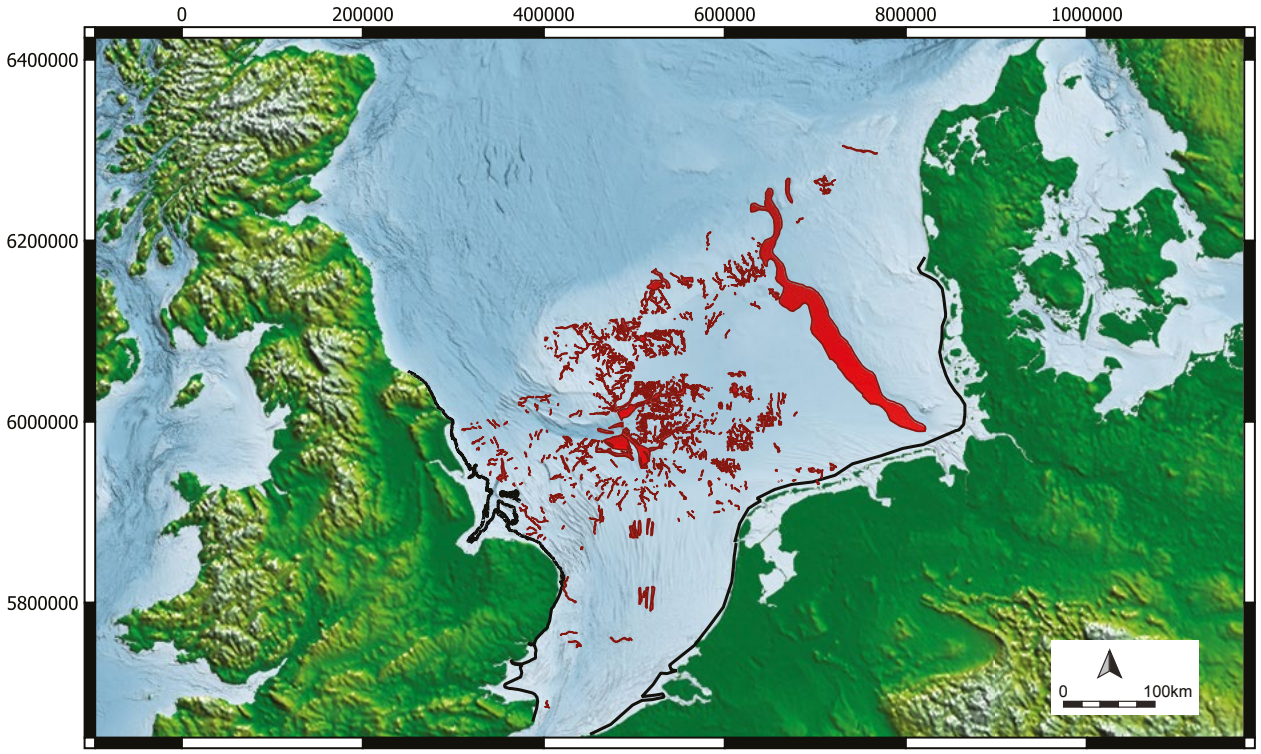

Figure 3.20 Coastlines of the earliest Neolithic c. 7000 BP.

It is during this period that the Dogger Bank became an island (Figure 3.19). Its links to the east was cut as waters flooded the Elbe palaeovalley. Additionally, with the coastline retreating from the south and into the central part of Doggerland, the terrestrial linkage between Britain and Europe would have rapidly reduced to a strip and was eventually breached. These relatively rapid changes presumably had an impact on the Mesolithic communities inhabiting the new coastlines. Not all change was bad. New coastlines may would have provided access to marine resources and enhanced the subsistence base for coastal communities, who may have also taken advantage of the new marine inlets for travel.

As the landscape fragmented and terrestrial interconnectivity reduced (Figures 3.18 and 3.19), it is possible that the groups living in this area may have found maintaining traditional links increasingly difficult. It is possible that connections were severed even before the inundation of the final land linkages.

By about 7000 BP, the emergent landscape of Doggerland was largely lost to the sea (Figure 3.20). During this period, Britain and Europe were separated by a considerable body of water and the Dogger Island would have been flooded. However, areas of landscape would still have existed as extensions of East Anglian and the European coastlines at the end of the Mesolithic and into the Neolithic (Figure 3.20). Continuing sea-level rise and loss of landscape would have remained noticeable to contemporary communities and was likely to have influenced the cultural development of these regions.

Conclusions

Europe's Lost Frontiers and its preceding projects have enabled a significant advance in our understanding of the emergent landscape of the southern North Sea and provided first pass mapping of an area of prehistoric landscape of *c.* 188,000km^2. The full archaeological implications of this work will be explored in later project volumes but will also act as a springboard for future researchers studying climate, sea-level history, palaeogeography, geology as well as archaeology.