DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2001/100

The Neogene Utsira Sand and its seal in the Viking Graben area, North Sea

Saline Aquifer CO2 Storage (SACS) project, Phase 2 Task 1.7 Geology

Ulrik Gregersen and Peter Niels Johannessen

GEOLOGICAL SURVEY OF DENMARK AND GREENLAND
MINISTRY OF ENVIRONMENT AND ENERGY

G E U S

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The Utsira Sand and its sealing units

The study has revealed the following nine Neogene, informal depositional units in the order of decreasing age: The ”Lowermost shale/sand unit”, the ”Sub Utsira Sand unit”, the ”Utsira Sand”, the ”West sand unit”, the ”East sand unit”, the ”Lower seal”, the ”Middle seal”, the ”Bottom-set sands” (6 sand wedges) and finally the ”Upper seal”.

The Utsira Sand

Characteristics and extension

The Utsira Sand has been mapped in the area from ca. 58°N to 62°N along the Viking Graben (Figs 1-2).

The mainly sandy part of the Utsira Formation, defined by Isaksen & Tonstad (1989), is here termed the Utsira Sand and constitutes the target reservoir of the CO_2 injection. The Utsira Sand is Late Miocene to earliest Late Pliocene in age (Fig. 3a) (Eidvin et al., 2000; Eidvin & Rundberg, 2001; Piasecki, in press; Wilkinson, unpublished report). The Utsira Sand body covers an area of ca. 450 km x 80 km, distributed in two main depocentres (Figs 4 & 5).

Lithology

Analyses of a core from well 15/9-A23 show that the sands of the Utsira Sand consists of unconsolidated, fine to medium-grained sand mainly composed of angular to sub-angular quartz with small amounts of feldspar, sheet silicates, glaucony, shell fragments and lignite, and with no visible layering or preferred orientation of minerals (Pearce et al., 2000). This description corresponds to that of Isaksen & Tonstad (1989).

Geophysical characters

Seismically the Utsira Sand is most clearly distinguishable from surrounding units in the southern part, where it occurs as a basin restricted unit with internal, stacked mounds (Figs 3b, 4, 6-10). Towards north, other adjacent sand units make the stratigraphy more complex (Figs 11-14).

The Utsira Sand is generally characterised by low gamma-ray values, except locally in the northern part, were it is glauconitic (Eidvin et al., 2000), and by low sonic velocities due to its high porosities (25-40 %) of the unconsolidated sand with saline, probably paleo sea-water. Porosities have been measured from microscopic thin section (modal analysis) and calculated from geophysical logs (Chadwick et al., 2000). In most places the Utsira Sand is surrounded by clays with higher velocities. The lower seismic boundary of the Utsira Sand is usually marked by a velocity increase (seismic peak) with depth and its upper boundary usually by a velocity decrease (seismic trough) with depth. The Utsira Sand overlies the mid Miocene Lowermost shale/sand unit and is overlain by thin Upper Pliocene draping shale layers of the Lower seal, which is the base for downlaps from thick Upper Pliocene prograding wedges (the Middle seal) (Figs 3b, 4, 6-9). The base of the Lowermost shale/sand unit has been termed the Mid Miocene Onlap Surface or MMOS in Gregersen et al. (2000) and Chadwick et al. (2000) and corresponds to the intra Middle Miocene or IMM surface in Eidvin et al. (2000).
The oldest mounds of the Utsira Sand are located most centrally and deepest in the basin, downlapping onto the Lowermost shale/sand unit (Fig. 4). This boundary is locally very irregular (Figs 7, 11) and disturbed by diapiric shale diapirs and mud volcanoes (Heggland, 1997; Gregersen et al., 1997; Zweigel et al, 2000). The depositional area of the sand mounds of the Utsira Sand seems to have expanded upwards and onlap the MMOS to the east and pinches out towards the basin margin. The Utsira Sand seems to have successively onlapped the Miocene clays and shales towards west and pinches out at the toes of eastward prograding wedges (Figs 4, 7-9). Locally the wedges contain Hutton sand, which is derived from the British Isles and deposited along the eastern margin of the East Shetland Platform (Gregersen et al., 1997). To the south the Utsira Sand deepens and passes into a thick shale succession (Fig. 7) and towards the north the Utsira Sand pinches out, just before the marked basin deepening of the northernmost North Sea (Figs 11-12).

Extension

Seismic sections tying to well data (Fig. 4) show that the Utsira Sand forms a stratigraphical distinct unit occupying the central part of the North Sea basin, partly within the Viking Graben area and partly east of it, close to the UK/Norway median line (Figs 1, 5). It has an elongated depositional extent of more than 450 km and mainly about 50-90 km wide (Fig. 5b). Two distinct depositional basins have developed, separated by a saddle area, where the Utsira Sand is thin and narrow. In the southern depocentre the Utsira Sand reaches a thickness of 270 ms (~300 m), while it reaches about 180 ms (~200 m) in the northern depocentre (Fig. 5b).

The Utsira Sand covers an area of about 2.6 x 10^4 km^2 (Fig. 5b) and with a porosity of a least 25% it gives an estimated total pore volume in the magnitude of 5.5 x 10^{11} m^3 (Chadwick et al., 2000).

The western margin and northern parts of the Utsira Sand is the most difficult to map as it becomes thin, narrow and irregular and due to more restricted well information. At its northern limit, the Utsira Sand narrows and deepens markedly, appearing to occupy a north-trending channel system and internal seismic surfaces of the Utsira Sand (e.g. through well 30/3-1) dip northward just above the channel, predating the formation of the channel (Fig. 11). The interpretation of channelised Utsira Sand was also suggested by Jordt et al.(1995), Rundberg et al. (1995), Gregersen et al. (1997), Gregersen (1998) and Martinsen et al. (1999). However, Eidvin et al. (2000) interpreted this channel to have been cut into the Utsira Sand, based on seismic correlation to dated wells, and give a late Pliocene age for the channel formation. Thus, it may be discussed if parts of this channel system, that seem to be Miocene in age in Fig. 8 have been cut other places by a younger systems.

Stratigraphy and depositional environment

Biostratigraphic analyses (Piasecki et al., in press; Wilkinson, unpublished report) from a cored interval in well 15/9-A23 indicate an early Late Miocene to Early Pliocene age of the Utsira Sand. A neritic environment, possibly with oceanic influence during deposition with water depths around 100 m or more is suggested by Piasecki et al. (in press). The mixed content of nearshore indicators (lignite fragments) and marine indicators (bivalve shell fragments, glauconite, dinoflagellates), and the subangular, mature quartz sediments without visible layering from core samples (Pearce et al., 2000), indicate an environment with some energy. The tabular to mounded morphology of the sand bodies, corresponding to blocky low gamma-ray values, is separated by shale layers within the Utsira Sand (Figs 4, 7-9) and indicate several events of high energy deposition, separated by relaxation times with clay deposition. The sharp-based, mounded nature of the sand bodies deposited with mixed near-shore and more open-marine indicators in the deepest central part of the Viking Graben area points toward mass-flow/gravity-flow deposition, possibly turbidites or other processes (Gregersen et al., 1997; Eidvin et al., 1999). The period of total deposition, from early Late Miocene to Early Pliocene possibly about 4-5 my., compared to an average of 80-100 m sand, gives a low sedimentation rate (1.5-2.5 cm/k.y.). However, the sedimentation rate was probably much higher during each depositional event. Deposition of the Utsira Sand succeeded an earlier sand unit (Sub Utsira Sand) after the regional latest Early to earliest Late Miocene unconformity, where the Viking Graben area possibly has been starved. The oldest and lowermost mounds of the Utsira Sand are located centrally in the basin and successive mounds are more extensive and gradually onlaps towards east and west. This may indicate that the first mounds of the Utsira Sand was deposited as basinal lowstand deposits and succeeded by more extensive onlapping transgressive sand units. The transgressive nature may be indicated by upward fining deposits and glauconitic deposits, locally in the northern Viking Graben area, where they interdigitate with or drape the main Utsira Sand (Eidvin et al., 2000).

Reservoir aspects

Deposition of the sand bodies of the porous Utsira Sand into mounded units are separated by less permeable shale layers, compartmentalises the reservoir into reservoir sub units (Zweigel et al., 2001). This expected mounded reservoir architecture (e.g. Gregersen et al., 1997) has now been documented from increased seismic amplitudes on seismic timelaps sections (Eiken et al., 2000; Zweigel et al., 2001) during injection of CO_2. The CO_2 seems to have elevated from the injection point at the base of the Utsira Sand and locally captured under local clay seals. Through minor connections in the local clay seals between the sand units, the CO_2 eventually rose to the top of the Utsira Sand, where it laterally has expanded below the Lower seal (Eiken et al., 2000; Zweigel et al., 2001). The southern depocentre has the thickest caprock package with its top buried more than 800 ms (~900 m) below the sea floor, but the seal generally thins towards the basin margins (Fig. 5a). In the saddle between the two depocentres (Fig. 5b), the Utsira Sand seems to be narrow and thin. This area is without well control and therefore the lithology and thus the hydraulic continuity between the two depocentres is uncertain.

Sand units adjacent to the Utsira Sand

The Sub Utsira Sand unit

Centrally in the northern Viking Graben area a seismic unit, the Sub Utsira Sand unit, containing sand can be separated from the Utsira Sand above (Figs 11 & 13). This unit contains internal seismic mounds, probably corresponding to sand sub units, as in the Utsira Sand. Furthermore, the more or less direct contact with the Utsira Sand above may indicate that the sands could be in hydraulic connection. The position indicates that its is slightly older than the Utsira Sand and thus may represent the first sands after the mid Miocene hiatus.

