NGU Report 2000.104

Geological atlas of the southern part of the Norwegian Trench and the northeastern North Sea

NGU
Norges geologiske undersøkelse
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REPORT

Report no.: 2000.104	ISSN 0800-3416	Grading: Open

Title:
Geological atlas of the southern part of the Norwegian Trench and the northeastern North Sea

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County:	Commune:
Map-sheet name (M=1:250.000)	Map-sheet no. and -name (M=1:50.000)
Deposit name and grid-reference:	Number of pages: 23 Price (NOK): 350,- Map enclosures: 15

Fieldwork carried out:	Date of report:	Project no.:	Person responsible:
1991-1996	1.12.2000	2301.39	[signature]

Summary: This report contains 15 maps (scale 1: 1.5 million) presenting the geological database, bathymetry and various interpretations of the geology in the Norwegian Trench off southern Norway and the northern part of the adjacent North Sea Plateau. A short description is given for each map.

The maps, made as a part of the Skagerrak Project (Longva & Thorsnes 1997, Ottesen et al. 1996), have been extended further west and north, resulting in a map coverage from Langesund to Stavanger and west to 3°E.

The following maps are presented in the report:

1. Bathymetry
2. Side scan sonar interpretation and multibeam bathymetry
3. Seismic lines
4. Sea bed samples/short cores
5. Depth to bedrock
6. Bedrock geology
7. Quaternary geology
8. Total thickness of Quaternary sediments
9. Thickness of pre-Late Weichselian sediments
10. Depth to Late Weichselian erosion surface
11. Thickness of upper unit of glaciomarine sediments
12. Thickness of Holocene sediments
13. Interpeted seismic profiles
14. Shallow gas and pockmarks
15. Sea bed sediments

Keywords: Marine geology	Bathymetry	Seabed sediments
Bedrock geology	Quaternary geology	Holocene sediments
Glaciomarine sediments	Shallow gas	Stratigraphy

CONTENTS

1. INTRODUCTION

This report contains 15 maps (scale 1: 1.5 million) presenting the geological database, bathymetry and various interpretations of the geology in the Norwegian Trench off southern Norway and the northern part of the adjacent North Sea Plateau. A short description is given for each map.

During this project the maps, made as a part of the Skagerrak Project (Longva &Thorsnes 1997, Ottesen et al. 1996), have been extended further west and north, resulting in a map coverage from Langesund to Stavanger and west to 3°E.

Four different data sets constitute the basis for the maps presented in the atlas: 1) Shallow seismic, 2) Seabed cores, 3) Multibeam bathymetry, and 4) Side scan sonar data (Fig. 1).

The following maps are presented in the atlas:

1. Bathymetry
2. Side scan sonar interpretation and multibeam bathymetry
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14. Shallow gas and pockmarks
15. Seabed sediments

The maps are available in digital format as Arc-Info covers.

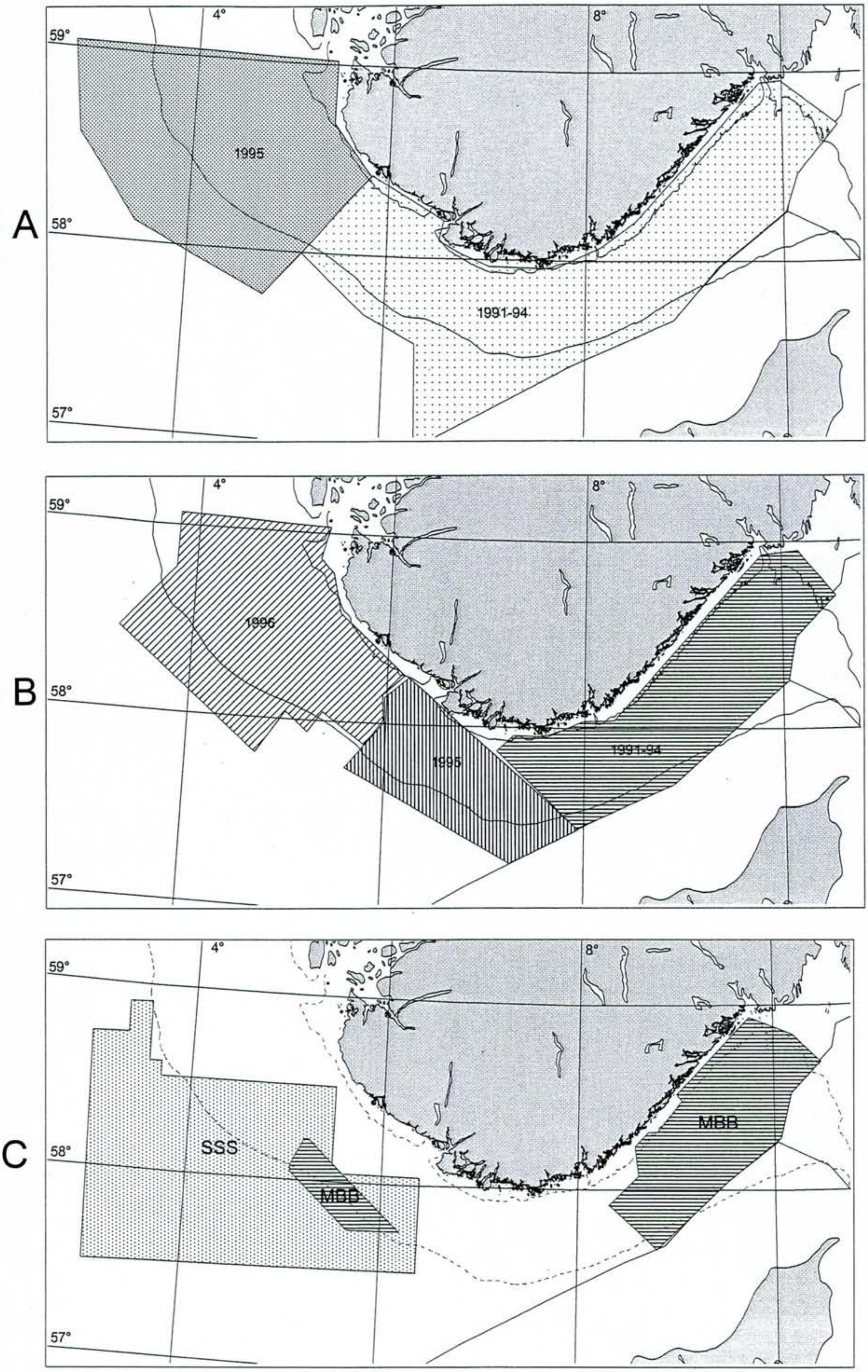


Figure 1. Map showing the different data sets: A) Shallow seismic B) Sea bed samples C) Multibeam bathymetry (MBB) and side scan sonar (SSS) data (from Norwegian Hydrographic Service).

2. MAP DESCRIPTIONS

Map 1 Bathymetry

In this map, the detailed swath bathymetry data sets are combined with other available bathymetric data sets within the area. The contour interval is 50 m. The map is compiled from various sources with different scales and precision, and must thus be considered as an overview map.

The Norwegian Trench is the largest depression in the North Sea. It starts in the inner part of the Skagerrak outside Langesund, and can be followed along the Norwegian coast for about 900 km, before terminating at the shelf edge west of Nordfjord (62°N). The widest and deepest part of the Norwegian Trench is within the easternmost part of the Skagerrak, with maximum water depths of c. 700 m at a distance of 50 km off the coast. East of the deepest trough, the bottom shallows towards the outlet of the Kattegat (just east of the map). Westwards, the trench becomes gradually shallower towards a sill at 280 m water depth west of Stavanger. The northern slope of the Norwegian Trench is generally steeper and more irregular than the southern slope, resulting in an asymmetrical shape of the trench. The seafloor is particularly irregular along the coast, where crystalline rocks crop out.

South of Langesund and towards the deepest part of the Skagerrak, the topography is characterised by several south to southwest trending trenches. Outside Arendal, there is a large subhorizontal area at about 400 m water depth, informally named the "Arendal Terrace". The terrace comprises thick, horizontally bedded sediments. It lies parallel to the coast, is 60 km long and up to 15 km wide (see map 9).

South of Lista, the deepest part of the trench (370 m) is located very close to the coast. The shallower "Hidra mountains" are located ca. 30 km from the coast between Lista and Egersund. These "highs" consist of crystalline bedrock protruding up to 60 m above the generally flat seafloor dominated by soft sediments. A large area just west of Jæren is fairly shallow (<250 m water depth). The shallowest sill in the Norwegian Trench (280 m) is located just west of this area.

The relatively flat North Sea Plateau becomes shallower towards the south and southwest, reaching 65 m in the southwestern corner of the map.

Map 2 Side scan sonar interpretation and multibeam bathymetry

During the period 1991-1995 the Norwegian Hydrographic Service collected multibeam bathymetry data in most of the Norwegian part of the Skagerrak. The data were collected by Simrad EM-100, and cover an area of about 8 000 km^2 in water depths between 100 m and 700 m. Production of the bathymetric maps involved generation of a digital elevation model, plotting of maps in many scales (1: 5000 to 1: 500 000) and in different forms (shaded relief images, coloured contour maps, etc.). The original bathymetric database is held by the Norwegian Hydrographic Service.

The shaded relief maps reveal the sea-bed morphology both in areas of bedrock and Quaternary sediments. Many glacial and non-glacial forms, such as drumlins and flutes, iceberg plow marks, buried fan deposits, pockmarks and sand waves can be seen (see Longva and Thorsnes (1997) for details).

In 1993 the Norwegian Hydrographic Service collected a multibeam bathymetric data set in a 1300 km^2 large area on the Egersund bank and the southern slope of the Norwegian Trench south of Egersund. The data were collected during a cooperative cruise, where NGU collected shallow seismic data. Prominent features in this data set are iceberg plow marks and pockmarks.

During the years 1982-1985, the Norwegian Hydrographic Service collected *side scan sonar data* in the Norwegian Trench and on the northeastern part of the North Sea Plateau. The data set comprises north-south oriented lines with a line spacing of 500 m. The side scan sonar applied was a Klein 531T dual, mainly operated at 50 kHz and displaying 300 m of the seafloor to each side of the towed fish. The data were printed on paper, and the data set covers an area of about 25 000 km^2. The interpretation (Lien 1995, Ottesen et al. 1998a, 1998b) of bottom types was based on sea-bed reflectivity. Hard bottom substrate results in strong reflectivity, whereas softer sediments give weaker reflectivity. Sea-floor morphology such as glacial flutes, iceberg plow marks, pockmarks, sand waves, etc. can be observed in the side scan records. The side scan sonar interpretation reveals low reflectivity (soft bottom) in the sandy areas of the North Sea Plateau and in the areas with fine-grained sediments in the Norwegian Trench, whereas high reflectivity occurs in areas of hard bottom (till, over-consolidated clays, lag deposits) on the North Sea Plateau.

The western part of the sea-bed sediment map (map 15) has been produced from the side scan sonar data, supported by information from sea-bed sediment samples and shallow seismic data (Ottesen et al. 1999).

Map 3 Seismic lines

During six cruises in 1991-95, about 20 000 km of shallow seismic profiles were collected during cooperative cruises by the Norwegian Hydrographic Service (NHS) and NGU. The profiles are either located in a regional grid (mostly 10 km spacing between the lines), or were collected simultaneously with the swath bathymetry data acquisition. These profiles are between 150 m and 1 km apart, and are generally oriented parallel to the depth contours. The energy sources used were sleeve guns (5-40 inches^3) recorded down to 1 second two way travel time (twt), and a high resolution Geopulse boomer system giving better resolution in the upper strata.

