

Chapter 14

Tributaries of the Elbe Palaeovalley: Features of a Hidden Palaeolandscape in the German Bight, North Sea

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Abstract Prior to postglacial global sea-level rise in the present North Sea area, Mesolithic hunters and gatherers were able to settle in the coastal lowland landscape between England, Germany and Denmark, commonly known as Doggerland. Regarding the reconstruction of this now drowned palaeolandscape, the German exclusive economic zone (EEZ) sector is still ‘terra incognita’. Recent discoveries of two ancient fluvial systems, both of which were tributaries of the Elbe Palaeovalley, give new insights into the formation of the Mesolithic Doggerland landscape in the German EEZ. One of these fluvial systems developed during the last glaciation and connected the Dogger Hills with the Elbe Palaeovalley. The second river structure discovered in the south seems to be slightly younger and can be identified as the drowned extension of the modern Ems River.

14.1 Introduction

Nearly 10,700 years ago, Mesolithic people were able to cross an extensive coastal lowland which is now covered by the south-eastern North Sea. Archaeological and palaeoenvironmental data document that hunters and gatherers were present in the area between England, Germany and Denmark at this time, living in a landscape shaped by a system of rivers, lakes, birch groves, pine woods, fens and grasslands (Coles 2000; Fitch et al. 2005; Gaffney et al. 2007; Spinney 2008; Cohen et al. 2014). The present shallow water area, the so-called Dogger Bank, was a hill ridge and the exposed red sandstone rocks of Helgoland stood out against the surrounding plains, rather like Uluru (Ayers Rock) in Australia today. This submerged Mesolithic palaeolandscape is known as Doggerland (Coles 1998).

The final postglacial transgression drowned the prehistoric surface of Doggerland by shifting the coastline southwards towards its current position. Presently, the former Doggerland is covered by modern North Sea sands (Zeiler et al. 2000). There is, however, still considerable cultural heritage buried in the ancient sediments (Coles 2000; Spinney 2008; Gaffney et al. (n.d), Chap. 20). Despite

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this, no German state heritage authority has responsibility in the German Exclusive Economic Zone (EEZ) outside its territorial waters (12 nautical miles). Moreover, this heritage is currently threatened by diverse and potentially destructive economic activities, for example, laying of submarine cables and pipelines, the construction of offshore wind farms, oil and gas production, offshore mining, engineering installations, fisheries and sea farming activity. Almost every inch of seafloor within the German EEZ is affected by such activities.

On the other hand, this intensive and extensive commercial exploitation of the seabed has been accompanied by numerous surveys of surface and sub-surface features, and these offer a vitally important source of scientific knowledge on the origin and development of this unique prehistoric landscape (Ward et al. 2014).

During recent decades especially, scientists from the UK and the Netherlands have re-discovered the Doggerland landscape in the British and Dutch sectors of the North Sea (Fitch et al. 2005, 2011; Gaffney et al. 2007, 2009; Spinney 2008; Cohen et al. 2014; van Heteren et al. 2014). Whilst the German EEZ comprises prominent parts of the late Pleistocene-Holocene drainage system of Doggerland, particularly the Elbe Palaeovalley or 'Elbe-Urstromtal', its presence and extent is still largely 'terra incognita'.

During surveys within the German EEZ running high resolution reflection seismics, two shallow palaeo-river structures draining into the Elbe Palaeovalley were discovered (Fig. 14.1). One is located in the northern part of the German EEZ, at the entry of the so-called Duck's Beak ('Entenschnabel'; study area 1, Fig. 14.2), the second runs through the southern part of the German EEZ, about 40 km north of the island of Juist (study area 2, Fig. 14.3). The two study areas are located about 170 km apart.

Although both palaeo-river systems drained into the Elbe Palaeovalley, they were affected in different ways by the Holocene marine transgression. This raises two questions. Firstly, how did each river system contribute to the formation of the late glacial-postglacial palaeolandscape? And secondly, how did they interact with the late Weichselian/early Holocene hydrogeological regime on the North Sea shelf in the course of sea-level rise?

14.2 Database

In both study areas, all seismic profiles are based on channel boomer seismic data. Boomer data were obtained using a boomer plate operating at an energy level of 300 J. The data were recorded using a short single-channel streamer with 20 hydrophones. This configuration provided a maximum shot rate of 3.5 shots per second, which offered a good horizontal resolution.

Study area 1 was sampled during one expedition in 2012 with a seismic grid of south–north and east–west seismic tracks using a spacing of approximately 300 m. For methodical reasons (namely the density of the seismic grid), study area 2 is sub-divided into a northern sector (surveyed during three expeditions from 2009 to 2011) and a southern sector (surveyed in 2013). For the northern sector, a dense grid of south–north and east–west seismic tracks was run with a spacing of approximately 200 m. The southern sector was added to trace the southern connection of the river structure towards the outer Wadden Sea. Due to the test character of this latter survey, and the fact that a Traffic Separation Scheme crosses the survey area, the resulting grid has a line spacing of only about 500 m. This difference in line spacing has to be taken into account in any further interpretations.

The seismic data were used to produce initial seismic profiles of the proposed Holocene surface and to define the location, form and dimensions of the palaeorivers. For the depth estimation of the base of the ancient valleys, the two-way-traveltime (TWT) was converted into metres using a propagation velocity of 1,600–1,650 m/s. The difference between the depth of the seafloor and the estimated base of the valley gives the depth of the valley in metres below sea floor (mbsf). The base of the valley was used to compute gridded maps based on a method of natural neighbour interpolation.