The West sand unit

The West sand unit is located just west of the Utsira Sand, possibly at the same stratigraphic level (early Late Miocene 8Fig. 3)) in a small area (around well UK211/28-2), without connection to the Utsira Sand (Figs 14 & 15).

The East sand unit

The East sand unit is located just east of the Utsira Sand (Figs 14 & 15) in a small area. Seismic correlation indicates that the unit terminates east of the Utsira Sand, and seems to be time equivalent to its uppermost part or slightly younger (Fig.3). It is uncertain if there is a direct contact between the sands, but more seismic lines and new wells may clarify this. The East sand unit is thickest in its middle part and wedges out to the west, just before the Utsira Sand and to the east, just below the unconformity at the base of the Pleistocene Upper seal (Fig. 14). Should there be contact between the two sand units, the sands could provide a possible hydraulic connection from the central northern North Sea basin and towards the eastern basin margin, and possibly further up through local sands just below the sea floor in the Norwegian channel.

Furthermore, a sandwedge, not treated further here, has been identified just above the Utsira Sand, in the central to eastern part of the south Viking Graben area, from detailed interpretation of dense wells and 3-D seismic data (Zweigel et al., 2000).

The sealing units

The total seal thickness is in most places more than 800 m, but thins towards its margins (Fig. 5a). The seal consists mainly of Pliocene and Pleistocene clays, but locally the seal contain minor sands. The seal has been divided into three seismic units: The Lower seal, draping the Utsira Sand, the succeeding prograding Middle seal and finally the Upper seal, with a truncating lower boundary (Figs 4, 6-14).

The Lower seal

In the southern Viking Graben area, a well defined shale unit, the Lower seal, drapes the Utsira Sand and constitutes the lowermost part of the regional seal, where the upper boundary is a regional downlap surface from the succeeding prograding Middle seal (Figs 4 & 6). Drill cuttings from the Sleipner area indicate a grey mudstone with a high content of clay minerals and log analyses indicates at least 80 % shale volume (Chadwick et al., 2000).

The unit becomes more difficult to resolve towards south and north. South of the Sleipner area the unit becomes less well defined due to the absence of the Utsira Sand and it is uncertain where it terminates and if it merges with the Lowermost shale/sand unit (Fig. 6). Towards the north, seismic correlation shows that the unit locally prograded from around 60ºN (Fig. 13) and its upper boundary locally can not be identified as a downlap surface. However, as this local thick prograding part of the Lower seal thins out again further north, it becomes draping again and the upper boundary again becomes a prominent regional downlap surface (Figs 11, 12 & 14). The most basinal parts were probably subjected to marine condensation at the Early to Late Pliocene transition, prior to the progradation of the succeeding unit towards Northwest. In its draping areas, the Lower seal probably constitutes the most efficient of the sealing units, due to its concordant stratification and it's generally much lesser sand content compared to the other units.

The Middle seal

The succeeding part of the seal, the Middle seal, is characterised by inclined reflections, indicating progradational from Southeast towards Northwest, but also locally from the westernmost part towards East (Figs 4, 6-14).

The bottom-sets downlap the Lower seal and the upper parts are truncated along the eastern margin of the Viking Graben area, towards the Norwegian Trench (Figs 10 & 12). Cuttings descriptions from NPD papers and well logs (Figs 7-14) show that the deposits of this unit mainly consists of clays, but minor sands occur locally. Due to the thick clays, this unit generally seems to be a fairly efficient seal, though other factors as minor fractures may also have an influence.

The variations in thickness and dip of the internal clinoforms are limited and indicate mainly balanced rates between sediment supply and creation of accommodation space, though internal erosional surfaces, interpreted as sequence boundaries (Gregersen et al., 1997), indicate breaks in the overall progradation.

Biostratigraphy (Eidvin et al., 2000) indicates that deposits of this unit represents Late Pliocene to Pleistocene ages (Figs 7-8).

Towards northwest, in the northernmost part of the Viking Graben, the lower part of this prograding Middle seal contains minor mounded features or wedges, the Bottom-set sands. The base and top of the Middle seal corresponds, respectively, to the BUTp and the BP horizons of Eidvin et al. (2000).

The Bottom-set sands

Minor wedges with moderate to high amplitudes are found within the Middle sealing unit, at the slope toe or bottom-set of the prograding reflections and correlate with minor sands in wells (Figs 11 & 12). As a part of the Middle seal seems to have prograded towards northwest, the main part of these Bottom-set sands are located towards northwest in the mapped area. Out of several wedges at the bottom-sets, the six wedges (numbered 1-6) that correlate with sands in wells used in this paper have been mapped (Fig. 15). Some of the mapped wedges represent more than one sand layer, indicated by internal clay layers in wells, and as such more events, but has been mapped as one wedge due to the seismic resolution. The mapped wedges are up to 60 m thick and extend typically 5-10 km (in length and width) in irregular patterns (Fig. 15). The stratigraphical location of the sand wedges at the slope-toes or bottom-sets of the prograding clinoforms indicates that they probably represent massflow sands.

Some of these wedges have also been observed and related to the Pliocene by others (e.g. Gregersen et al., 1997; Gregersen 1998; Martinsen et al. 1999 and Eidvin et al. 2000).

The Upper seal

The Upper seal is here defined as the uppermost seismic unit between a basal regional unconformity and the sea floor (Figs 6-14). In the Norwegian Trench its deposits seem to be almost concordant stratified and onlap dipping parts of the basal unconformity, while the succeeding parts seem to prograde towards east and downlap the lower concordant part (Figs 13-14). It has been suggested that the cause for this unconformity may be a grounding ice cap, and that the northern North Sea was glaciated ca. 850 k.a. (Sejrup et al., 1991).

The deposits are Pleistocene in age (Figs 7-11, 13-14). Analyses of more than 100 m long cores just Southwest of the investigated area and to the Northeast, in the central part of the Norwegian Trench, show that the Pleistocene deposits are glacio-marine clays, deposited under shallow-marine, arctic conditions and glacial tills (Sejrup et al., 1991). Seismic sections Southwest of the investigated area show several levels of channels, caused by river erosion during glacially introduced low sea-level stands (Stoker et al., 1985; Long and Stoker, 1986; Sejrup et al., 1987, 1991). Sandy layers have been interpreted from this unit, especially at the Norwegian Trench (Fig. 13). Local high amplitudes and troughs, probably channels or tunnel valleys support an inhomogene and locally sandy character of the Upper seal.

Amplitude map

A map with amplitude anomalies in the lower 500 ms of the seal (Lower seal and Middle seal) has been made in order to spot possible leakage pathways (Fig. 16). Minor anomalies are observed in the southern part of the Utsira Sand, in the injection area and towards northwest in the possible migration route. However, these minor anomalies seem to be isolated and may represent local sands or shallow gas. Although most of the anomalies lies above the Utsira Sand some are observed outside (Fig. 16).

The highest concentration of high amplitudes are seen in the northernmost part, where they coincide with the mapped bottom-set sands in the Middle seal. Also towards east, over the northern Utsira Sand depocentre, are observed many anomaly-trends. These trends are connected on seismic sections and probably reflect sandy channel systems (Fig. 16).

Conclusions

Nine Neogene informally named stratigraphical units in the Viking Graben area have been mapped and discussed. These are in the order of decreasing age: The Lower Miocene Lowermost shale/sand unit, the lowest Upper Miocene Sub Utsira Sand unit and West sand unit, the Upper Miocene to lowest Upper Pliocene Utsira Sand, the Upper Pliocene East sand unit, the Upper Pliocene Lower seal, the Upper Pliocene Bottom-set sands, the Upper Pliocene Middle seal and finally the Pleistocene Upper seal.

The Utsira Sand extends along and just west of the Viking Graben area near the UK/Norwegian median line, and covers a more than 450 km long and 50-90 km wide area. The Utsira Sand is distributed in two main depositional areas, with up to nearly 300 m in the southern and 200 m in the northern area. This gives with a porosity of 25-40 % a large potential for CO_2 storage. However, adjacent sand units and the thickness and quality of the seal have to be taken into account for evaluating the storage possibilities. Locally the seal contains minor sands. The total seal thickness is most places more than 800 m, but thins towards its margins.

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Figure captions

Fig. 1. Regional structural map of the Viking Graben area with the outline of the Utsira Sand area shown (white line).

Fig. 2. Map with shown sections and wells. The extension of the Utsira Sand is shown as a light grey area.

Fig. 3. Stratigraphy of the Neogene deposits from east to west in the Viking Graben area. (a) time stratigraphic scheme and (b) lithostratigraphic scheme.

Fig. 4. Seismic line from east to west across the southern Viking Graben area, close to the Sleipner Field, with the Utsira Sand and its sealing units. Well profiles show gamma-log traces. Location is shown in Fig. 2. Modified from Chadwick et al. (2000).

Fig. 5. Maps in two-way travel time (milliseconds) of the main Utsira Sand (a) map to its top and (b) thickness map, showing two depocentres. Black rectangle denotes the Sleipner area. Modified from Chadwick et al. (2000).

Fig. 6. Composite Geo-section with the Utsira Sand and succeeding units from the Central Graben area to the southern Viking Graben area, where it merges with the E-W crossing section (Fig. 4). Location is shown in Fig. 2.

Fig. 7. Geo-section (seismic line CNST82-RE18-CGT81-12) and well-logs with the Utsira Sand and succeeding units from south to north from the Central Graben to the southern Viking Graben area. Location is shown in Fig. 2.

Fig. 8. Geo-section (seismic line CNST82-19-07-18) and well-logs with the Utsira Sand and succeeding units. It is the northern extension of Fig. 7 in the southern Viking Graben. Location is shown in Fig. 2.