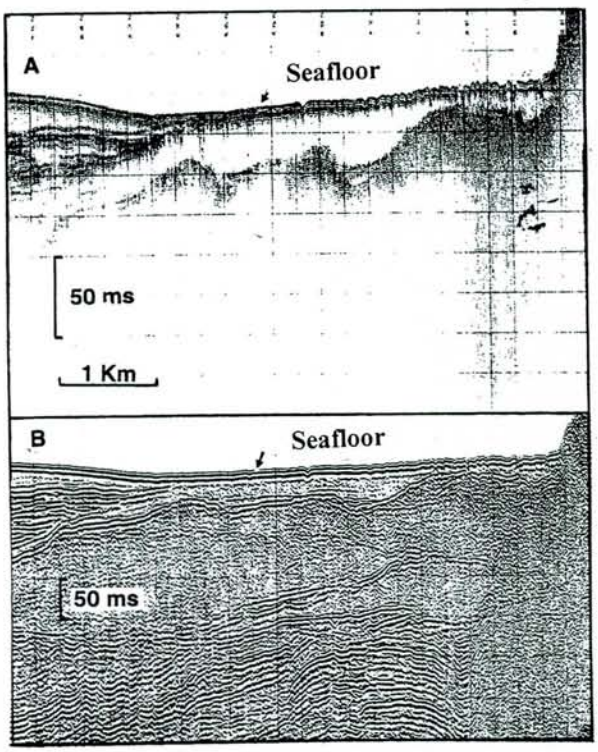
Table 1. NGU/NHS-cruises in the reported area

Cruise no.	Year	Km			NGU-report	Cruise report
		Regional net	Detailed net	Total		Reference
9101	1991	1225	2025	3250	91.014	Bøe et al. (1991)
9204	1992	1600	1640	3240	92.287	Thorsnes et al. (1992)
9301	1993	110	3440	3550	93.090	Bøe et al. (1993)
9306	1993	910	3180	4090	93.133	Thorsnes et al. (1993)
9401	1994	1680	0	1680	94.031	Ottesen et al. (1994)
9503	1995	2740	1400	4140	95.099	Ottesen et al. (1995)

Example of seismic data
Profile 9401007

A) Geopulse.
Sweep 250 ms.
Filter: 600-5000 Hz.

B) Sleeve gun,
40 inch^3.
Sweep: 500 ms.
Filter: 120-1200 Hz.



Map 4 Sea bed samples/short cores

"Undisturbed" cores for environmental investigations were collected at 268 stations during five NGU-cruises between 1991 and 1996 using Niemistø corer (1991-93) or Multicorer (1994-1996), (Paetzel 1992a, b, Ottesen and Paetzel 1995, Bjerkli 1997, Bjerkli and Moen 1997).

1992	55 stations
1993	20 stations
1994	58 stations
1995	45 stations
1996	90 stations

Most of the cores are shorter than 50 cm, with a core diameter of 59 mm. The sample stations are located at the cross points between regional seismic lines. Various analyses were performed on the sediments, e.g. age determination, organic and inorganic chemical analyses, geotechnical analyses, physical properties, and grain size and microfossil analyses (Bøe 1993, Bøe 1994, Bøe 1995, Bøe et al. 1996, Bøe and Rise 1997, Bøe et al. 1997, Kunzendorf et al. 1996, Olsen 1996, Rise and Bøe 1995, Rise et al. 1996, Sæther 1996).

In 1997, Surface Geochemical Services (SGS) collected nearly 300 vibra- and gravity cores on the northeastern North Sea Plateau and in the Norwegian Trench. Most of the cores are located on Egersundbanken, and with an average length of about 2.2 m. The cores contributed with a lot of detailed sedimentological information. The sediments in the top and bottom of the cores were briefly described at sea. A total of 38 samples was opened and described in detail at NGU (Ottesen and Bøe 1998).

Map 5 Depth to bedrock

The map shows the large scale morphology of the bedrock surface (in milliseconds twt). Due to sound velocity variations in the Quaternary units, a map with depths in metres has not been produced. The map illustrates, however, major form elements such as trenches/troughs, ridges, steep slopes, etc. It is important to keep in mind that these forms were not necessarily formed during the same glacial erosional event. In some areas pre-Late Weichselian sediments exist (see map 9), and in these areas the deepest glacial erosion may be of different age. In most of the Norwegian Trench, within the studied area, the bedrock surface was glacially eroded during the late Weichselian maximum when a huge ice-stream followed the axis of the trench parallel to the coast.

Normally, the bedrock surface is easily recognized in the shallow seismic data, as the dipping sedimentary sequences are cut by glacial erosion with flat-lying Quaternary layers above. The depth to the bedrock is therefore confidently mapped in most of the area. The largest uncertainty of the map is in the shallowest south-western part, where the base Quaternary does not appear as a clear angular unconformity, or is below the sea bed multiple on the seismic records.

The bedrock surface lies deepest in the eastern part of the Skagerrak, about 50 km southeast of Arendal. The Skagerrak reaches here the greatest water depth (approximately 720 m), and the Quaternary is about 50 m thick. Another major erosional trough appears ca. 15 km northwest of the deepest one (see section I, map 13). This trough is probably also of glacial origin, but formed during an earlier glaciation. Slightly further west, the glacial erosion during the Late Weichselian maximum has formed two deep troughs sub-parallel to the Norwegian coast, with a ridge in between (see section II, map 13). The two troughs coalesce southwest of Kristiansand and continue further northwest close to the coast. A few km west of Lista, the trough disappears towards the Eigerøy Horst (the Hidra mountains), a ridge of hard crystalline rocks extending southwards from Egersund. Most of this ridge is buried below sediments, but some "mountain peaks" protrude up to 60 m above the seafloor.

Southwest of the crystalline bedrock ridge, another major trough originates and continues towards the northwest. The axis of the trough is located approximately 15-20 km off the coast outside Jæren. Most of the erosion in this trough (northwestwards from Egersund) occurred during an early glaciation, and thick units of pre-Late Weichselian sediments have been deposited in this part of the Norwegian Trench (maps 8 and 9).

The slope of the bedrock surface is generally steeper towards the Norwegian coast than towards Denmark. In the steepest part of the southern slope of the Skagerrak, Cretaceous rocks crop out. These rocks are rather resistant to glacial erosion and have guided the glacier flow.

Map 6 Bedrock geology

This map (Bøe et al. 2000) is a revision of the older bedrock maps covering the area (Sigmond 1992, Jorde et al. 1995, Padget and Brekke 1996). The revision is based on several new data sets, mainly digital seismic profiles by Norwegian Petroleum Directorate (NPD) and Continental Shelf and Petroleum Technology Research Institute (IKU), and analogue shallow seismic lines by NGU. IKU has undertaken several shallow drillings in Skagerrak, and data from these drillings have been utilised in the map interpretation.

In the Skagerrak, Precambrian gneisses extend 10-20 km out from the Norwegian coast. In the eastern part of the Skagerrak, Permian intrusive rocks occur, as a direct southward continuation of the intrusive rocks located on the mainland east of Langesund. West and southwest of the Permian intrusives, a zone of Cambro-Silurian metasediments occur. Similar rocks are found on land in the Langesund area and occur on the sea bottom (below the Quaternary sediments) in a zone along the coast, southwestwards towards Mandal. Discordant above the Lower Palaeozoic rocks, a succession of Mesozoic rock occurs. The thick, lower part of this package was previously interpreted as Triassic. Biostratigraphical analyses of cored sediments indicate that the whole package is of Lower Jurassic age (Rise et al. 1999). Above this follows a thin package of Middle Jurassic rocks, and further Upper Jurassic, Early Cretaceous and Late Cretaceous successions. The Jurassic and Cretaceous units are locally strongly faulted, especially south and southwest of Kristiansand. This is an area of abundant salt tectonics and complex structural geology.

West of Lista, the Varnes Graben is situated close to the coast. The basin is bordered to the southwest by a ridge of crystalline rocks (the Eigerøy Horst) extending about 50 km from the coast in a southerly direction. New data indicate that the oldest sedimentary rocks in the Varnes Graben are of Early Jurassic age. Stratigraphically above these, Mid- to Late Jurassic and Early Cretaceous rocks occur. A large N-S-trending fault is located south of Lindesnes, and marks the eastern border of the Varnes Graben.

On the western side of the Eigerøy Horst and further north along the coast, Carboniferous to Permian sedimentary rocks occur discordant above Precambrian and Early Palaeozoic rocks. In most places these occur in large half grabens. The main fault directions are generally N-S to NNW-SSE. West of these rocks, Late Jurassic, Cretaceous and Tertiary rocks occurs.

Northwest of Jærens Rev and south-southwest of Karmøy, the lower boundaries of the Upper Palaeozoic rocks have been difficult to locate due to a complicated tectonic pattern. Along the southern and southwestern side of the Eigerøy Horst, a fault between the Lower Cretaceous and the Upper Palaeozoic sedimentary rocks occur.

Map 7 Quaternary geology

The map shows the sediments on the sea bed or close to the sea bed and is based mainly on interpretation of shallow seismic data. In some areas, limited resolution of the seismic lines has made an accurate interpretation impossible. The vertical sections in map 13 illustrate the stratigraphy of the mapped units. The interpreted depositional environment (see legend) is based mainly on seismic character and a general understanding of the geological development of the area.

Holocene marine clays are deposited in the Norwegian Trench and cover most of the underlying Late Weichselian glaciomarine clays. The glaciomarine clays mainly crop out west of Mandal, where they have a wider distribution at the surface than the Holocene clays.

In water depth shallower than 200 m, in the southeastern slope towards Denmark, silty fine sand occurs of probable Late Weichselian or Early Holocene age. In this area, large, probably relict, sand waves indicate that sand was transported towards the southeast at that time.

Sand is widely distributed on the shallow North Sea plateau, and is commonly more than one metre thick. In some areas, active sand waves migrating towards the southeast have been mapped. Sand/silt was deposited in the upper part of the southern slope of the Norwegian Trench. The sediment types on the northern slope of the Norwegian Trench vary in composition.

On the North Sea Plateau large areas of glacial sediments comprise overconsolidated marine/glaciomarine clays, till, or coarse lag deposits (boulders, gravel and sand). In some areas on the North Sea Plateau and in the southern slope of the Norwegian Trench pre-Late Weichselian sediments, mainly of till/glaciomarine/marine nature, occur.

South of Egersund, a ridge of crystalline rocks extends in a southerly direction. The bedrock ridge is covered by a thin layer of Quaternary sediments.

Outside Jæren, up to 300 ms thick packages of Quaternary sediments occur. In the uppermost part, these sediments may consist of glaciomarine or Holocene sediments (a few metres thick).

Map 8 Total thickness of Quaternary sediments

The Quaternary succession comprises pre-Late Weichselian sediments (map 9), Late Weichselian sediments and Holocene sediments (map 12). The boundary to the underlying sedimentary rocks is usually easily recognized in the seismic records as an angular unconformity, and the thickness of the Quaternary sediments is therefore confidently mapped in most of the area. Also in areas with crystalline bedrock, the base of the Quaternary is easily recognized. The largest uncertainty of the map is in the shallow, south-western part, where the base Quaternary does not appear as a clear angular unconformity or is below the seabed multiple. As the sound velocities of the Quaternary sediments vary between 1550 m/s and 2000 m/s, we have not been able to make an accurate map in metres. In areas of thick pre-Late Weichselian sediments, the average sound velocity is estimated to be 1900- 2000 m/s, and the thickness in metres will be only slightly less than the ms-values shown on the map. In other areas, the ms-values have to be reduced 10-15% in order to get the thickness in metres.

Outside Arendal, an area of thick Quaternary deposits (100-300 ms) occurs, most of which is older than Late Weichselian. Except for this area, the thickness of Quaternary sediments is generally less in the eastern part than in the western part of the investigated area. In the deepest part of the Skagerrak, where the water depth is more than 550 m, the sediment thickness is generally less than 50 ms. Southeast of Kristiansand, a maximum area (125-175 ms) occurs in the lowest part of the southern slope. A minimum area (0-25 ms) in the upper part of the southern slope occurs where rocks of Cretaceous age crop out in the steepest part of the slope.

West of Kristiansand, the thickness of Quaternary deposits is generally more than 100 ms. The thickest deposits are located in depressions sub-parallel to the axis of the Norwegian Trench. Only a thin cover of Quaternary deposits occurs on the Eigerøy Horst (Hidra mountains). The thickest deposits (225-325 ms) occur west of the horst and continue further NNW. The oldest of these sediments were to a large extent deposited in a coast-parallel trough (see map 5). Most of the Quaternary sediments off Jæren are of pre-Late Weichselian age. In the area south of Egersund, however, thick units of Late Weichselian glaciomarine clays have been deposited.