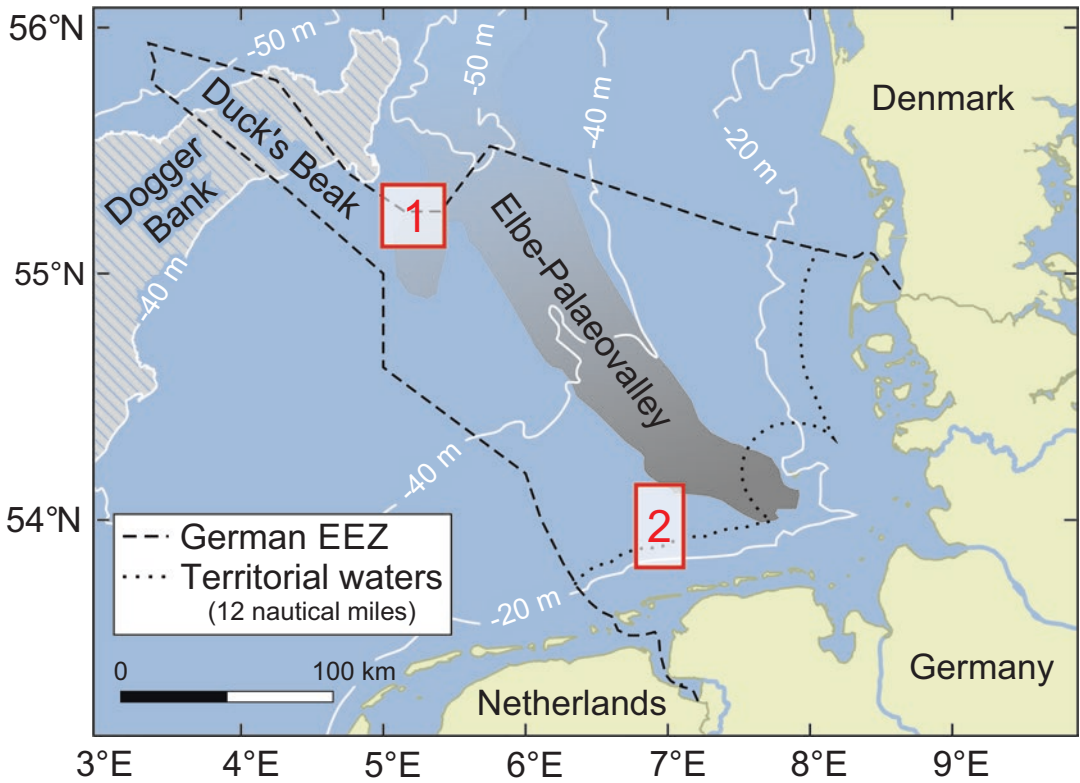


Fig. 14.1 The southern North Sea, showing the locations of study area 1 (see Fig. 14.2), at the entry of the Duck's Beak ('Entenschnabel'), and study area 2 (see Fig. 14.3), which is about 40 km north of the island of Juist. *Shading* indicates the Elbe Palaeovalley and the Dogger Bank. The *dotted line* marks the border of German territorial waters (12 nautical miles) and the *dashed line* marks the German exclusive economic zone (EEZ). Contour lines for -50 m, -40 m, and -20 m (*white solid lines*) are with reference to the present sea level and represent hypothetical shorelines at about 10.6, 9.8, and 8.2 ka

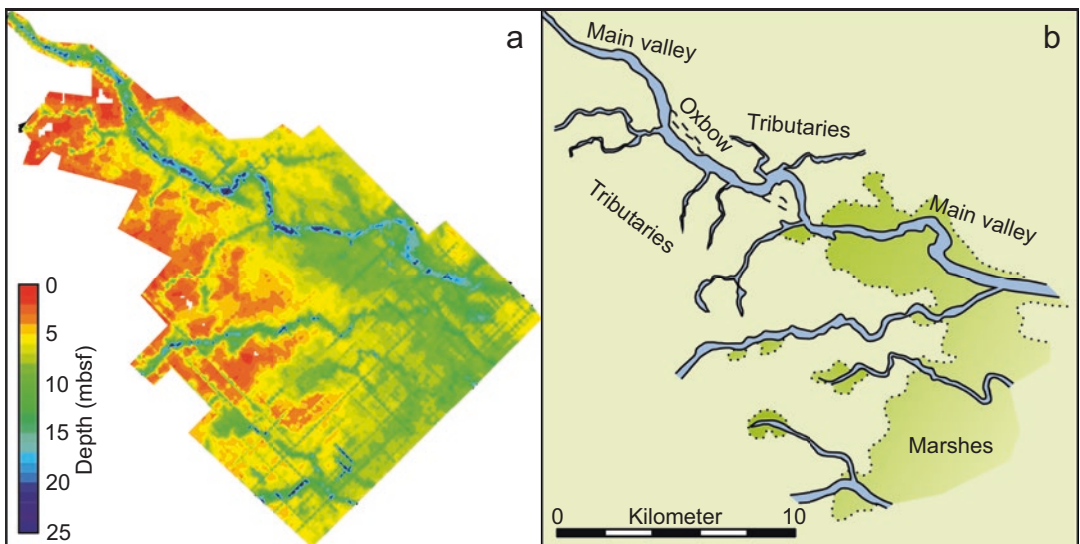


Fig. 14.2 Study area 1 at the entry of the Duck's Beak: **a** Seismic visualization of the earliest Holocene palaeosurface and valley base showing a complex fluvial system of a main valley with eight tributaries, two separated valleys in the south-eastern part as well as marshes. **b** Interpretation of the seismic grid showing rivers (*blue*), Oxbows (*dashed line*) and the extension of marshes (*green and dotted line*)