Fig. 9. Geo-section (seismic line CNST82-07) and well-logs with Utsira Sand and succeeding units from West to East through the southern part of the Viking Graben. Location is shown in Fig. 2.

Fig. 10. Geo-section (seismic line CNST82-10) and well-logs with the Utsira Sand and succeeding units from West to East through the middle part of the Viking Graben. Location is shown in Fig. 2.

Fig. 11. Geo-section (seismic line NNST84-17) and well-logs with the Utsira Sand and succeeding units from south to north through the northern Viking Graben area. Location is shown in Fig. 2.

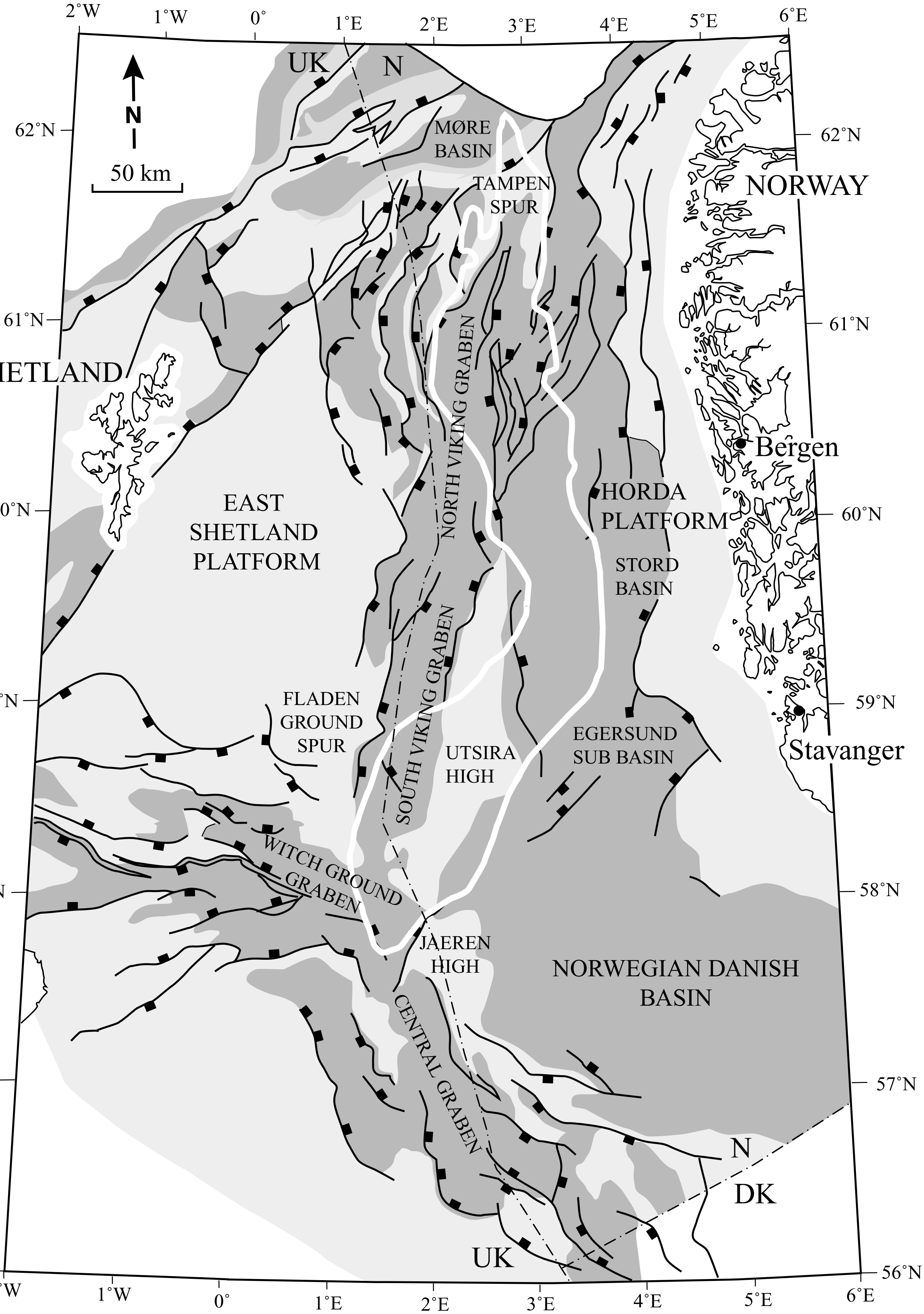
Fig. 12. Geo-section (seismic line NVGT88-11-NNST84-11) and well-logs with the Utsira Sand and succeeding units from West to East through the northern part of the Viking Graben. Location is shown in Fig. 2.

Fig. 13. Geo-section (seismic line NNST84-05) and well-logs with the Utsira Sand, the Sub-Utsira Sand Unit and the succeeding units across the northern Viking Graben area. Location is shown in Fig. 2.

Fig. 14. Geo-section (seismic line NNST84-07) and well-logs with the Utsira Sand and succeeding units, including the East sand unit, across the northern Viking Graben area. Location is shown in Fig. 2.

Fig. 15. Location map of the Sub Utsira Sand unit, the East sand unit and the Bottom-set sand units.

Fig. 16. Map of Utsira Sand with seismic anomalies within the cap-rock..



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MØRE BASIN
TAMPEN SPUR
NORWAY
62°N
61°N
60°N
59°N
58°N
57°N
56°N
SHETLAND
NORTH VIKING GRABEN
Bergen
EAST SHETLAND PLATFORM
HORDA PLATFORM
STORD BASIN
SOUTH VIKING GRABEN
FLADEN GROUND SPUR
UTSIRA HIGH
EGERSUND SUB BASIN
Stavanger
WITCH GROUND GRABEN
JAEREN HIGH
NORWEGIAN DANISH BASIN
CENTRAL GRABEN
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Fig. 1

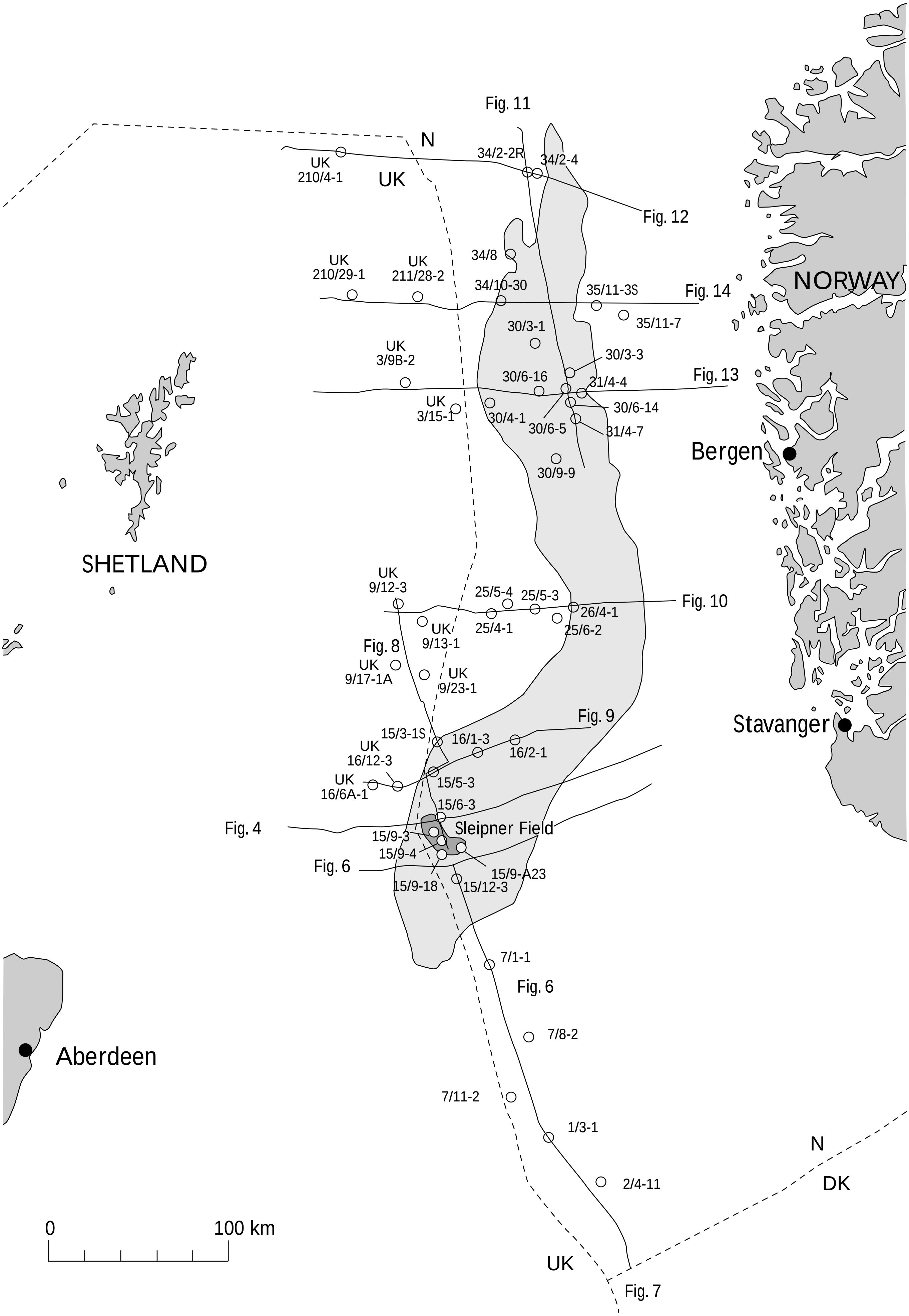

Fig. 11
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34/2-4
Fig. 12
34/8
UK
210/29-1
UK
211/28-2
34/10-30
35/11-3S
Fig. 14
NORWAY
35/11-7
30/3-1
30/3-3
UK
3/9B-2
30/6-16
31/4-4
Fig. 13
UK
3/15-1
30/4-1
30/6-5
30/6-14
31/4-7
Bergen
30/9-9
SHETLAND
UK
9/12-3
25/5-4
25/5-3
Fig. 10
26/4-1
25/4-1
25/6-2
UK
9/13-1
Fig. 8
UK
9/17-1A
UK
9/23-1
Stavanger
Fig. 9
15/3-1S
16/1-3
16/2-1
UK
16/12-3
UK
16/6A-1
15/5-3
15/6-3
Fig. 4
Sleipner Field
15/9-3
15/9-4
Fig. 6
15/9-A23
15/9-18
15/12-3
7/1-1
Fig. 6
Aberdeen
7/8-2
7/11-2
1/3-1
N
2/4-11
DK
0
100 km
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Fig. 7