West of the areas with thick successions of glacial sediments outside Egersund and Jæren, a relatively thin cover of Quaternary sediments occurs.

Map 9 Thickness of pre-Late Weichselian sediments

Erosion during the last glacial maximum removed much of the existing sediments. Most of the glacial erosion was done by the Norwegian Trench Ice Stream flowing parallel to the trough axis from Skagerrak to its outlet outside Nordfjord (62°N). Pre-Late Weichselian sediments are found within three different areas:

1. The «Arendal Terrace» (60 x 15 km^2) comprises mainly horizontally layered sediments interpreted as glaciomarine/marine deposits with a maximum thickness of 250-300 ms (c. 250 m). The terrace is interpreted as a remnant of an extensive unit of pre-Late Weichselian sediments that was largely removed during the Weichselian maximum by the Norwegian Trench Ice Stream. Late Weichselian till and glaciomarine/marine clays are deposited on top.

2. Several seismic units (maximum thickness 300 ms), interpreted as both till and glaciomarine clay units, occur in the northeastern part of the Norwegian Trench, off Egersund - Stavanger. The oldest units are partly deposited in a glacially eroded trough (main trend southeast to northwest) outside Jæren (see map 5). The infilled trough starts about 50 km south of Egersund and continues all the way beyond Stavanger. The upper half of the succession comprises numerous thin units, probably mainly deposited as till. Some large erosional slopes/glacial troughs indicate that the ice moved parallel to the axis of the Norwegian Trench. There are also examples of erosion/deposition, indicating that the regional ice in some periods flowed from the mainland and towards the offshore areas.

3. A large area with older Quaternary deposits is located in the southwest part of the Norwegian Trench and in the Norwegian Trench south of Lista and Mandal. These sediments represent several seismic units with different seismic signatures that reflect different properties and origins. The maximum thickness of these sediments is 200 ms.

The lack of old sediments between area 2 and 3 is mainly due to strong glacial erosion by the Norwegian Trench Ice Stream during the last glacial maximum. North of the studied area the erosion during the Late Weichselian maximum never managed to remove all the existing sediments and erode into the bedrock.

Map 10 Depth to Late Weichselian erosion surface

This map presents the large scale morphology of the interpreted glacial erosion surface during the Last Glacial Maximum (30 000-15 000 ^{14}C-years BP). In the Skagerrak area, this map is similar to map 5 (depth to bedrock), except for the "Arendal Terrace". This terrace was part of a basin fill deposit, covering most of the deepest parts of Skagerrak. During the last glacial maximum, the Norwegian Trench Ice Stream eroded selectively a large part of these sediments, but the "Arendal Terrace" was left as an erosion remnant. South of the "Arendal Terrace", a major glacial trough reveals heavy glacial erosion. The trough turns slightly towards the coast further west. Another glacial trough starts further south and continues westwards, ending west of Lista close to the coast. Crystalline rocks extending southwards from Egersund has survived erosion and the "Hidra mountains" constitute the shallowest part of this ridge. South and west of these crystalline rocks a younger glacially eroded trough occurs, revealing extensive glacial erosion during the Late Weichselian. This glacial trough is about 100 km long and ends rather sharply west of Egersund. These features indicate that the Norwegian Trench Ice Stream lost its erosional power and was deflected towards the west. This may partly be due to the thick packages of glacial sediments (mainly till) located outside Jæren, and partly due to deflection of the ice stream by glaciers from land areas flowing out into the Norwegian Trench.

Map 11 Thickness of upper unit of glaciomarine sediments

A thick glaciomarine succession was deposited during and after the deglaciation of the Skagerrak basin. We have separated the glaciomarine sediments into three different units, where the youngest is presented in this map. This unit is commonly acoustically layered, with a high frequency of reflectors that can be followed over long distances. The sediments were deposited in an open marine environment with drifting icebergs, probably in the period ca. 14 000–10 000 ^{14}C years BP. The thickest part of the unit is drilled and sampled, showing that it consists of normally consolidated clay with some sand and gravel fragments.

Large areas of the Skagerrak have moderate thicknesses of glaciomarine sediments, commonly less than 25 ms. The thickness of the glaciomarine sediments is greatest in the southern part of the Norwegian Trench in the Skagerrak, between 7° E and 9° E, reaching more than 100 ms. South of the area of maximum deposition, glaciomarine sediments are absent in the steepest part of the southern slope, probably because strong bottom currents prevented sedimentation. West of 7°30′ E, only small amounts of glaciomarine deposits are present in the southern slope of the Norwegian Trench, in contrast to the eastern part where thick deposits exist.

Outside Egersund, the greatest thickness (up to 100 ms) is located in the central and deep part of the trench.

Outside Jæren, glaciomarine sediments are absent over large areas. However, glaciomarine sediments cover a larger area than the Holocene sediments, although with a thickness of only a few metres.

Map 12 Thickness of Holocene sediments

In the Norwegian Trench, mainly Holocene clay occurs, whereas in the southern slope coarser sediments are also present (map 15).

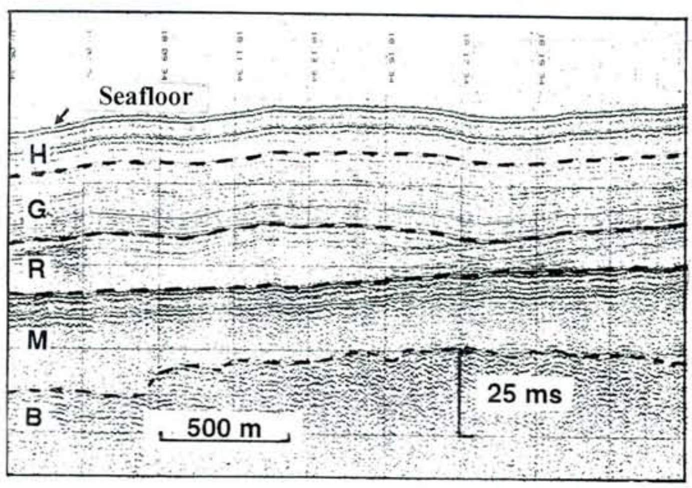
In the central part of the Norwegian Trench, east of Lista, the Holocene soft clay is 10-20 ms thick (Olsen 1996). Further west it is generally less than 10 ms thick, with a maximum outside Egersund (more than 20 ms). In the northern slope of the trench, east of Mandal, the thickness varies between 20 ms and 50 ms. West of Mandal, on the northern slope, Holocene sediments occur only within local basins.

In the steepest part of the southern and southeastern slope of the Norwegian Trench, in the Skagerrak, and along the northern part of the plateau south of the trench, the Holocene unit is absent. This area of erosion/non-deposition extends east-southeast for about 100 km, and terminates in a narrow trench in the easternmost part. East and northeast of the area of erosion/non-deposition, up to 130 ms of Holocene sediments occur. On the plateau south of the Norwegian Trench, the Holocene sediment thickness increases towards the east-southeast to a maximum of 60-70 ms near the median line between Norway and Denmark.

In the southwest slope of the trench, west of 7°E, the Holocene fine-grained sediments grade into coarser sandy sediments up-slope and it is, therefore, difficult to define the southwestern limit of Holocene sediments.

In large areas outside Jæren, Holocene sediments are not shown. However, a thin cover may occur, at the most a few metres.

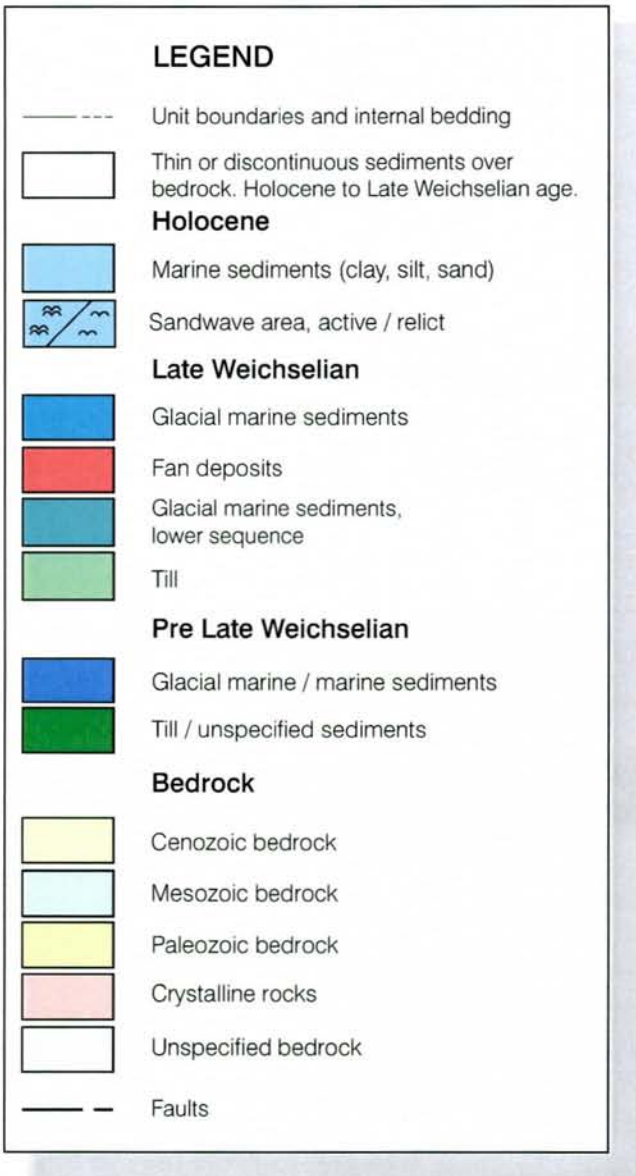
Interpreted seismic section showing the stratigraphy from the sea floor to bedrock



H-Holocene, G-Glaciomarine, R-Avalanche deposits, M-till, B-Bedrock

Map 13 Interpreted seismic profiles

Six interpreted seismic cross sections (I-VI) are presented and located on the relevant maps (Maps 5-12). The cross sections are aligned perpendicular to the axis of the Norwegian Trench.



Map 14 Shallow gas and pockmarks

The distribution of **shallow gas** has been mapped from seismic profiles where acoustic blanking on high frequency seismic records may occur. Shallow gas has been mapped in four areas in the Norwegian part of the Skagerrak. Southeast of Langesund and in the southeastern slope of the Norwegian Trench towards Denmark, the acoustic blanking reaches the seabed or close to it, and gas seems to be evenly distributed in the sediments.

In the southern slope, further to the west, the acoustic blanking becomes less distinct, and the distribution of gas seems to be more discontinuous in the upper layers of the seabed. The gas is associated with various types of old Quaternary deposits. Pockets of gas in sandy sediments may exist. Acoustic blanking in Mesozoic sedimentary rocks is located in the Norwegian Trench south of Lindesnes-Mandal.

Pockmarks are circular or elongate seafloor depressions associated with seeping of gas or fluids from the underlying sediments or bedrock. We have mapped pockmarks by multibeam bathymetry, side scan sonar data and seismic profiles.

In the Skagerrak, pockmarks were identified from swath bathymetric data. The circular depressions vary from 50 m up to several hundred metres in diameter, and can be up to 16 m deep. More than 90 % of the pockmarks occur in sediments above Mesozoic sedimentary rocks (Rise et al. 1999).

In addition to the circular pockmarks, an area of very large and deep elongated depressions, approximately half of which occur where there is gas blanking in seismic records, is located in the southeastern slope (Bøe et al. 1998).

In the west, pockmarks have been digitised from two fishery plotting charts (5704-1 and 5804-3), based on side scan sonar data published by the Norwegian Hydrographic Service. Between 6° 30'E and 8° 20'E, lack of data has precluded mapping of pockmark features.

Between Lista and Stavanger, seismic profiles are utilised to identify possible areas of pockmarks. The pockmark areas are outlined and the frequency of pockmarks is indicated with a number along the seismic lines.

The areas of pockmark occurs mainly within the areas of Holocene fine-grained sediments (map 12).

Map 15 Sea bed sediments

The seabed sediment map is presented as two individual maps, the Skagerrak and the North Sea west of Lista.