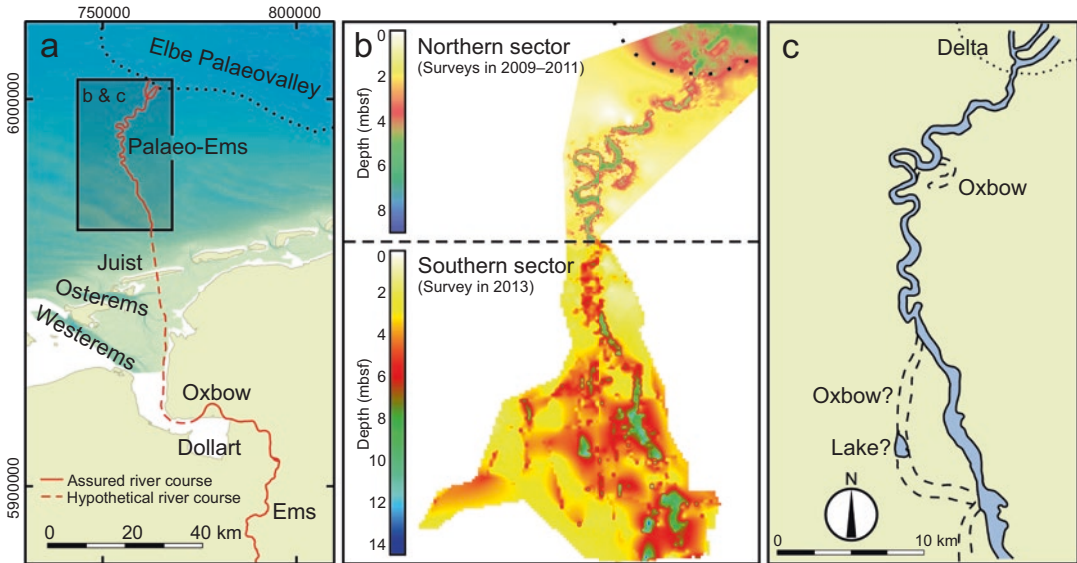


Fig. 14.3 Study area 2, Paleo-Ems: **a** Assumed river course of the drowned Palaeo-Ems and the modern Ems River (solid red lines) in relation to the Elbe Palaeovalley (dotted black line). The hypothetical course (dashed red line) crosses today's barrier island Juist, which was not formed when the Palaeo-Ems existed. **b** Seismic visualization of the palaeosurface and valley base, and **c** interpretation of the seismic grids showing a meandering river (blue) with oxbows (dashed lines) and oxbow lakes (blue) and the delta of the Elbe Palaeovalley (dotted line). The seismic visualization is separated into a northern and a southern sector due to different qualities of the seismic grid (see text for explanation)

The degree to which the river valley structures meander—their sinuosity—was measured by the ratio of the real length of a river section to the linear distance between its endpoints (Leopold et al. 1964). Sinuosity ratios ≥ 1.5 indicate meandering structures.

14.3 Stratigraphic Interpretation

Due to the lack of sediment cores and geological ground-truth data in study area 1, the stratigraphy is obtained by interpretation of seismic profiles. We used characteristic reflectors to identify seismic packages which cover or intersect the substratum (Figs. 14.4 and 14.5). The horizontally stratified reflectors 'A' and 'B' represent the top and base of the modern sea floor. The package they comprise is about 1 m thick and is observed in both profiles. Reflector 'C' may be congruent with the base of the mobile sand deposits spatially distributed in the North Sea (Zeiler et al. 2000). The c. 3.5 m-thick seismic package between reflectors 'B' and 'C' is characterised by a more transparent horizontal stratification which increases in strength downward and may reflect a fining downward in grain size from middle and fine sands to silts. This package is only seen in the profile in Fig. 14.4. Strong horizontal seismic reflectors 'D' are indicative for clay and peat deposits at the base of the mobile sand deposits of 'C'. Reflector 'E' marks the irregular-shaped base of various depressions in both profiles (Figs. 14.4 and 14.5), which incise 5–10 m deep into the substratum. They show different shapes and internal seismic patterns but seem to belong to the same stratigraphic horizon. The infill 'C–E' in Fig. 14.4 shows a complex depositional body with irregular internal reflectors. These internal reflectors partly overlie the seismic package 'C–D' and are partly cropped by the same seismic package. The base of the depression in Fig. 14.5 is more U-shaped and marked by a strong reflector indicating clay