Fig. 2

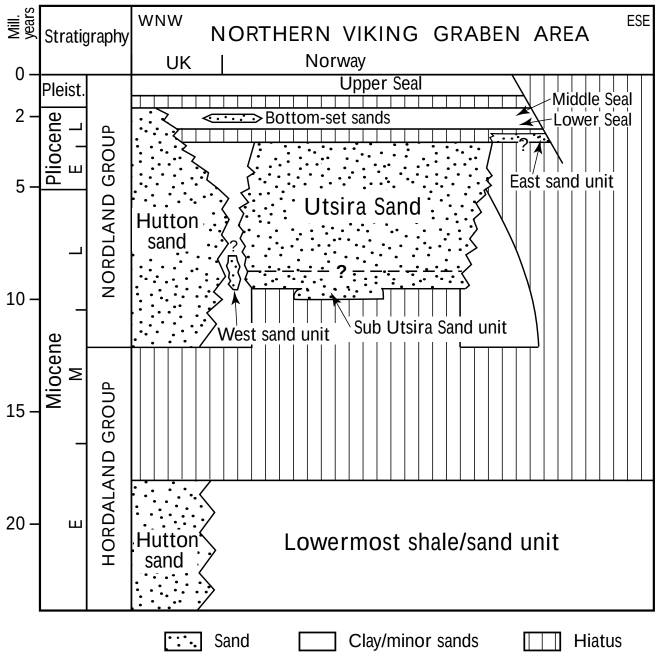

Mill. years
Stratigraphy
WNW
NORTHERN VIKING GRABEN AREA
ESE
UK
Norway
0
2
5
10
15
20
Pleist.
Pliocene
Miocene
NORDLAND GROUP
HORDALAND GROUP
Upper Seal
Middle Seal
Lower Seal
Bottom-set sands
East sand unit
Utsira Sand
Hutton sand
West sand unit
Sub Utsira Sand unit
Lowermost shale/sand unit
Sand
Clay/minor sands
Hiatus

Fig. 3a

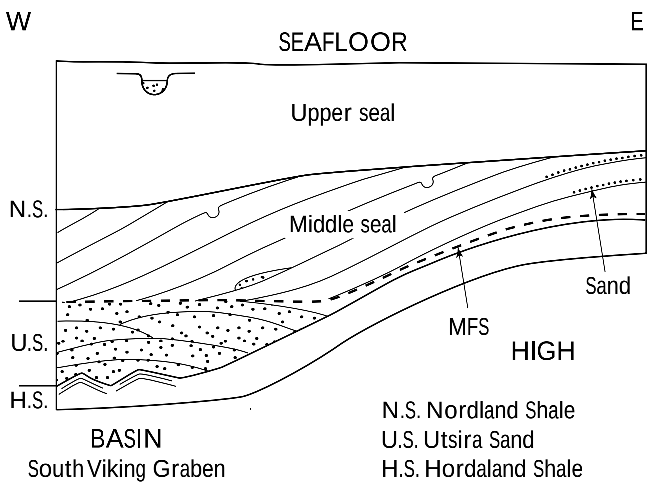

W
E
SEAFLOOR
Upper seal
Middle seal
N.S.
U.S.
H.S.
Sand
MFS
HIGH
BASIN
South Viking Graben
N.S. Nordland Shale
U.S. Utsira Sand
H.S. Hordaland Shale

Fig. 3b

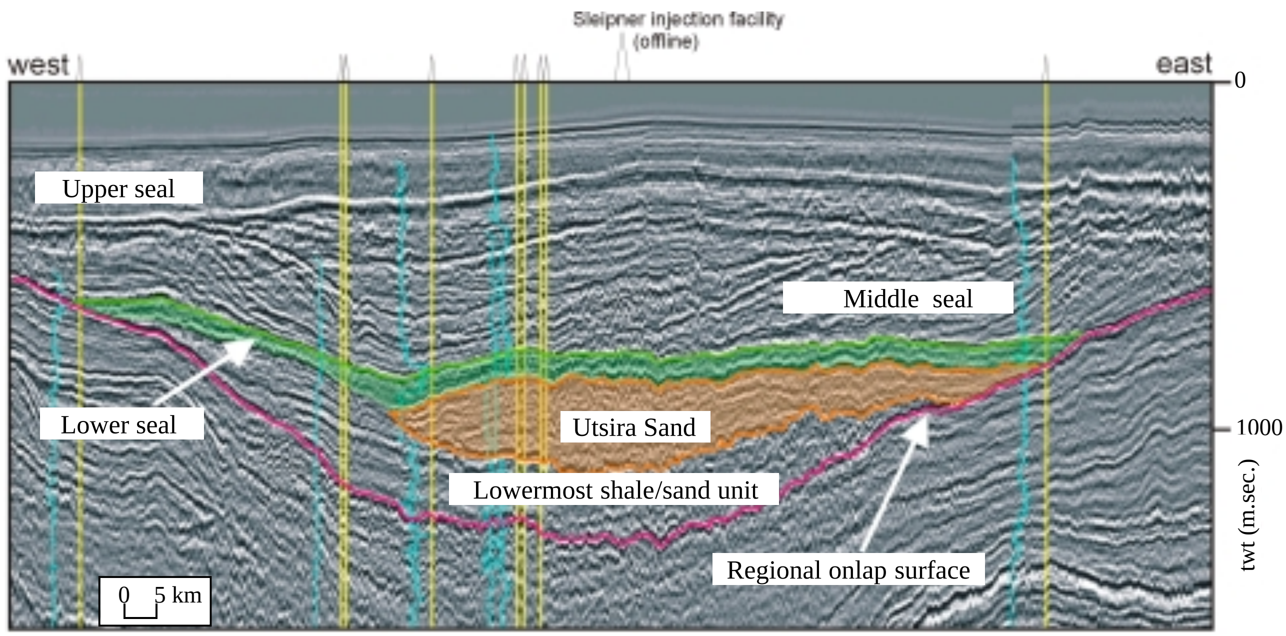

Sleipner injection facility
(offline)
west
east
0
1000
twt (m.sec.)
Upper seal
Middle seal
Lower seal
Utsira Sand
Lowermost shale/sand unit
Regional onlap surface
0 5 km

Fig. 4.

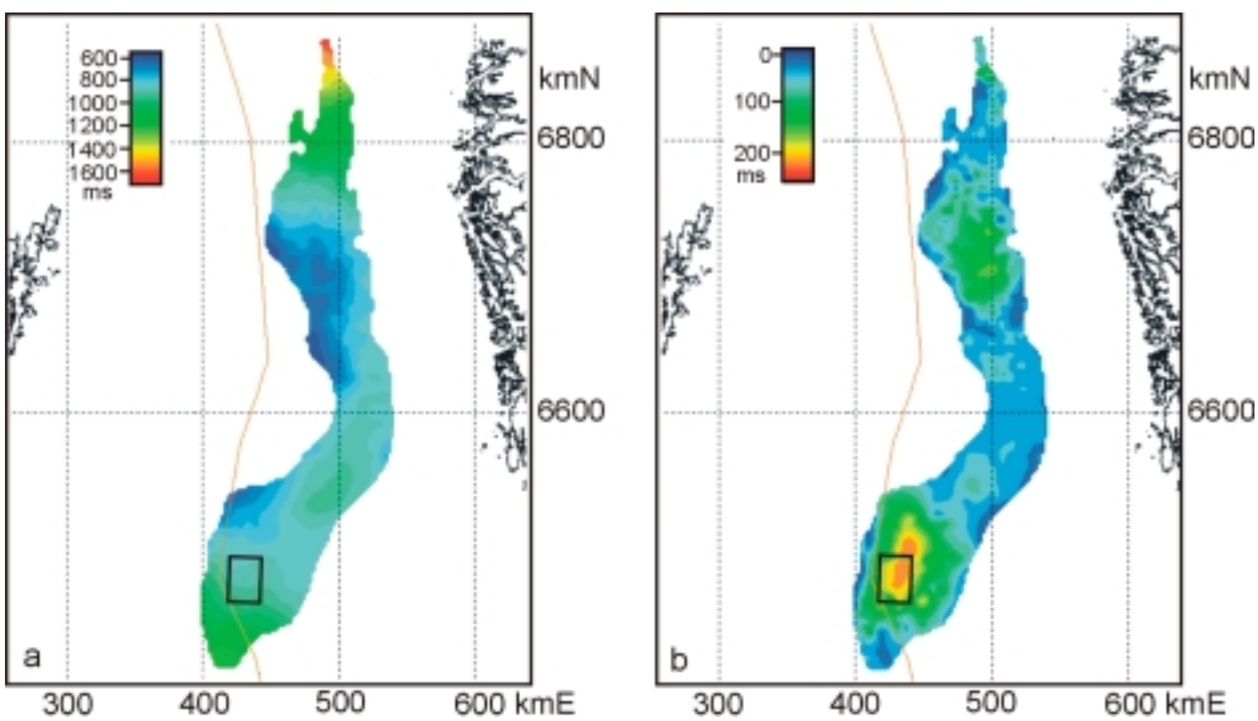

600
800
1000
1200
1400
1600
ms
kmN
6800
6600
a
300
400
500
600 kmE
0
100
200
ms
kmN
6800
6600
b
300
400
500
600 kmE

Fig. 5.