In the Skagerrak, grain size analyses with *Sedigraph* (Bøe 1993), show that the sea bed sediments over large areas in the Norwegian Trench and along its northern slope consist of homogeneous silty clay (with a clay content of 50-75 % and generally less than 2 % sand). Sediments on the plateau along the Norway-Denmark median line are dominated by fine and very fine sands, which become coarser at shallower water depths towards the southeast.

The map of the western area, covering the area between 3°E and 6°30'E and 57°30'N and 59°N, is based on several data sets (Ottesen et al. 1999), including side scan sonar data (approximately 20 000 km^2), shallow seismic profiles, short Niemisto cores (in the Norwegian Trench) and gravity and vibro cores (the North Sea Plateau and the Norwegian Trench). Grain size analyses with *Coulter Counter (LS 200)* gave much lower clay content than the Sedigraph did for comparable sediments in the Skagerrak. We have therefore chosen to use a different legend in the western part of the map.

The North Sea Plateau comprises hard glaciomarine/marine sediments or till. These sediments are exposed in several areas or may be covered by a thin layer of lag deposits (gravel, stones etc.). The hard sediments may in other areas be covered by sand (medium to coarse), with thicknesses varying from a few centimetres to several metres. Within areas of sandy sediments, local sand waves occur, showing sand transport towards the east/southeast. In the upper part of the southeastern slope of the trench, a transition zone with sandy silt and fine sand is present.

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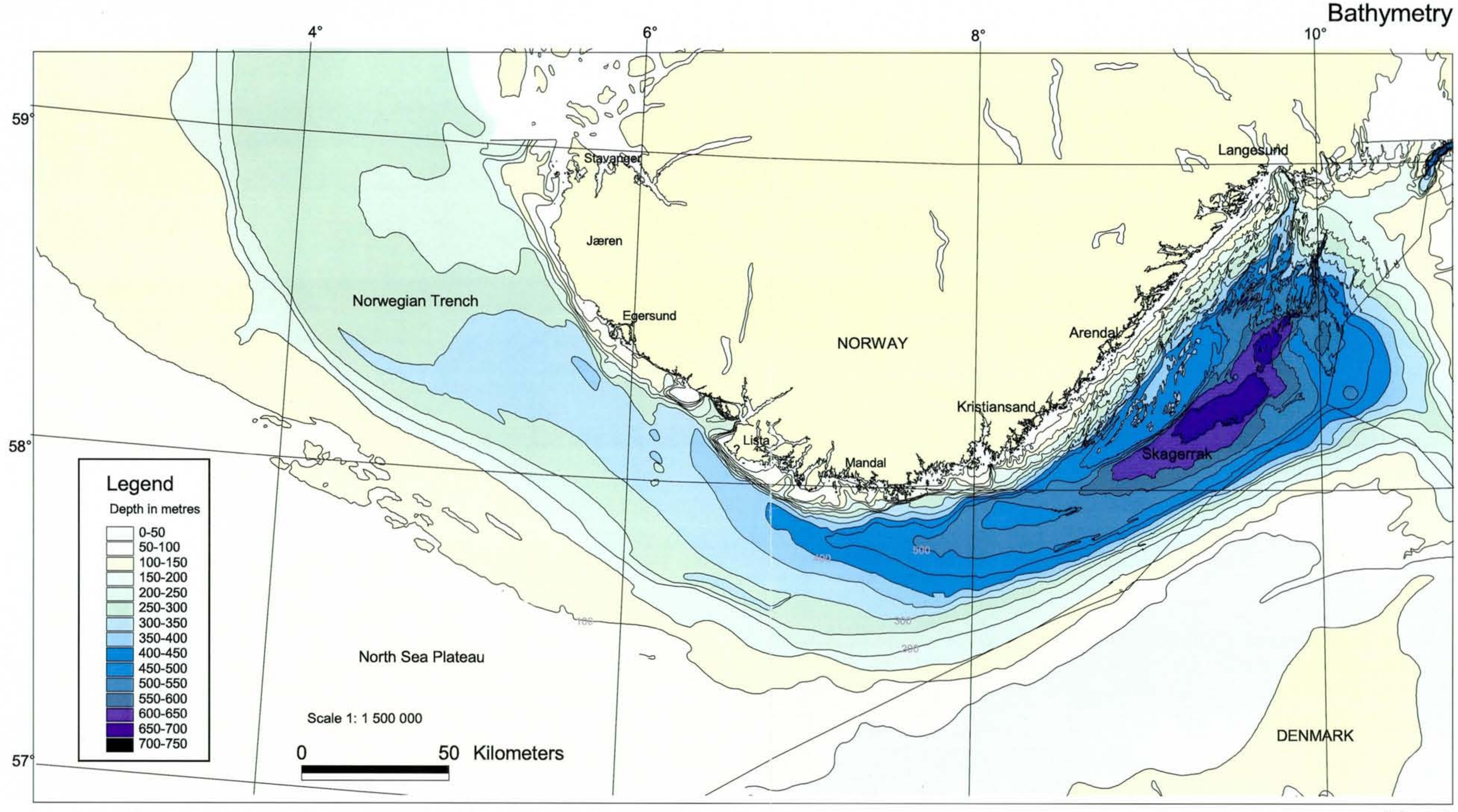
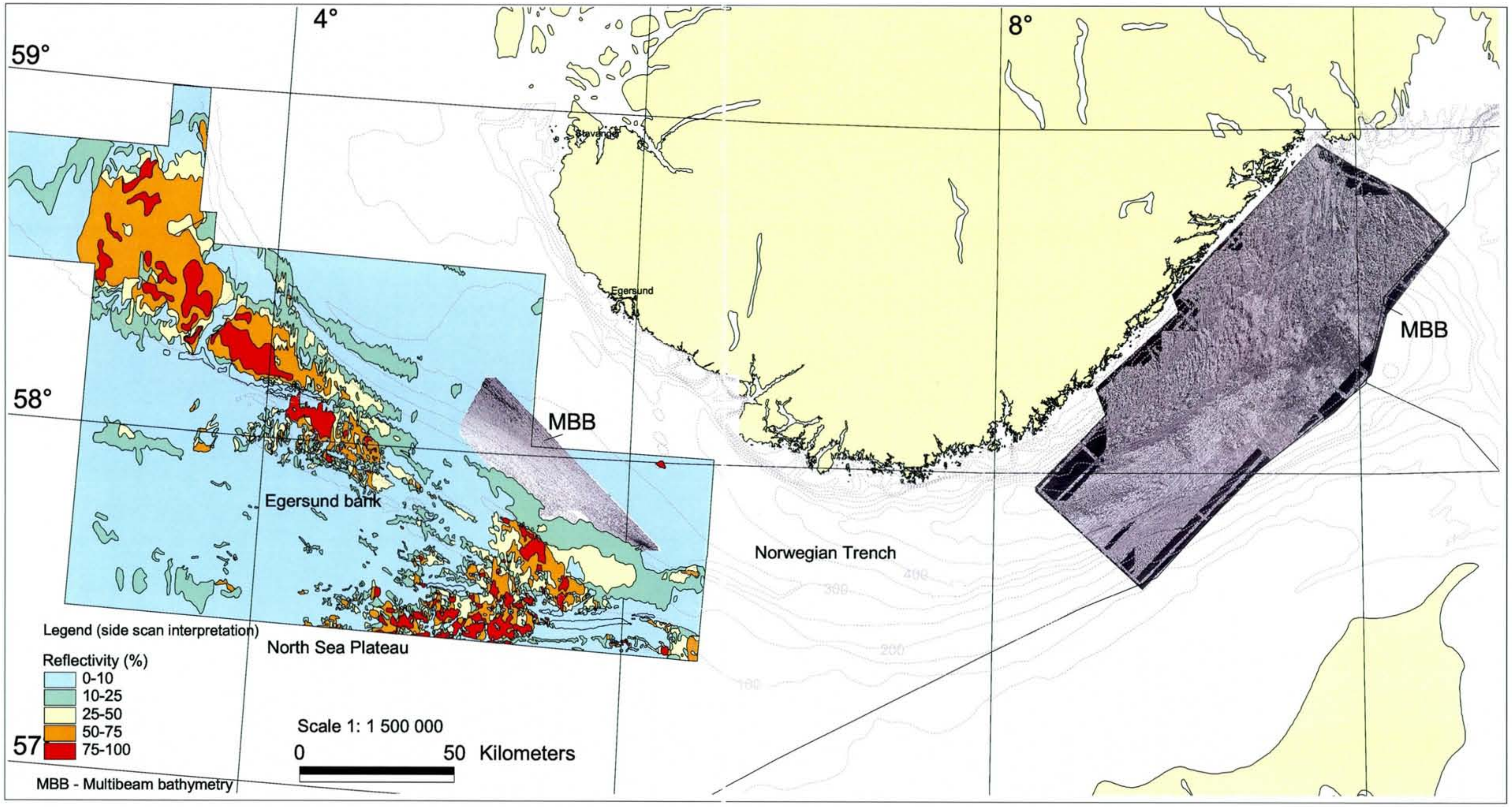


Bathymetry
4°
6°
8°
10°
59°
58°
57°
Stavanger
Jæren
Norwegian Trench
Egersund
NORWAY
Arendal
Langesund
Kristiansand
Lista
Mandal
Skagerrak
North Sea Plateau
DENMARK
Legend
Depth in metres
0-50
50-100
100-150
150-200
200-250
250-300
300-350
350-400
400-450
450-500
500-550
550-600
600-650
650-700
700-750
Scale 1: 1 500 000
0
50 Kilometers