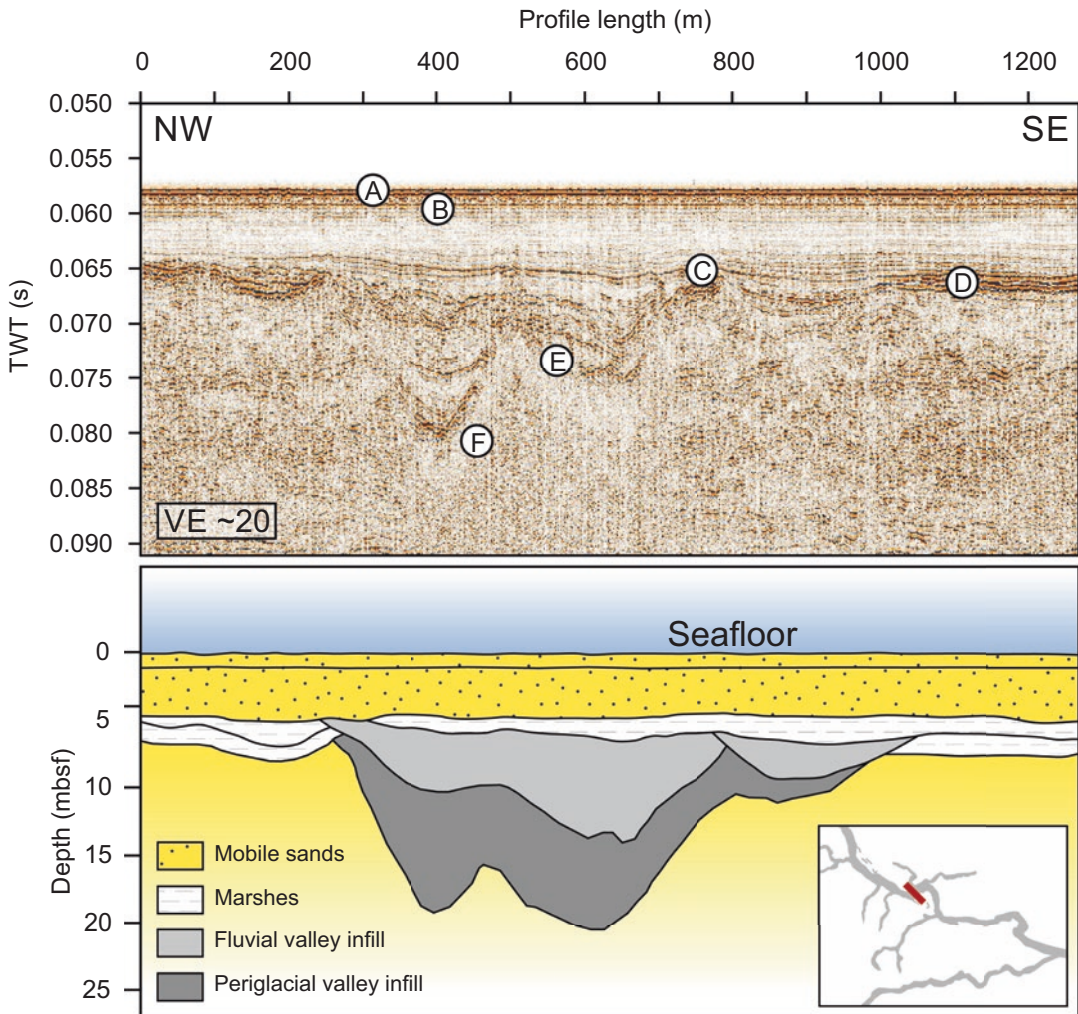


Fig. 14.4 Study area 1. Seismic cross section and interpretation of the main valley showing two drainage phases: (1) A deep periglacial valley which is incised up to 20 m into the subsurface can be related to the late Weichselian glacial, and (2) a shallower, down to 8 m-deep fluvial valley with repeated dislocations of its bed. Prominent seismic reflectors used for the stratigraphic interpretation are marked with capital letters A–F

and peat deposits. The infill of this depression is horizontally stratified and has similar characteristics to package ‘B–C’ in Fig. 14.4. A specific characteristic observed in Fig. 14.4 is that the already described depression cuts another stratigraphically older depression, which incises more than 15 m deep into the substratum. The base of this older depression is barely identifiable as a continuous transparent zone ‘F’. The infill of the depression is marked by some stronger internal reflectors.

Interpretation of seismic profiles in study area 2 (Figs. 14.6 and 14.7) is supported by visual descriptions of four cores (Fig. 14.8). The cores penetrate the entire valley infill from the seafloor to the base. The observed lithological succession is typical of this North Sea region. The river valley incises into glacio-fluvial sand deposits of the substratum. The base of the valley infill is determined by a 0.2–1 m-thick basal peat layer which is overlain by intertidal or marine deposits of clays or silty clays. The river valley is covered by modern or mobile sands, which is also evident in the horizontally