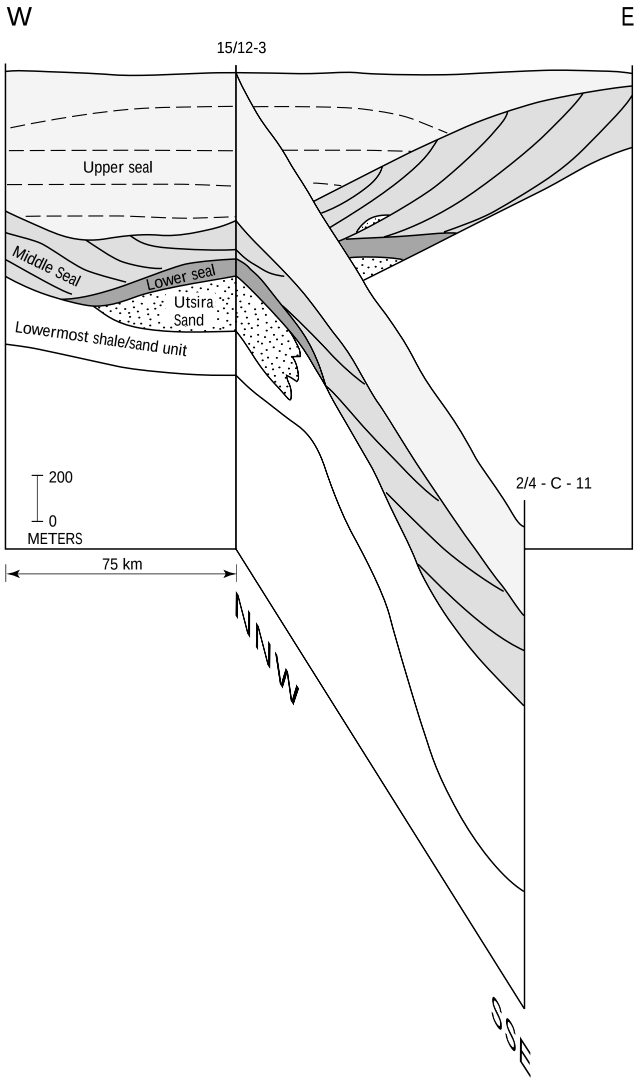
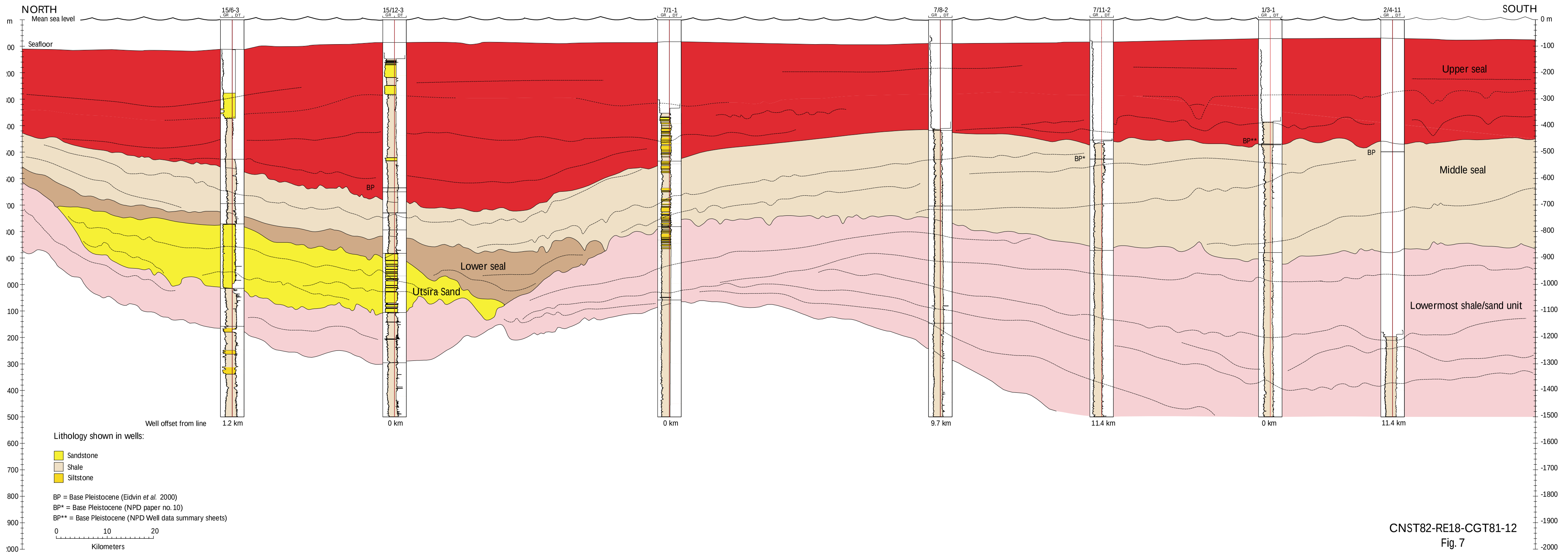
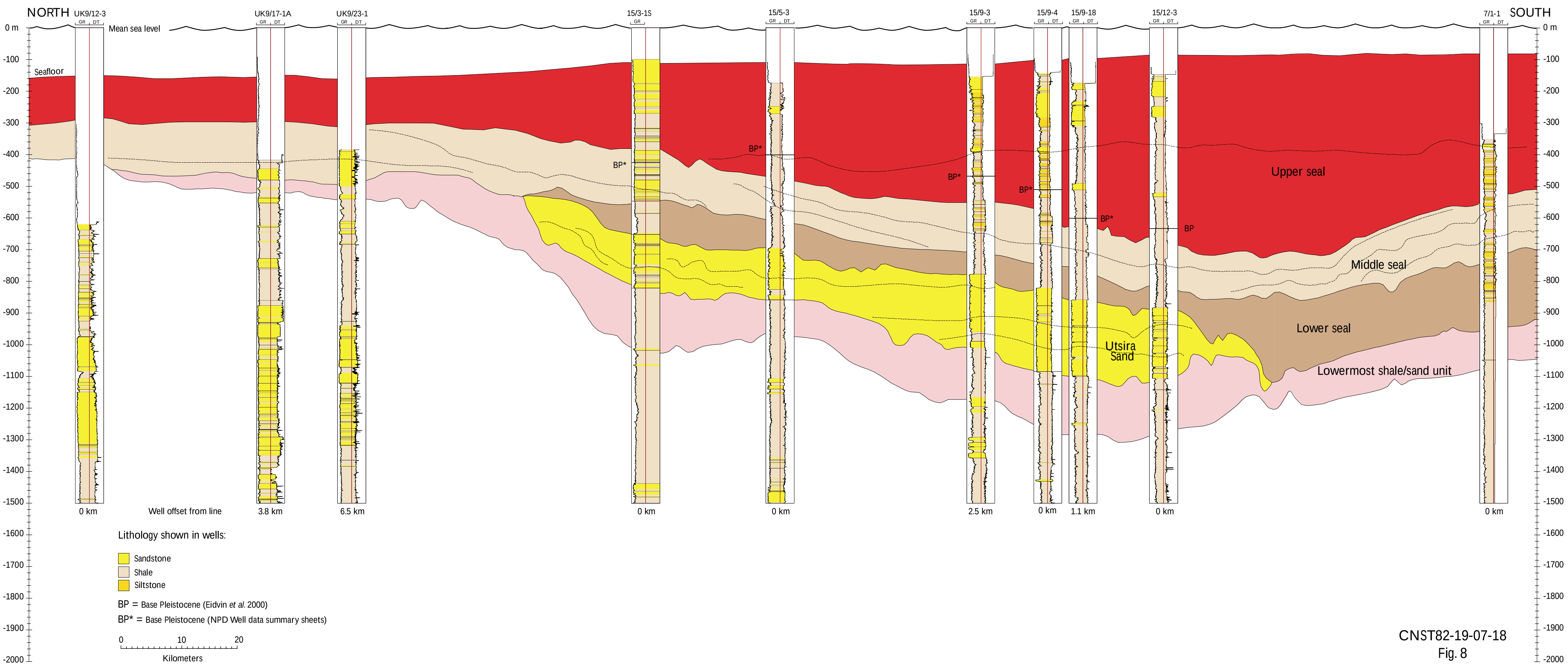

W
E
15/12-3
Upper seal
Middle Seal
Lower seal
Utsira
Sand
Lowermost shale/sand unit
200
0
METERS
75 km
2/4 - C - 11
NNW
SSE