Map 1

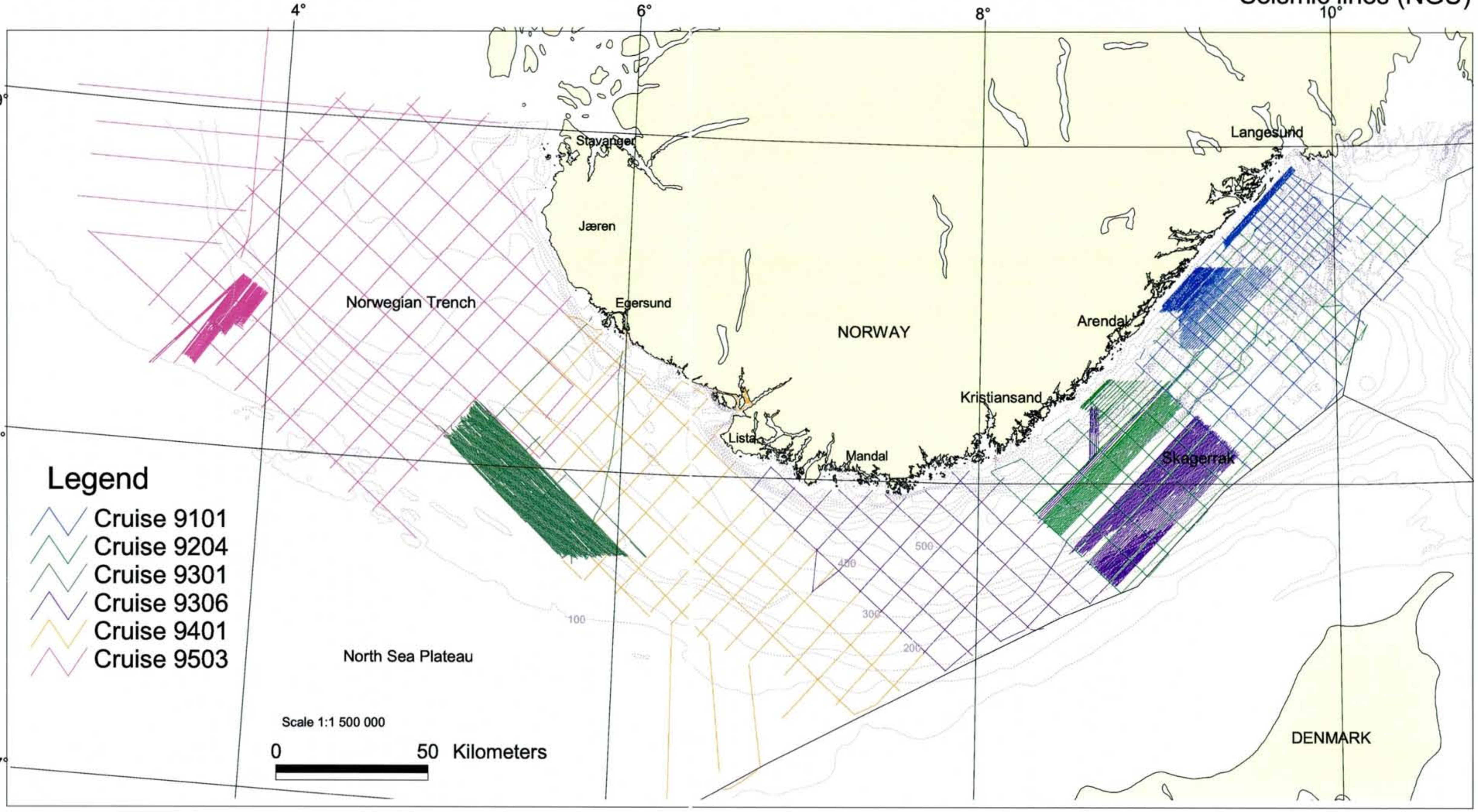
I

Side scan sonar interpretation
Multibeam bathymetry



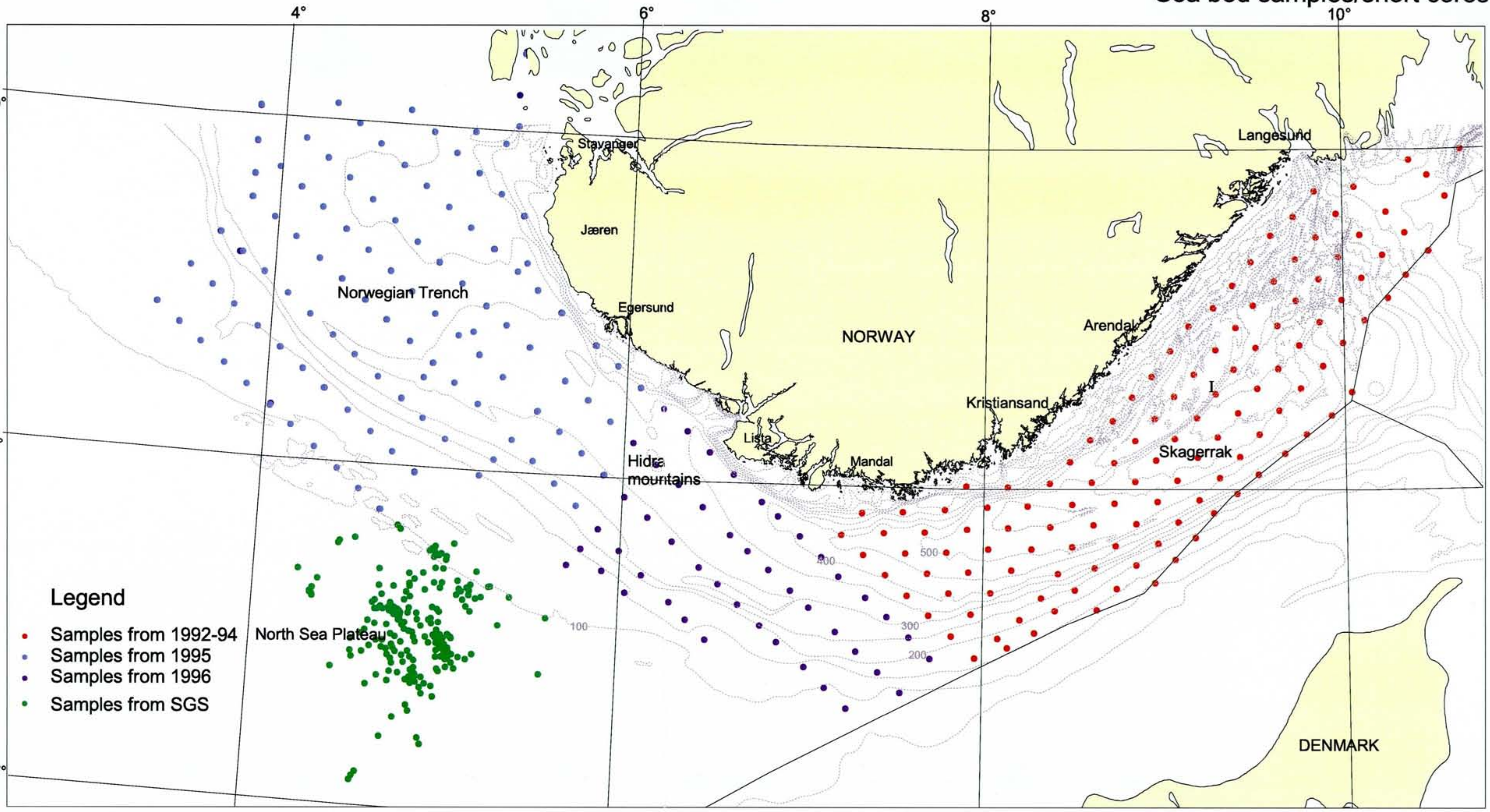
Map 2

Seismic lines (NGU)