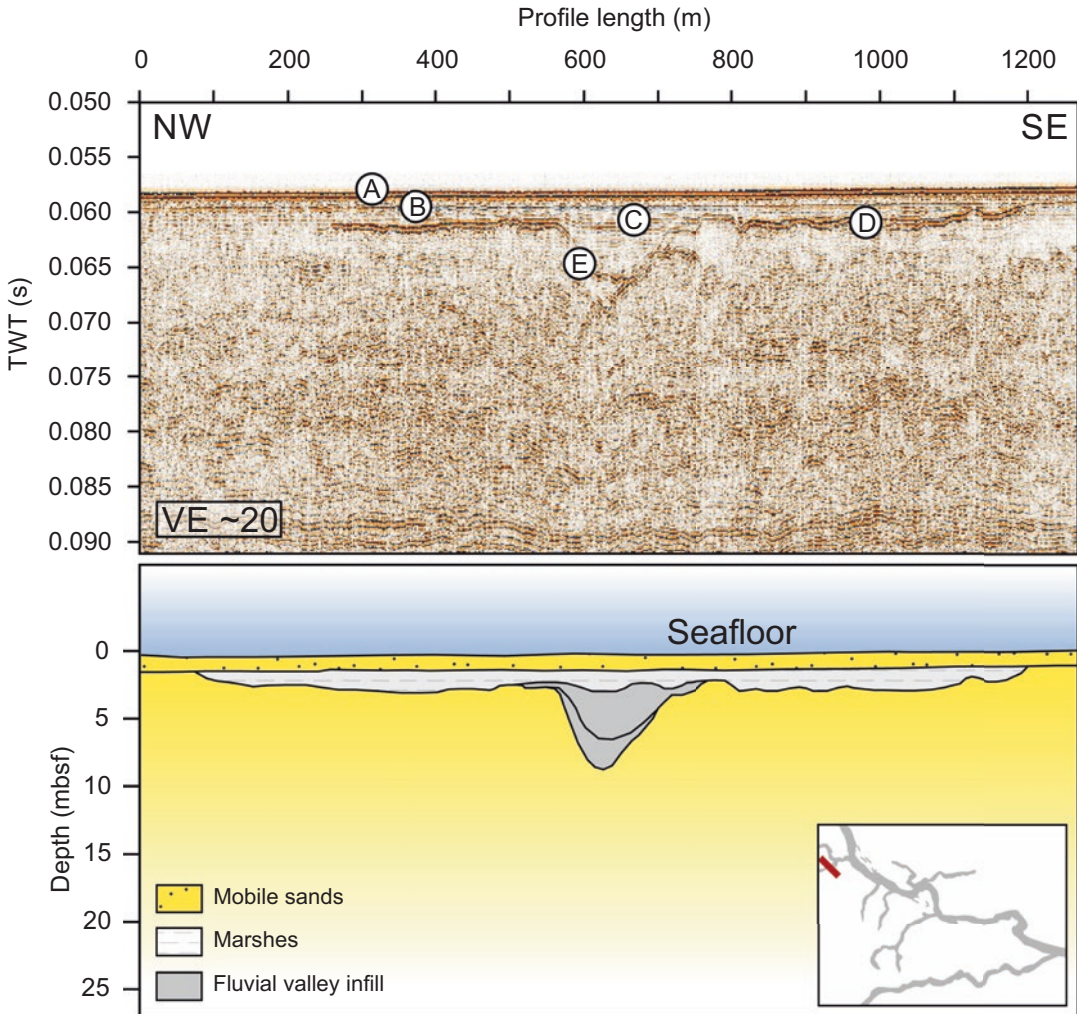


Fig. 14.5 Study area 1. Seismic cross section and interpretation of a tributary to the main valley shows an 8 m deep, V-shaped valley body with a homogeneous fill, which is embedded in a very shallow 2 m-deep body interpreted as a marsh. Prominent seismic reflectors used for the stratigraphic interpretation are marked with capital letters *A–E*

stratified seismic reflectors ‘*A–B*’ (Figs. 14.6 and 14.7). The strong seismic reflectors at the valley base in Figs. 14.6 and 14.7 can be attributed to the peat layers observed in the cores.

14.4 Fluvial Systems Seen in the Geophysical Record

14.4.1 Study Area 1

At the entry of the Duck’s Beak (‘Entenschnabel’), a system consisting of a deeper main valley with eight shallower tributaries (five on its southern side and two on its northern side) was observed in the seismic grid, running in a north-west to south-east direction from the Dogger Bank area toward the Elbe Palaeovalley (Fig. 14.2). Two separated valleys in the south-eastern part of the study area run

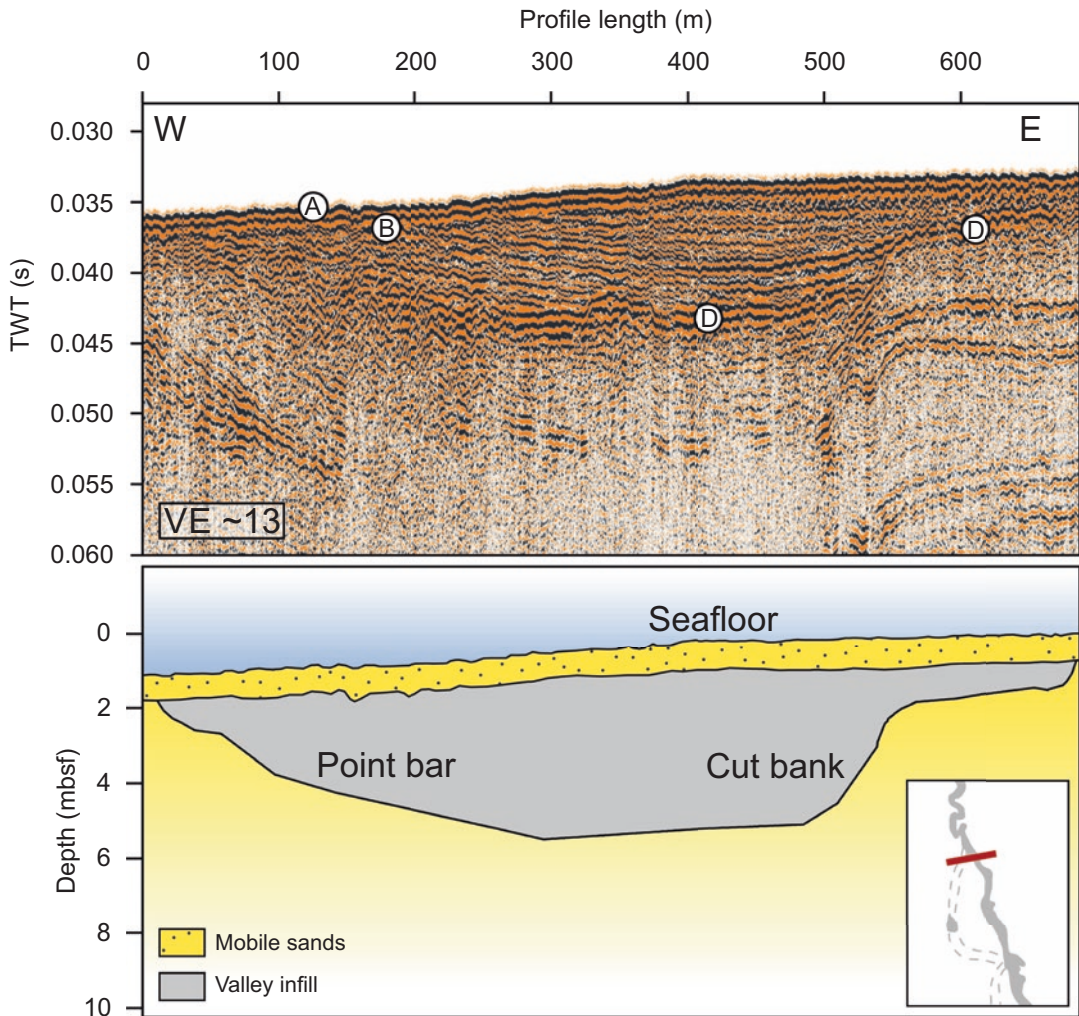


Fig. 14.6 Study area 2. Seismic cross section and interpretation of the Palaeo-Ems (southern sector) showing pointbar and cut bank of a meandering river structure. Prominent seismic reflectors used for the stratigraphic interpretation are marked with capital letters A–D