Fig. 6

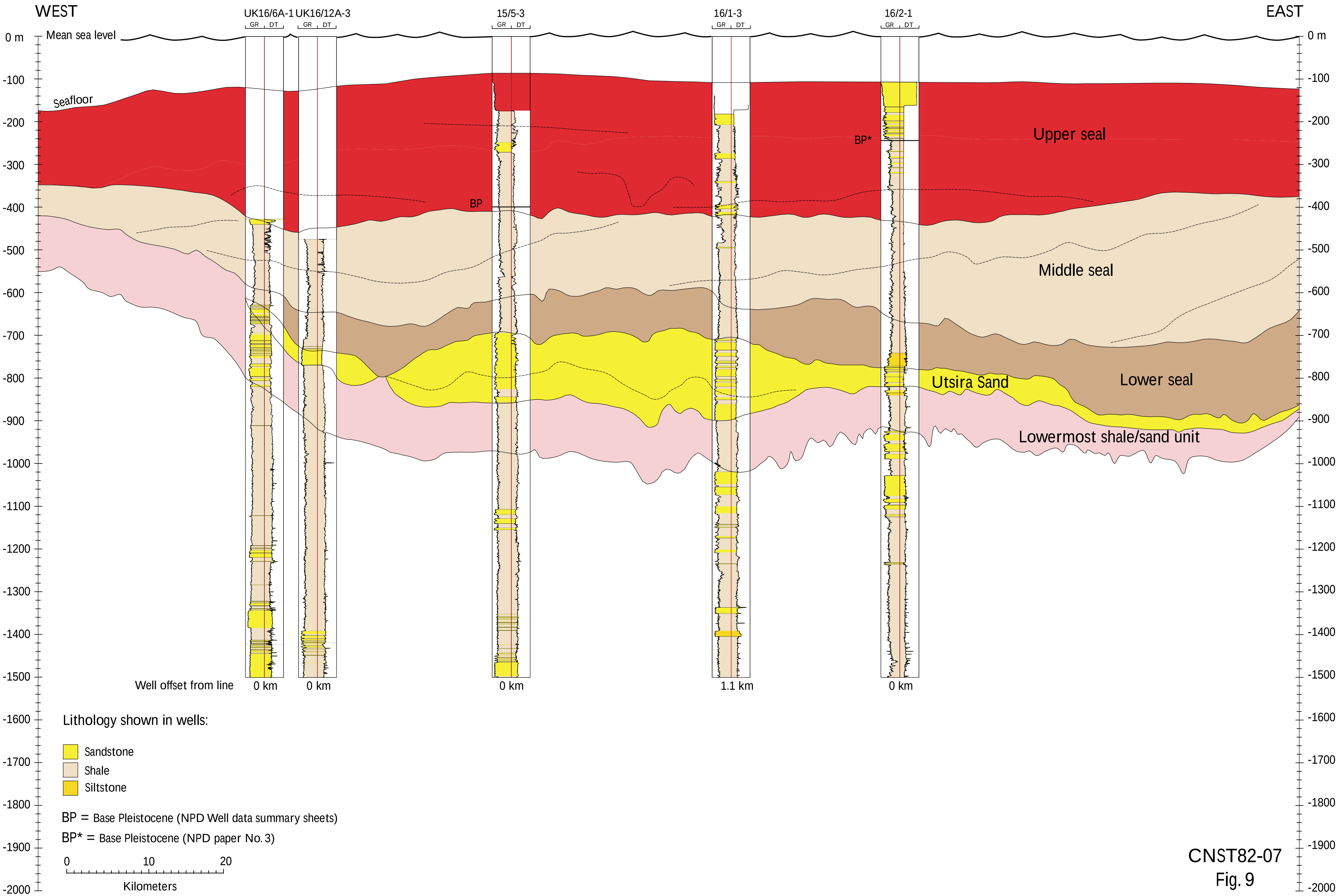


CNST82-RE18-CGT81-12

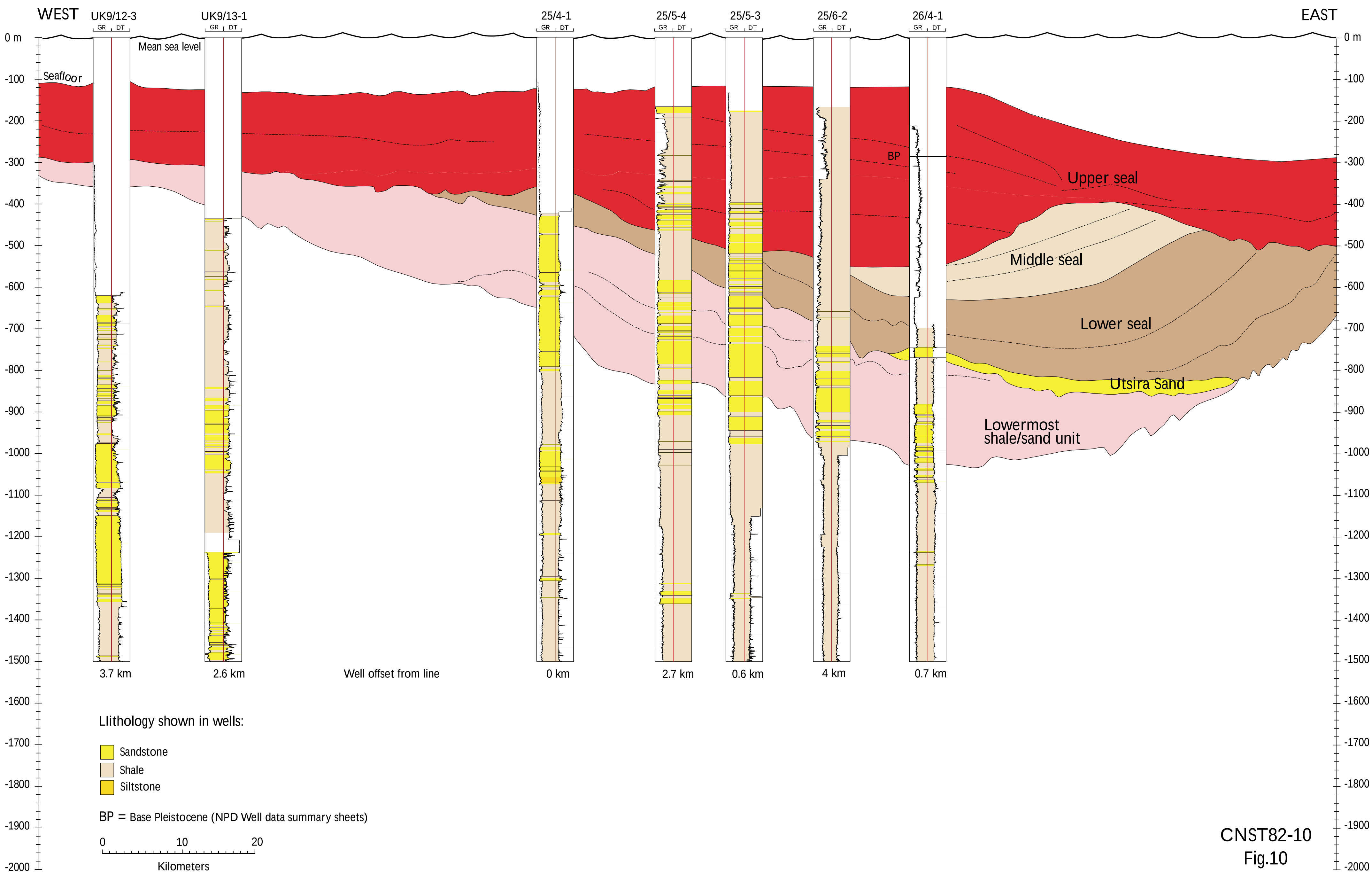
Fig. 7



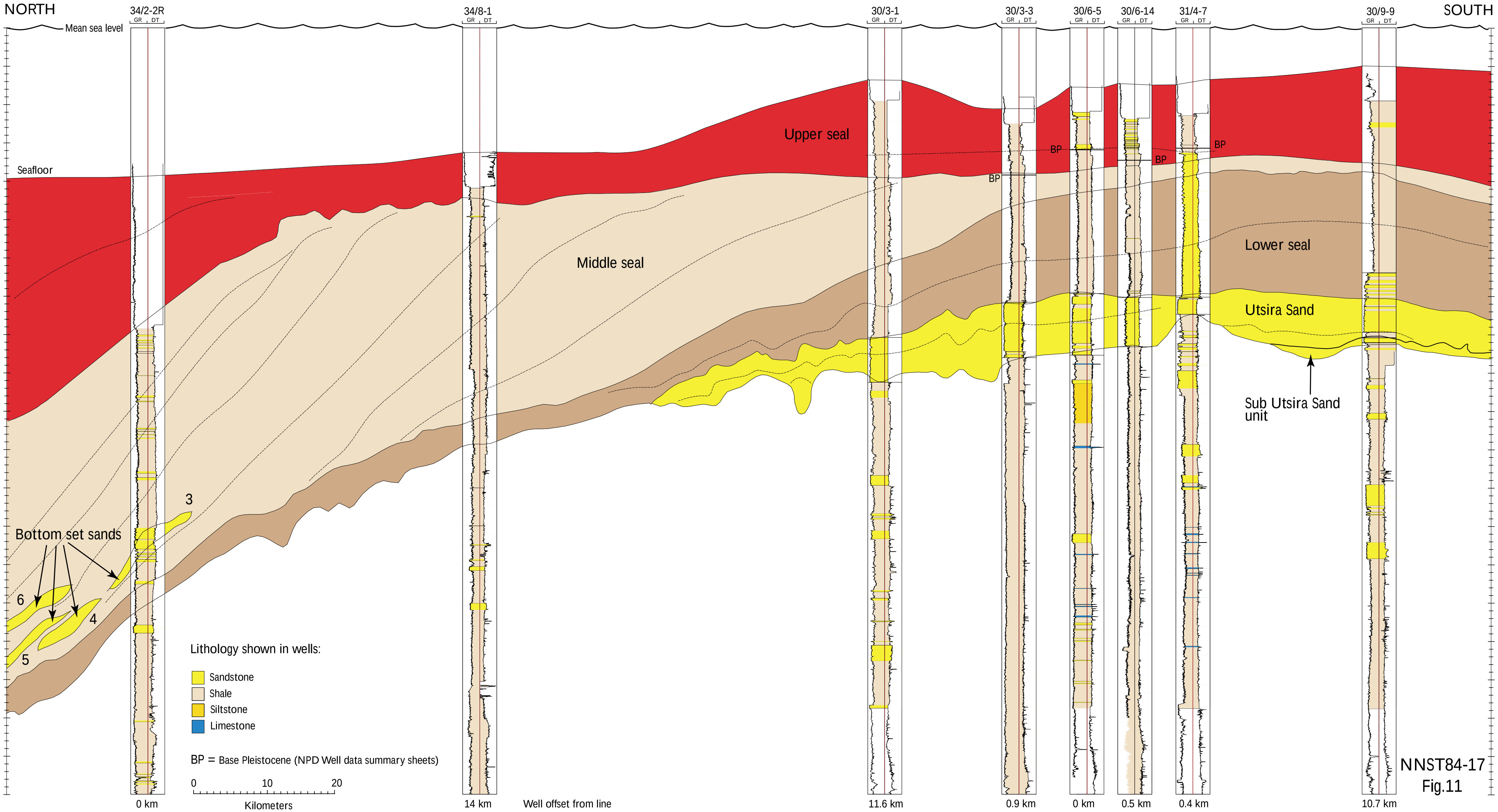
CNST82-19-07-18
Fig. 8

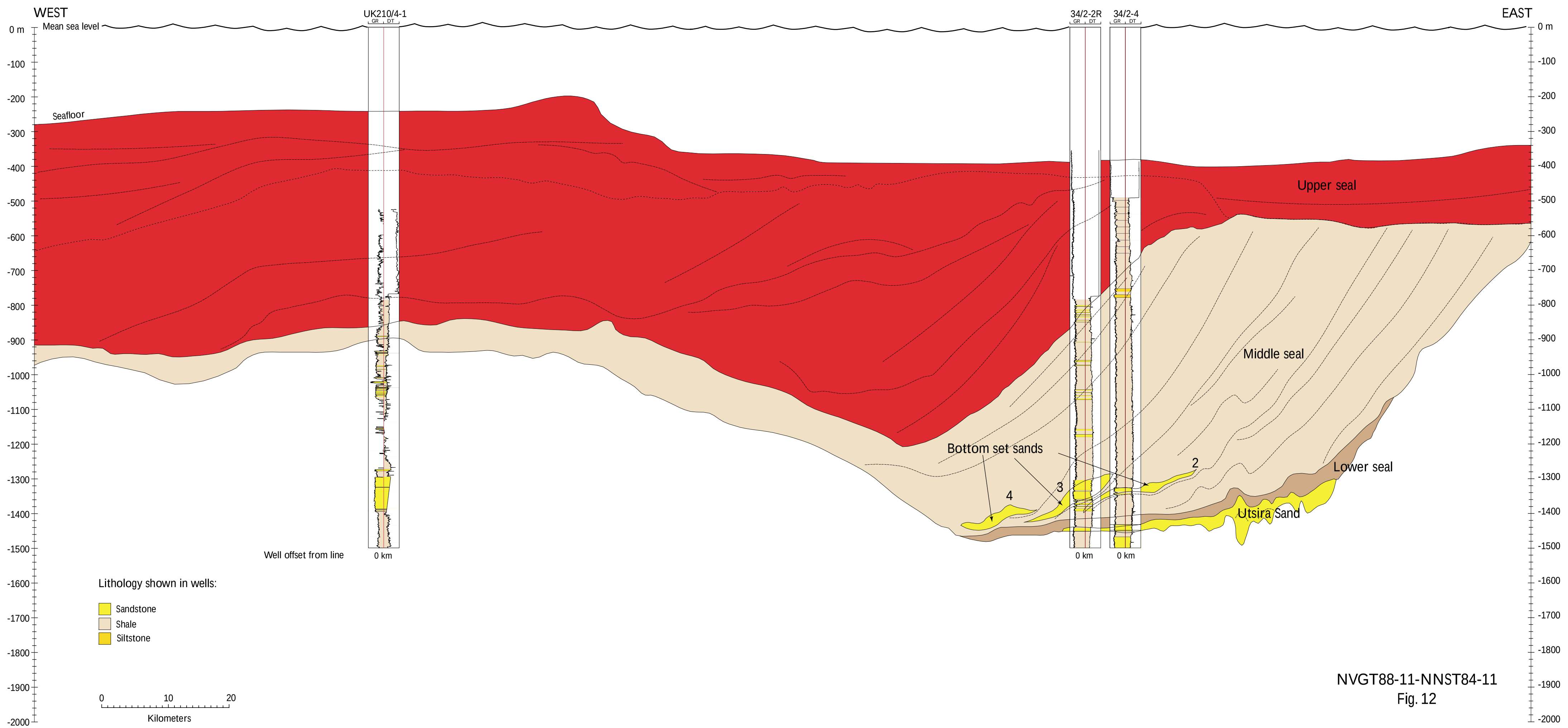


CNST82-07
Fig. 9

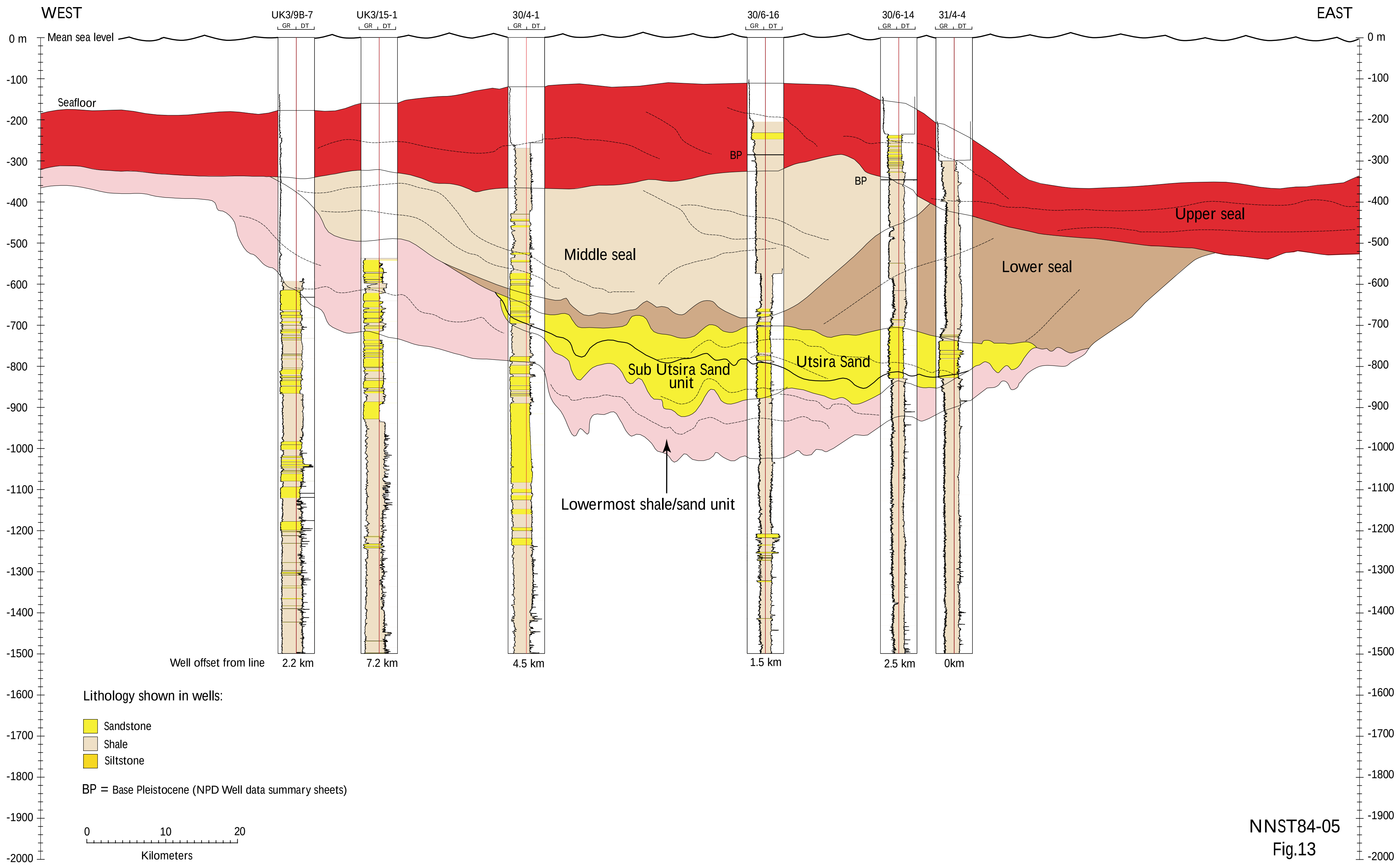


CNST82-10
Fig.10

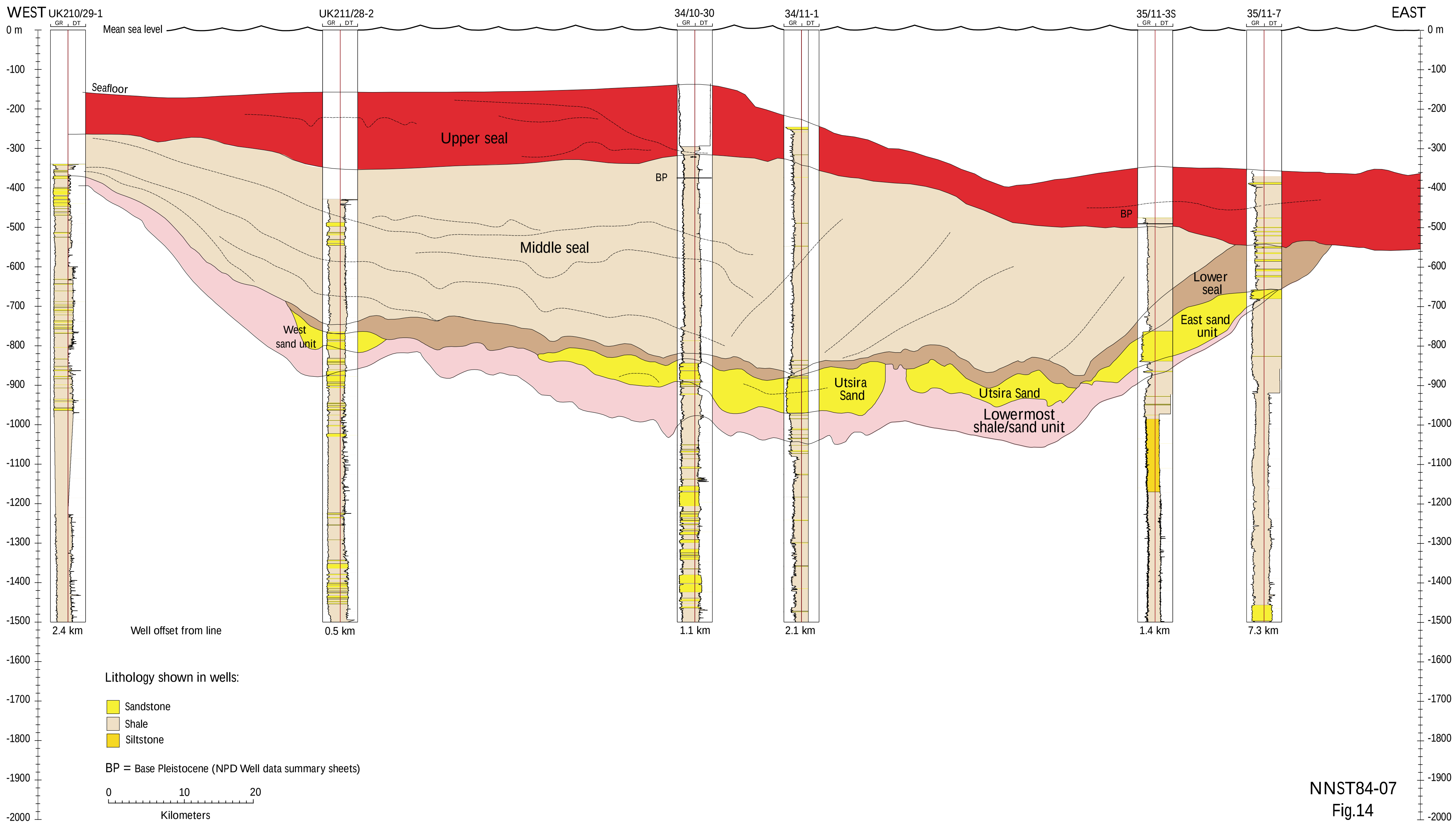

NORTH
SOUTH
Mean sea level
Seafloor
34/2-2R
34/8-1
30/3-1
30/3-3
30/6-5
30/6-14
31/4-7
30/9-9
GR
DT
BP
Upper seal
Middle seal