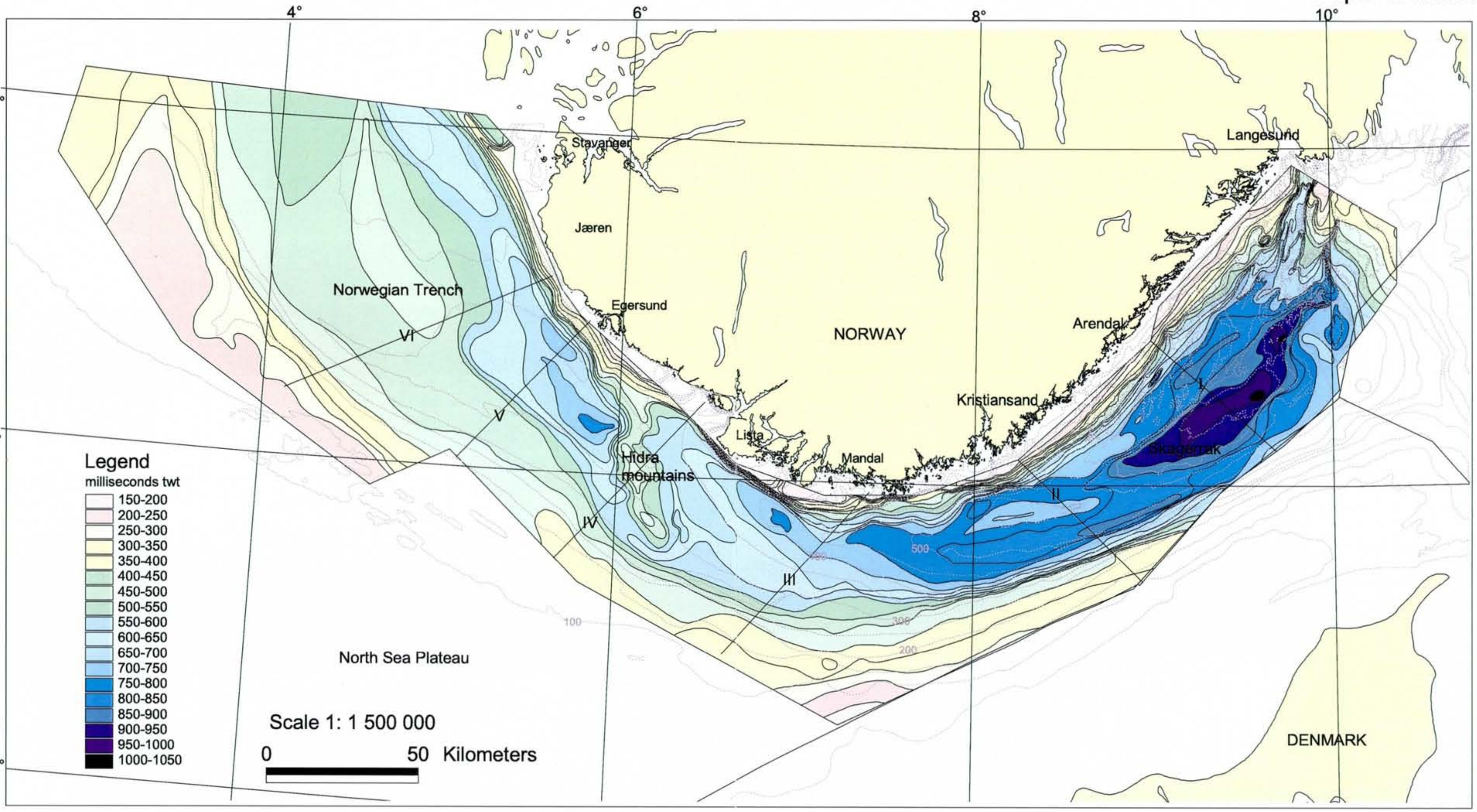
Map 3

Sea bed samples/short cores

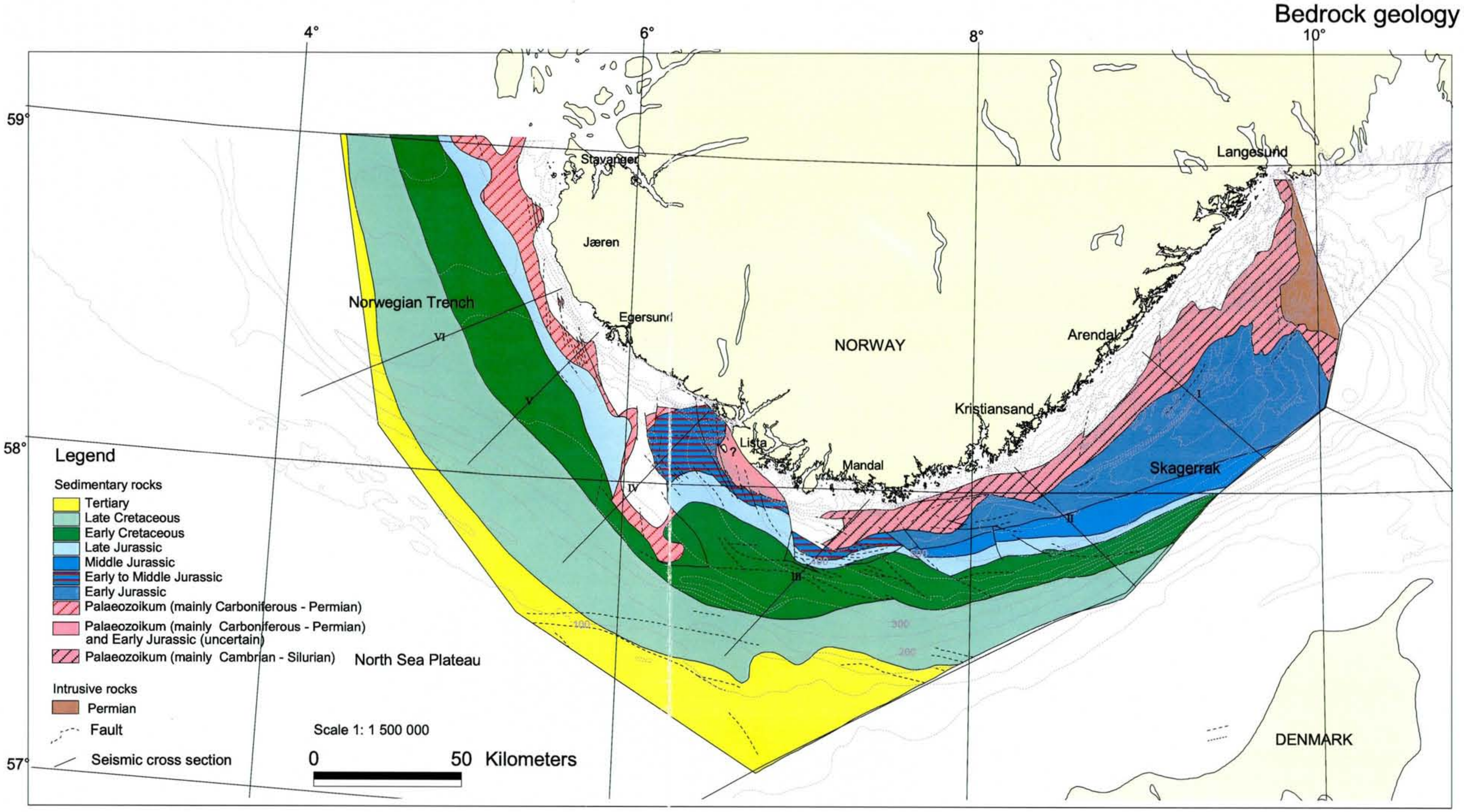


Map 4

Depth to bedrock

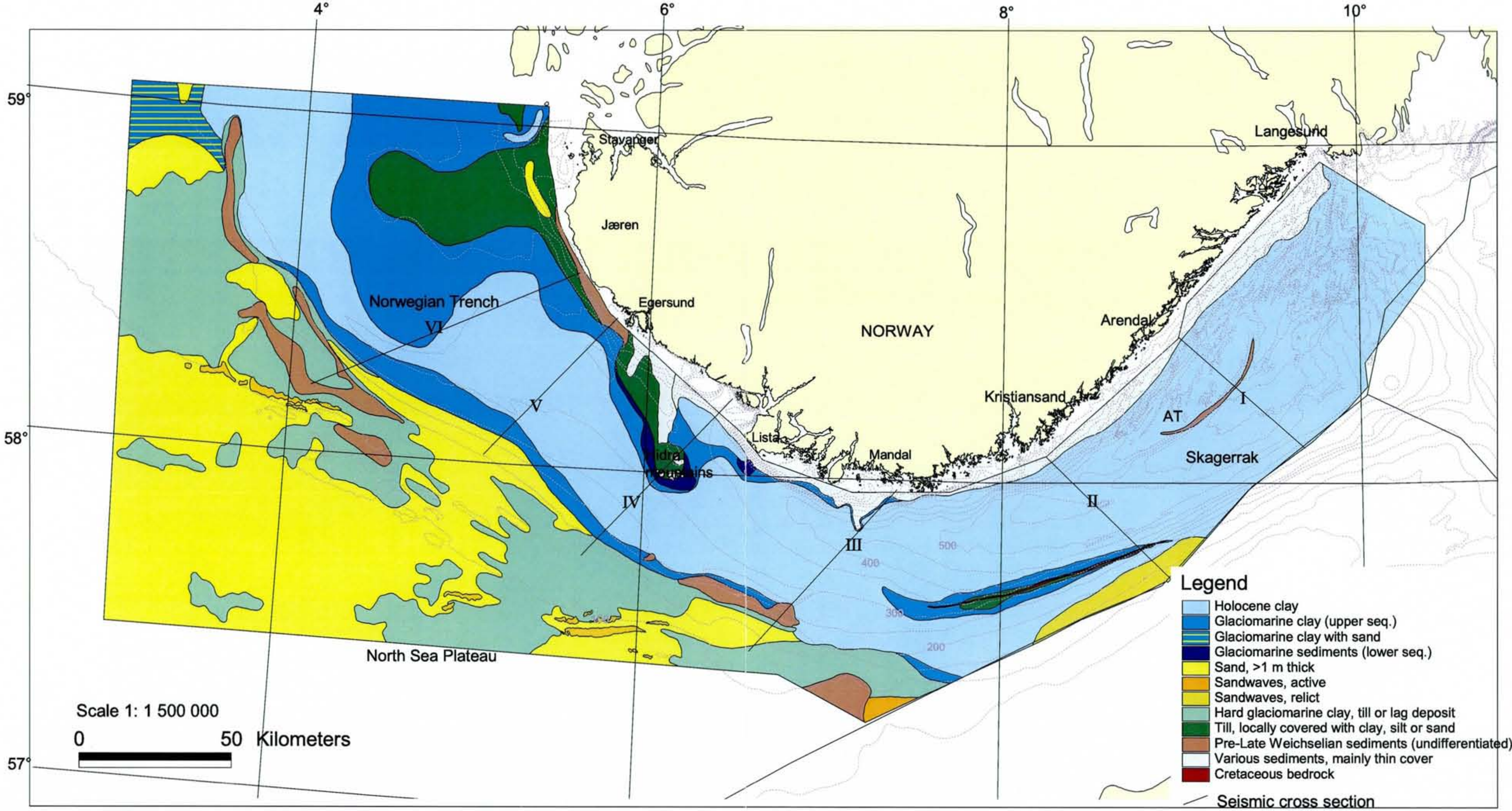


Map 5


Bedrock geology
4°
6°
8°
10°
59°
58°
57°
Stavanger
Langesund
Jæren
Norwegian Trench
Egersund
NORWAY
Arendal
Kristiansand
Lista
Mandal
Skagerrak
North Sea Plateau
DENMARK
VI
V
IV
III
II
I
Legend
Sedimentary rocks
Tertiary
Late Cretaceous
Early Cretaceous
Late Jurassic
Middle Jurassic
Early to Middle Jurassic
Early Jurassic
Palaeozoikum (mainly Carboniferous - Permian)
Palaeozoikum (mainly Carboniferous - Permian) and Early Jurassic (uncertain)
Palaeozoikum (mainly Cambrian - Silurian)
Intrusive rocks
Permian
Fault
Seismic cross section
Scale 1: 1 500 000
0
50 Kilometers
Map 6