more or less parallel to the main valley. The seismic visualization of the proposed Holocene base (Fig. 14.2) shows a slightly elevated area in the south-western and western part of the study area. This is interpreted as the origin of some of the tributaries. The north-eastern and eastern part of the study area is dominated by shallow depressions connecting the valleys. Strong seismic reflectors at the base of the depressions indicate clay or peat deposits. Hence, these depressions are interpreted as palaeo-marshes. Similar relationships have been documented in the Dogger Bank area for this time period by Fitch et al. (2005). The source of the main valley and its exit into the Elbe Palaeovalley are not covered by the existing surveys.

Inferred from seismic interpretation, the valleys are covered by a 3.5–5.0 m-thick unit of mobile sands. The greater thickness of the sand coverage compared to study area 2 is caused by the greater water depth and the associated reduced vulnerability to wave and current exposure on the shallow shelf. The water depths increase from 39 m in the South–east to 46 m in the North–west.

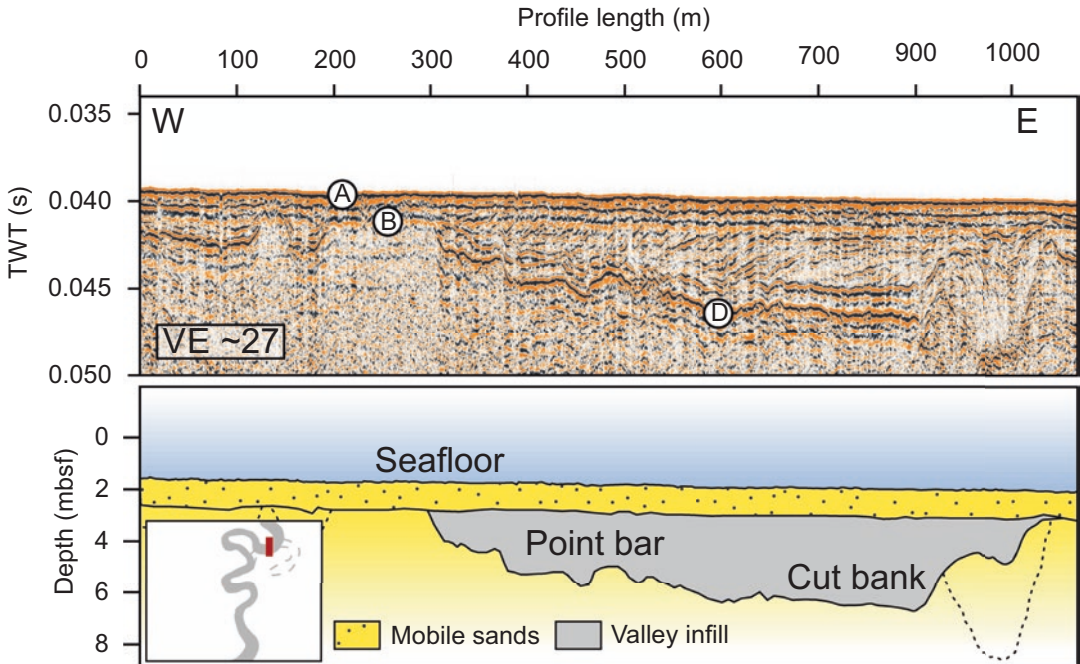


Fig. 14.7 Study area 2. Seismic cross section and interpretation of the Palaeo-Ems (northern sector) cut bank, showing an undulating base to the pointbar and cut bank of a meandering river structure. On its eastern flank the valley appears to truncate another valley structure (*dashed line*), although this has not yet been confirmed. Prominent seismic reflectors used for the stratigraphic interpretation are marked with capital letters A–D

The main valley was mapped over a length of 30 km. The sinuosity ratio is 1.19 and is therefore indicative of a rather linear river. The valley is approximately 700 m wide and incises, with relatively steep flanks, down to 20 mbsf into the sandy sediments of a larger Pleistocene glacial and fluvio-periglacial accumulation plain. This proposed periglacial deeper valley was re-used by a shallower valley system whose morphology is indicative for a fluvial valley with repeated dislocations of its bed. However, without ground truth data from sediment cores, it is not clear if the actual infill deposits are of fluvial or tidal origin. During the process of drowning, the river valleys were occupied by tidal channels and we have no indications as to how severe the reworking of the fluvial sands has been. Reflections of tidal sand deposits and fluvial sand deposits are often quite similar. This can lead to misinterpretations, as is shown by van Heteren et al. (2014) for the Dutch sector of the North Sea.

The bed of this shallower river valley is located at a depth similar to that of the other river structures and tributaries in the study area (Fig. 14.2). These tributaries are up to 6 km long, 250 m wide, and incise 8–12 m below the seafloor. Their sinuosity is rather linear, with ratios varying between 1.09 and 1.27. An example is given in the seismic cross section of a tributary to the main river in Fig. 14.5. The valley is U-shaped, 200 m wide and as much as 8 m deep. Its infill is more homogeneous and shows horizontally stratified seismic reflectors.