Lower seal
Utsira Sand
Sub Utsira Sand unit
Bottom set sands
3
4
5
6
Lithology shown in wells:
Sandstone
Shale
Siltstone
Limestone
BP = Base Pleistocene (NPD Well data summary sheets)
0
10
20
Kilometers
0 km
14 km
Well offset from line
11.6 km
0.9 km
0 km
0.5 km
0.4 km
10.7 km
0 m
-100
-200
-300
-400
-500
-600
-700
-800
-900
-1000
-1100
-1200
-1300
-1400
-1500
-1600
-1700
-1800
-1900
-2000
NNST84-17
Fig.11



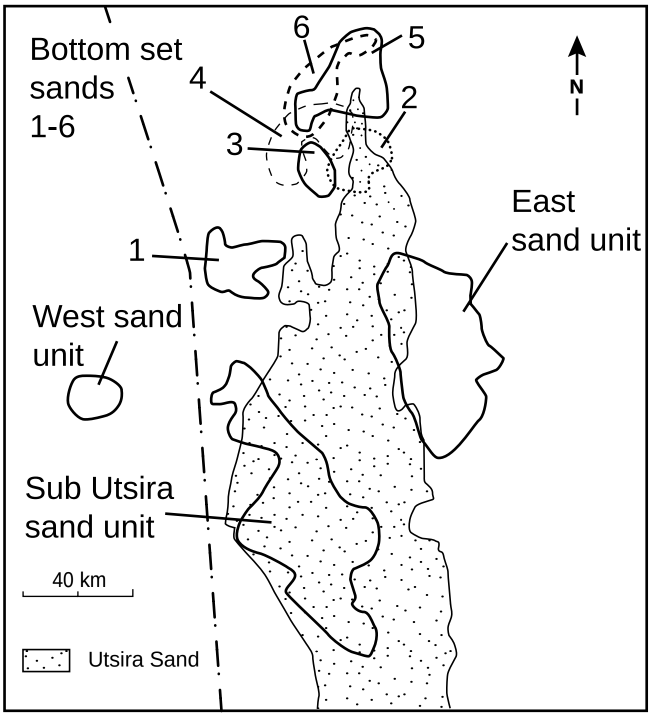
NVGT88-11-NNST84-11
Fig. 12