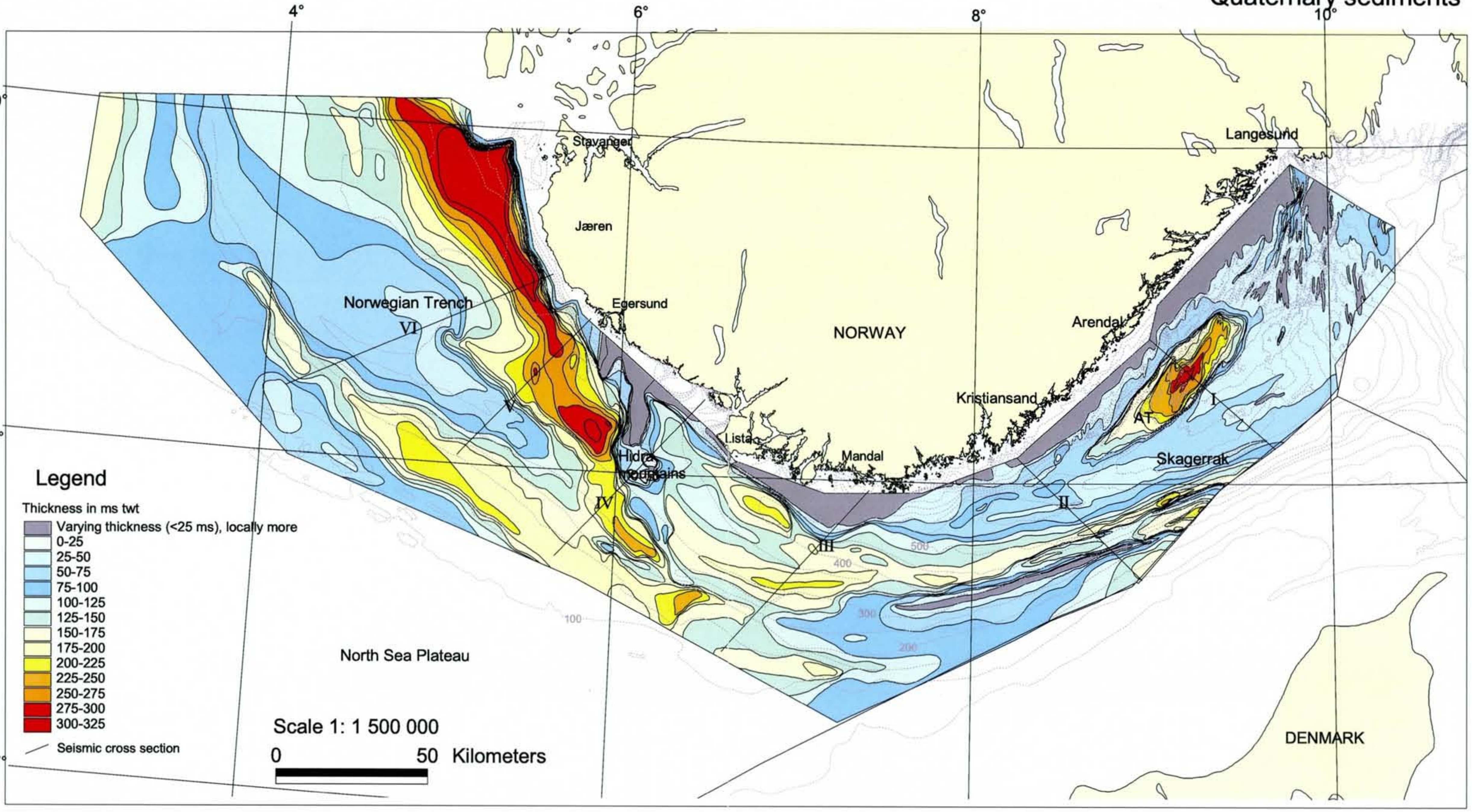
I

Quaternary geology



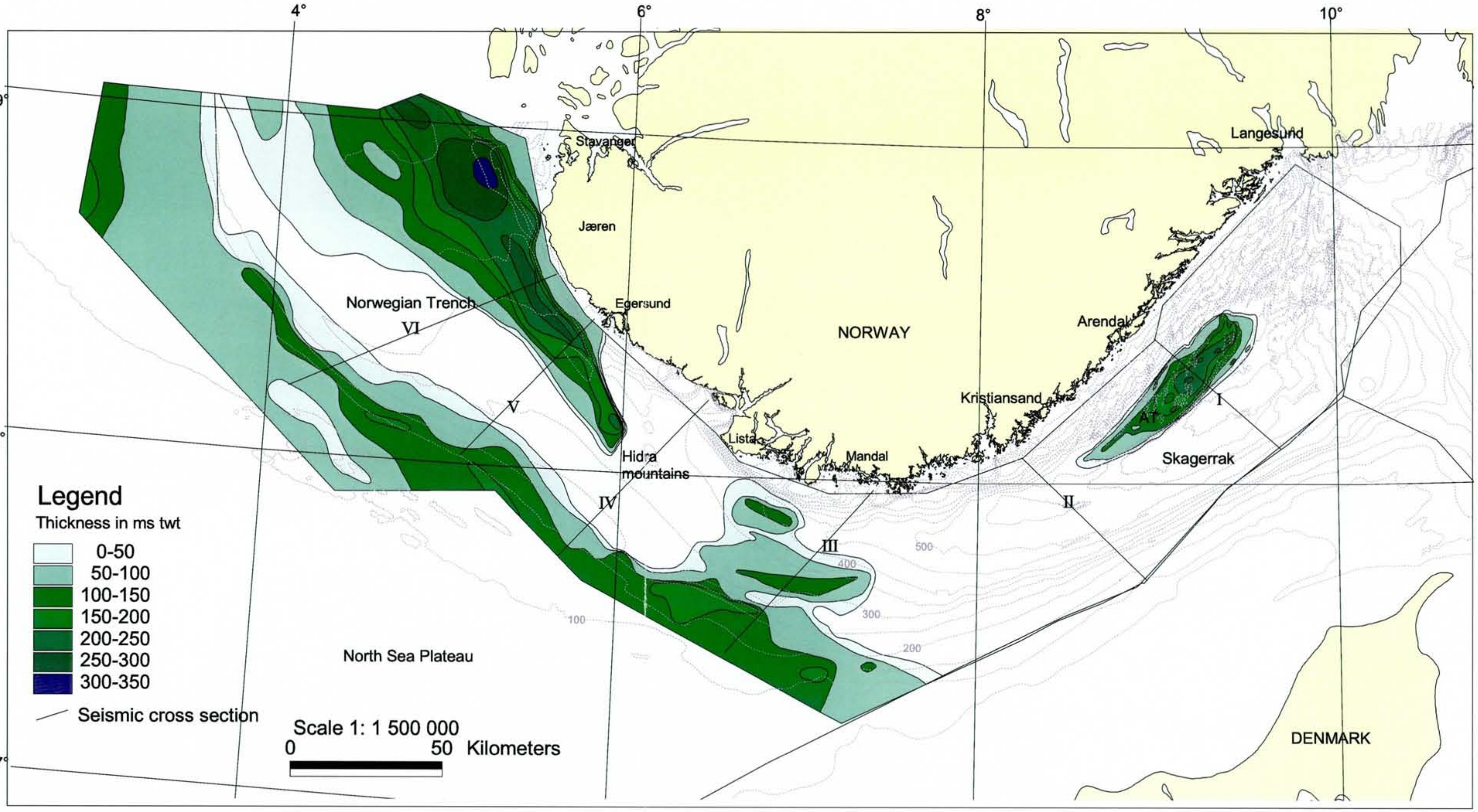
Map 7

Total thickness of Quaternary sediments



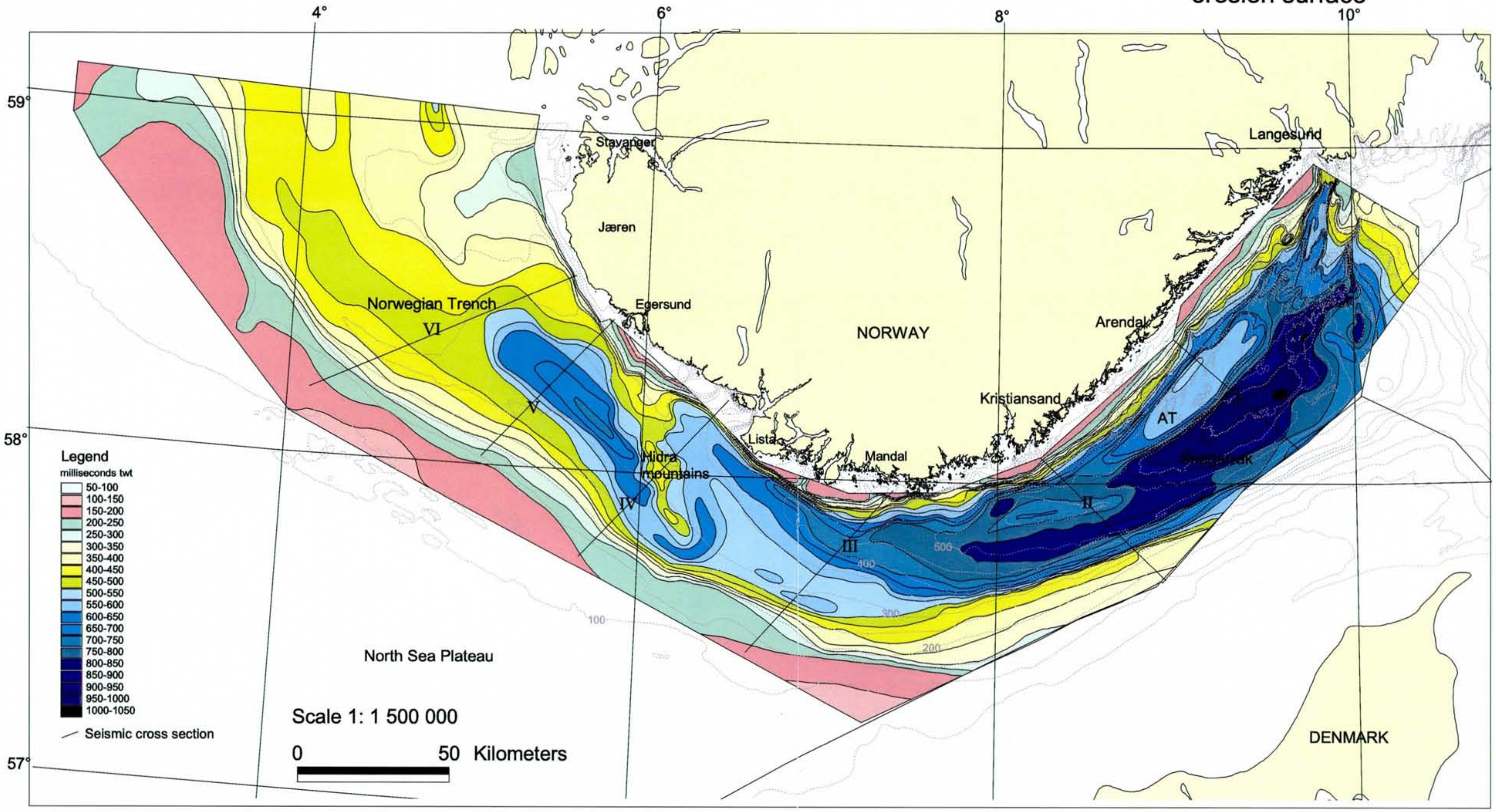
Map 8

Thickness of pre-Late Weichselian sediments



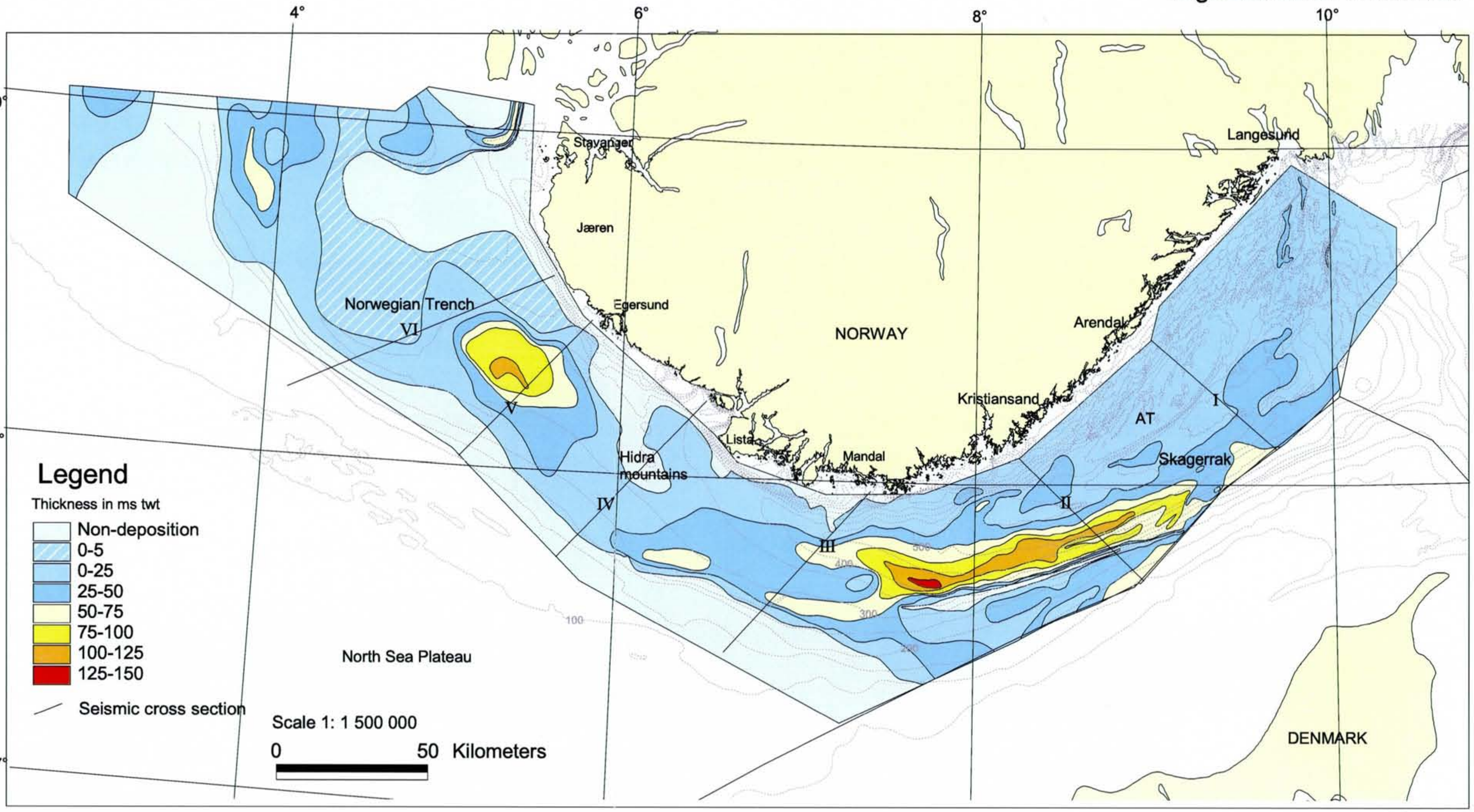
Map 9

Depth to Late Weichselian erosion surface



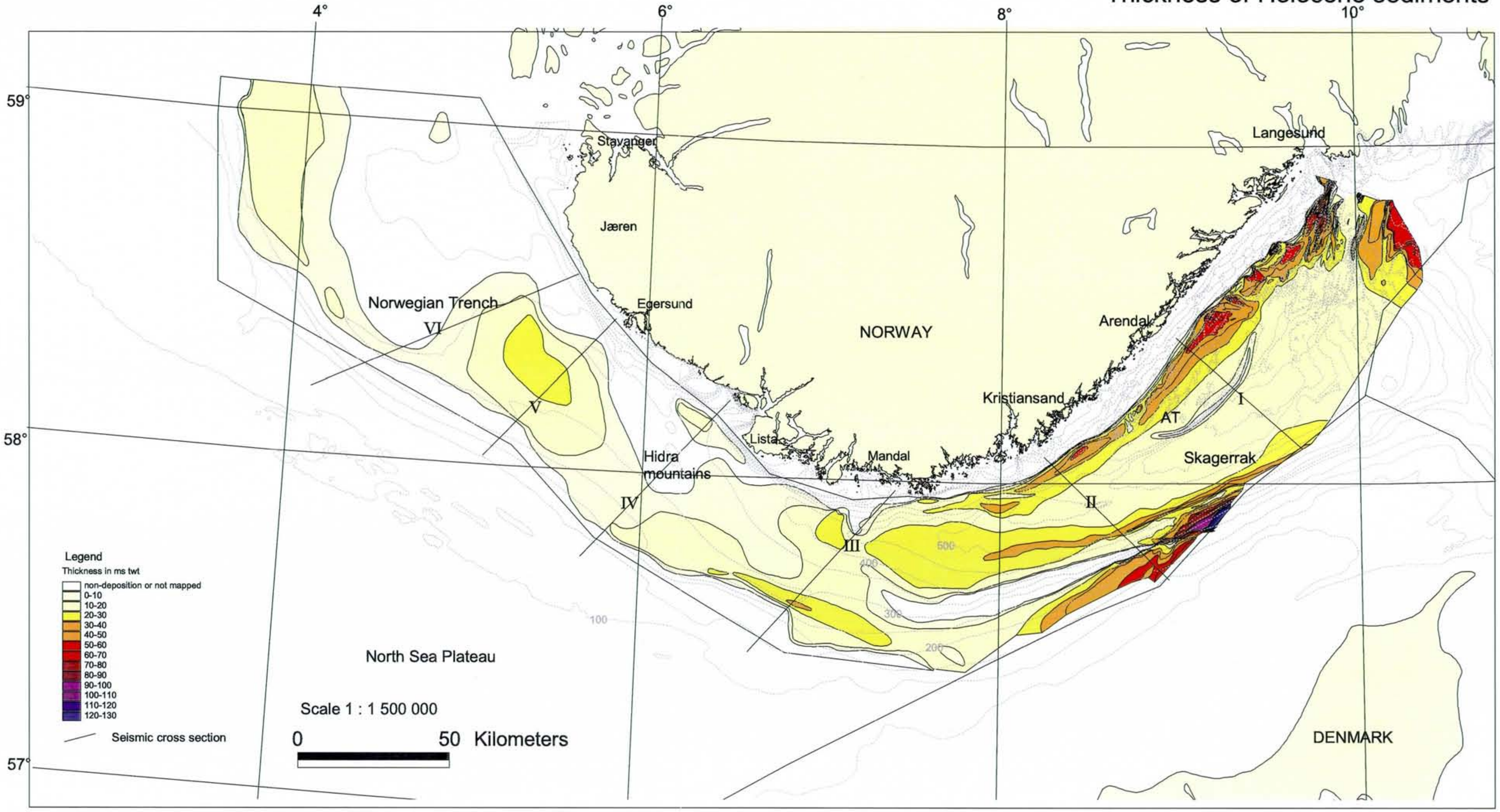