14.4.2 Study Area 2

About 40 km north of the island of Juist, a shallow south–north oriented buried valley with meanders, oxbows and possible oxbow lakes is observed on seismic grid profiles over a distance of nearly 50 km (Fig. 14.3). Water depths in this study area increase from South to North from 19 to 34 m. The valley

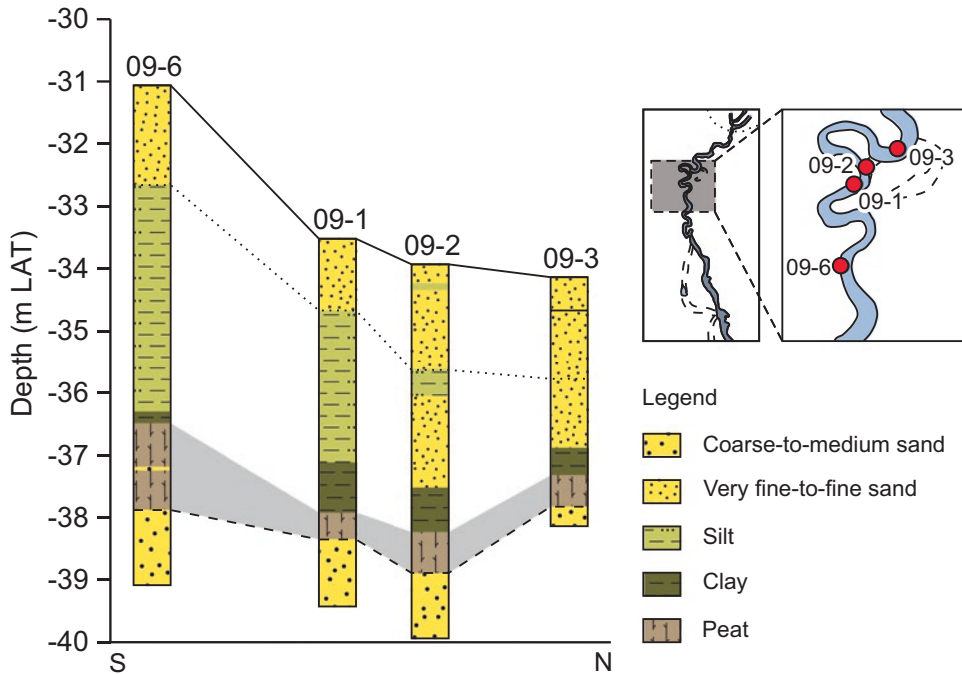


Fig. 14.8 Study area 2. Sediment columns derived from visual core description of four cores along a virtual south to north transect in the northern sector. The top of the cores are corrected to m LAT depths. The base of the river valley infill (*dashed line*) is determined by a basal peat layer (*grey shading*) which is overlain by intertidal or marine deposits of clays or silty clays. The valley is covered by modern or mobile sands (*dotted line* = approximate depth of the valley top). The different *thicknesses* of the valley infill reflect core locations at the centre of the valley or at the valley flanks

is covered by a 0.8–2.0 m-thick unit of mobile sands. As with the valley system in study area 1, the morphology of the valley in study area 2 is indicative of a fluvial valley. Peat layers at the base of the valley overlain by clay or silty clay deposits lead to the inference that the system gradually drowned due to transgression and that the valley infill is largely of intertidal or marine origin.

The valley incises to a depth of 7–14 m into the Pleistocene glacial and fluvio-periglacial sands, which form the sub-seafloor, with depths decreasing from South to North. The width of the valley varies between 500 and 1,500 m with a generally increasing width from South to North. The north-south gradient over the total length is broadly consistent with the very shallow slope of the seafloor of 0.027%.

The shallow gradient may have caused the meandering course of the valley. At first view, the sinuosity ratio of the valley structure shows apparent differences between the northern and southern sector. The river course in the northern sector has sinuosity ratios between 1.61 and 2.15, which clearly indicates a meandering river course of about 24 km length. In contrast, sinuosity ratios in the southern sector range between 1.02 and 1.33 indicating a more linear river course of about 26 km length. However, the more linear river course in the southern sector is obviously an artefact owing to the less dense seismic coverage, which may be too coarse to resolve details of the river's sinuosity. The southern origin of the river valley remains undiscovered so far. However, derived from its location and course, we suppose that the ancient river is the drowned predecessor of the modern Ems River (Fig. 14.3a). The northern end of the river valley fans out into at least three valleys forming a delta at the western flank of the Elbe Palaeovalley.

Morphological features of meandering rivers like point bars and cut banks are well-developed in seismic profiles (Figs. 14.6 and 14.7). The valley base in the cross section is irregular due to several

small adjoining valleys. Seismic reflectors within the infill are continuous and parallel to sub-parallel, showing a homogeneous, horizontally stratified infill (Fig. 14.6). In some seismic profiles, inclined reflectors indicate a different infill process across the western valley flank (Fig. 14.7).

14.5 Styles of Tributaries in the Elbe Palaeovalley

Studies in the British and Dutch EEZ subsurface suggest a diversity of styles of river systems related to the late Weichselian/early Holocene Doggerland palaeolandscape, depending on specific topographic settings and their change over time (Törnqvist 1993; Berendsen and Stouthamer 2000; Fitch et al. 2005; Gaffney et al. 2007; Hijma 2009). Data from the western Dogger Bank show that, during the Holocene, a complex meandering river system had developed consisting of a 600 m-wide palaeovalley with tributaries or distributary channels with moderately developed sinuosity, and associated lakes or marshes (Fitch et al. 2005). We infer that these were finally filled with tidal sediments due to transgression. The general fluvial morphology of study area 1 appears to have analogies with the earlier fluvial phase of this western Dogger Bank area in terms of a major river channel with low to moderate sinuosity, tributaries and associated marshes.