NNST84-05
Fig.13



NNST84-07
Fig.14



6
5
Bottom set
sands
1-6
4
2
N
3
East
sand unit
1
West sand
unit
Sub Utsira
sand unit
40 km
Utsira Sand

Fig 15

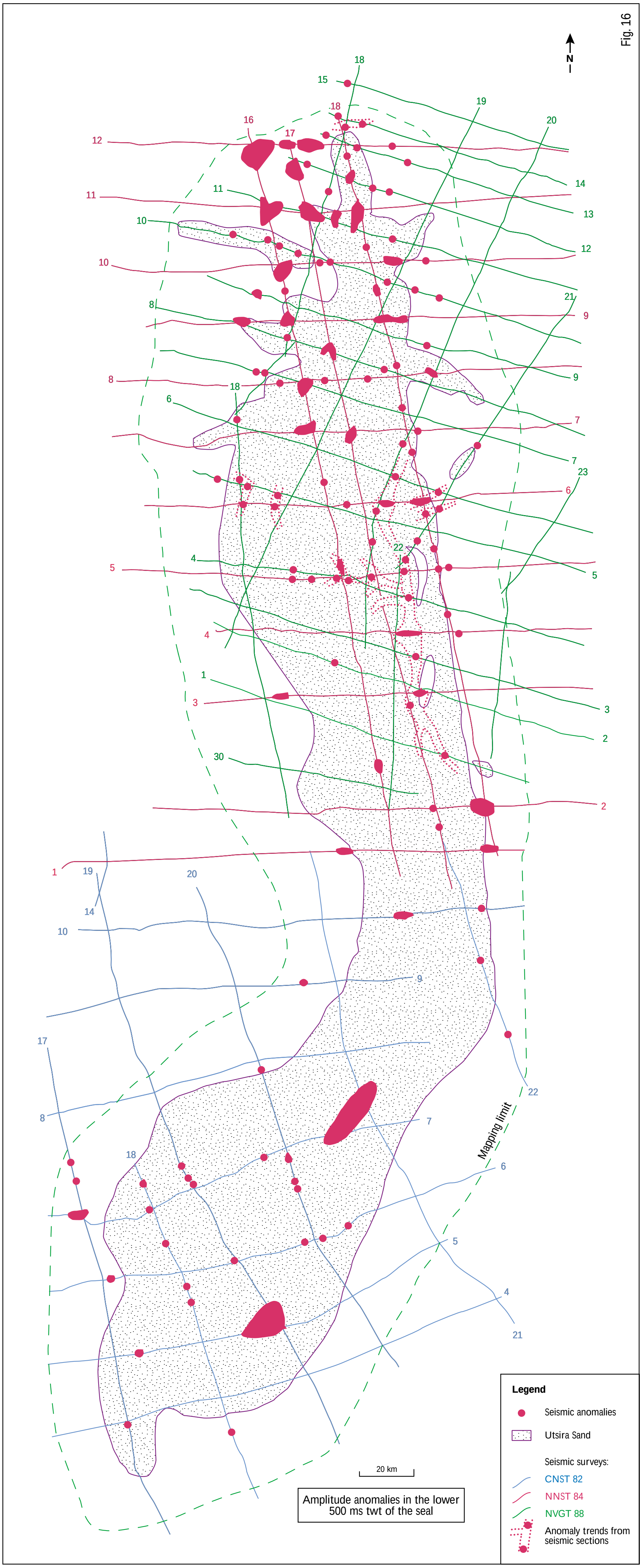


Fig. 16
N
Mapping limit
20 km
Amplitude anomalies in the lower 500 ms twt of the seal
Legend
Seismic anomalies
Utsira Sand
Seismic surveys:
CNST 82
NNST 84
NVGT 88
Anomaly trends from seismic sections

Fig 16

Danmarks og Grønlands
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