From our investigation, study area 1 seems to have experienced two phases of development with distinctive features forming in each case. The first phase consisted of a deep palaeovalley, which we suppose originated during or at the end of the last glaciation. Both the bottom of the periglacial valley and the plains of the early phases of the Elbe Palaeovalley are chronologically related, occurring at the same stratigraphic level (see Figge 1980). In the second phase, during a postglacial stage, the deeper valley was replaced by a valley system with tributaries of moderately developed sinuosity or distributary valleys and lakes. The valley fill of this younger system is associated with a higher stratigraphic level than the periglacial valley and may reflect a time when the Elbe Palaeovalley was already influenced by transgression. The estimated age for the second fluvial phase is based on the assumption of a coexistence of the fluvial systems in both study areas, whereas the Dogger Bank fluvial system overlies buried late Weichselian glacial tunnel valleys. The fluvial system ceased during the course of the North Sea transgression when this region was flooded not later than 9,800 years ago. This is based on the -40 m contour line (Fig. 14.1) and the regional sea level curve of Vink et al. (2007).

The river structure located in study area two to the South differs significantly from the valley system of study area 1. The river structure here is characterized by a clear meandering channel with lateral valley displacements running parallel to its flow direction and shifting sinuosities, but without any change in its dimension or meandering characteristics over time. Analogies in morphology, incision depth and dimensions are known from the late glacial/early Holocene Scheldt River (Kiden 1989, 1991) and from the early phase of the Rhine-Meuse system (Törnqvist 1993; Berendsen and Stouthamer 2000). The deposits of the late Weichselian river incision in the Scheldt are 7–8 m thick and the alluvial plain was about 1.8 km wide. The incision took place at about 13,000 BP, based on palynological studies and radiocarbon dating (Kiden 1991). According to Kiden (1989), the character of the valley experienced important changes after the first occurrence of peat layers at about 8,700 BP. After that time, a new river valley was incised into the already existing peat deposits of the alluvial plain. Several subsequent lateral migrations of the river course caused the formation of point bars whilst peat and underlying sediment deposits were eroded to form cut banks. Using a time-space model, Törnqvist (1993) illustrated a braided river system for the late glacial followed by an early Holocene meandering river system. From about 5,000 years ago the system changed to an alternating meandering anastomosing system associated with a rapid sea level rise.

The comparison of these findings from the Scheldt River and the Rhine-Meuse valley belt with the small incisions in the valley base of the river of study area 2, together with the formation of point bars and cut banks, suggests that the river of study area 2 may have changed its valley character from a

meandering, late glacial river valley to a wide, Holocene alluvial plain with migrating meanders, point bars and peat growth as a consequence of progressive North Sea transgression.

The river systems described for the two study areas seem to have their origin in the latest glacial, when permanently frozen ground was still present. We infer that the conspicuous difference in morphology of the river systems described for the two study areas originates in differences in their source areas and regional differences in relation to sea-level change after the Last Glacial Maximum. The perimarine river of the Ems palaeovalley persisted as a single migrating river draining across exposed land about 8,200 years ago based on the -20 m contour line (Fig. 14.1) and the regional sea level curve, at a time when the northern river system in the Duck's Beak area was already drowned.

14.6 Conclusion

The postglacial landscape in today's North Sea area known as Doggerland was covered by a network of rivers, lakes, wetlands and huge drainage channels. Seismic records of two newly discovered structures lying within the German EEZ that once formed part of Doggerland provide evidence for a morphology of clearly riverine origin and a complex hydrogeological regime. However, the riverine meanders are filled for the most part with intertidal deposits, which points to the fact that the sedimentary infill was only deposited when the river had already been transformed to an estuary during the course of marine regression.

Both river structures are tributaries of the Elbe Palaeovalley, and both are assumed to have developed since the latest Weichselian. However, differences in topography and source, as well as timing and intensity of fluvial activity, caused significant differences in river morphology.

The northern river structure connected the Dogger Bank in the North-west with the western flank of the Elbe-Palaeovalley. The system was influenced very early on by the postglacial sea-level rise and developed from a single, deep valley, which may initially have originated during the last glacial, to a network of shallower rivers and tributaries. Their morphology is in various aspects similar to river structures known from the western part of the Dogger Bank.

The southern river structure is the drowned extension of the modern Ems River and can be distinguished as part of the tributary system feeding the southern head of the Elbe Palaeovalley, together with the Elbe, Weser and Eider Rivers. The river structure was, from the beginning, formed as a meandering river valley with repeated dislocations of its river bed. However, the Ems palaeovalley still existed whilst the northern river structure was already being drowned by the advancing North Sea.

The development of both river systems reflects the landscape evolution of Doggerland along the west flank of the Elbe Palaeovalley. This, in turn, has implications for the landscape configuration available to Mesolithic hunter and gatherers. In the initial phase, the northern system was already draining the Dogger Bank area while the adjacent last-glacial ice-sheet was still collapsing. However, the southern Ems palaeovalley seems to have developed during the postglacial phase. It is evident that we need further investigations and stronger ground truth data from sediment cores to improve our understanding about the role of such drainage systems in forming the Doggerland landscape within the German EEZ and their influence on changing patterns of Mesolithic settlement.

Acknowledgments We gratefully acknowledge Sebastian Feldmann, Lukasz Socko, Mike Belasus and Vanessa Wahlers for their excellent technical and scientific operation on board *LEV Taifun* and for assistance with the data processing onshore. We thank Mark Coughlan for his suggested improvements to the text, and Henk Weerts and Dimitris Sakellariou for constructive reviews that improved our manuscript. This study was funded through DFG-Research Center/Cluster of Excellence 'MARUM – The Ocean in the Earth System' in cooperation with the project 'Bedrohtes Bodearchiv Nordsee' funded by the Federal Ministry of Education and Research (Germany). The study was further supported with data from several anonymous industry partners.

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