Map 10

Thickness of upper unit
of glaciomarine sediments



Map 11

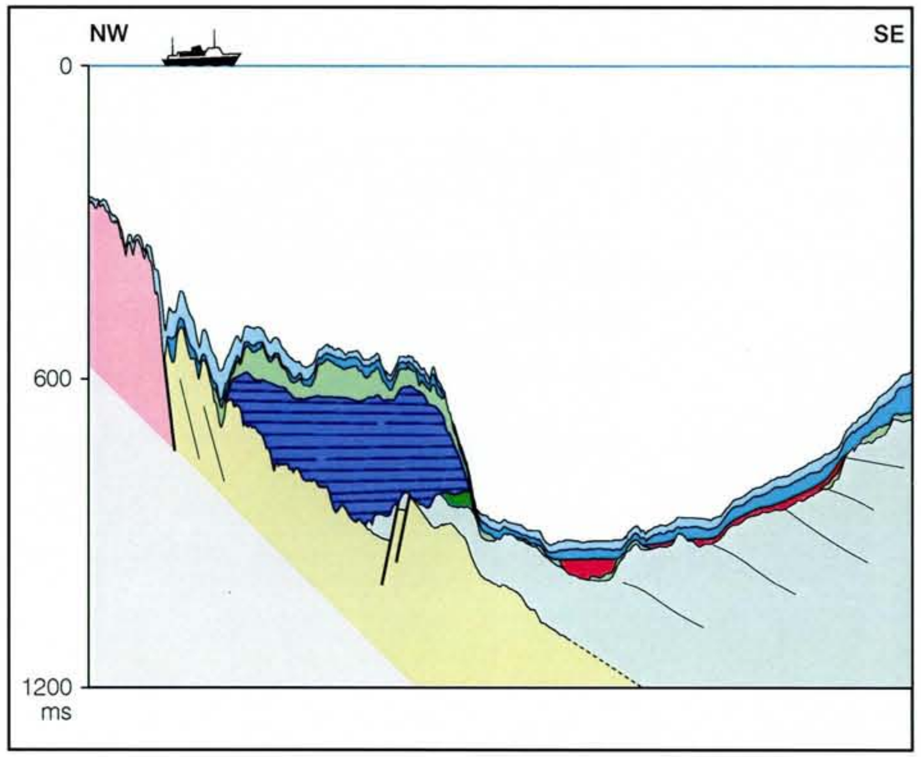
Thickness of Holocene sediments



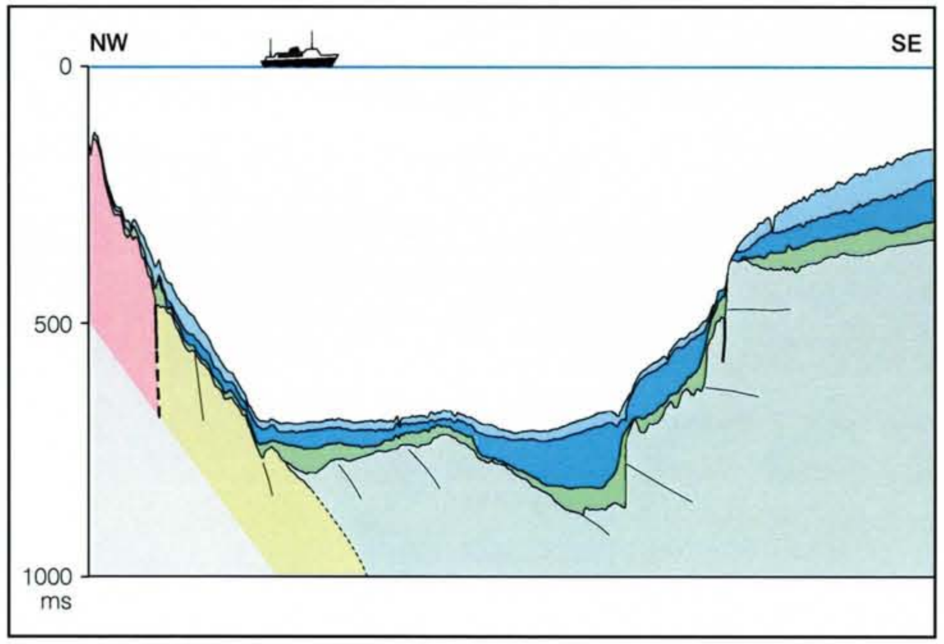
Map 12

Interpreted seismic profiles

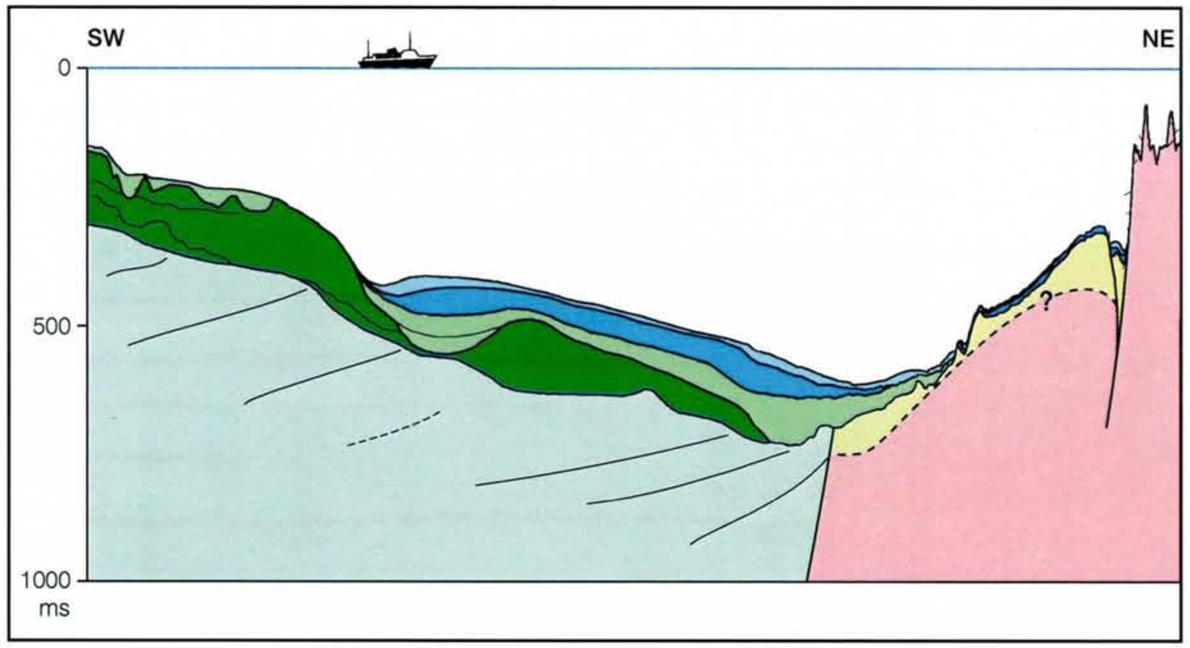
I



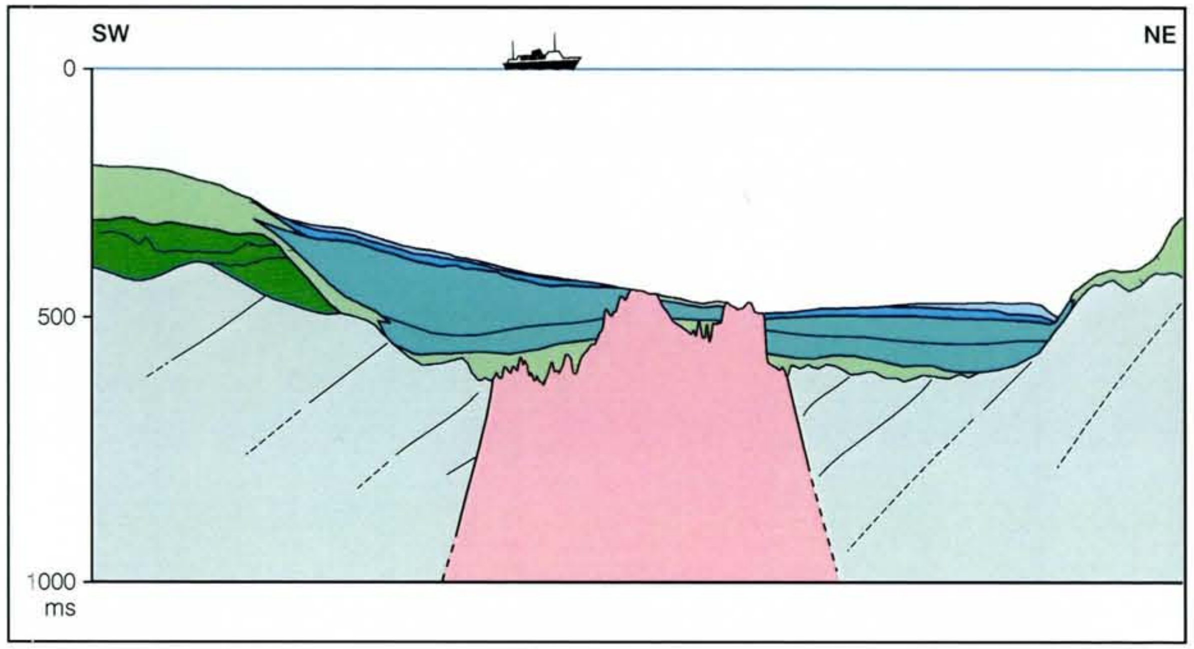
II



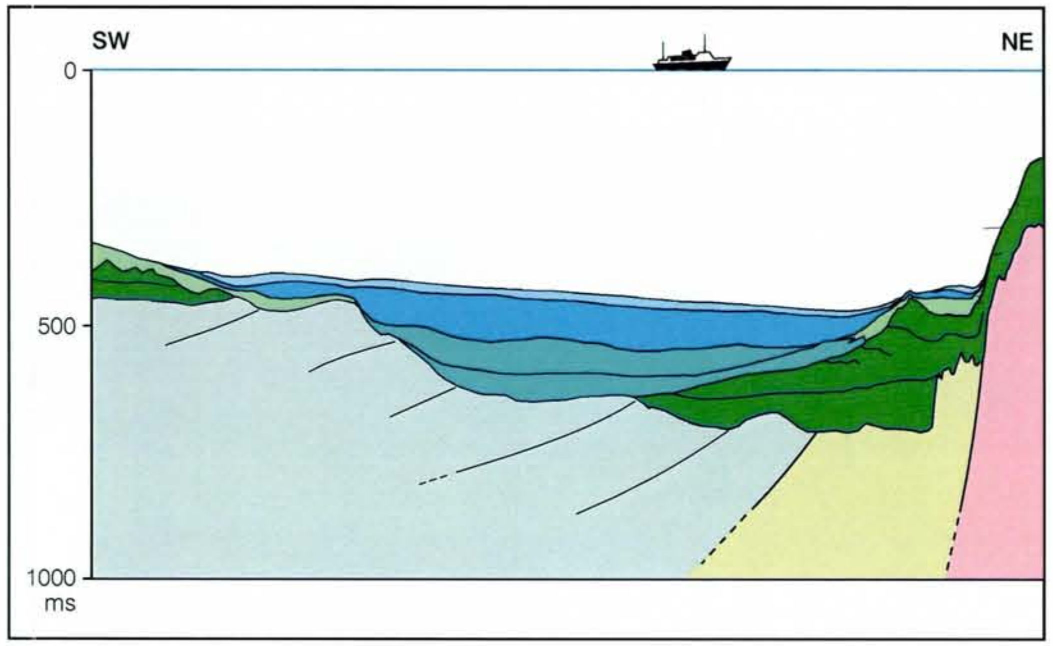
III



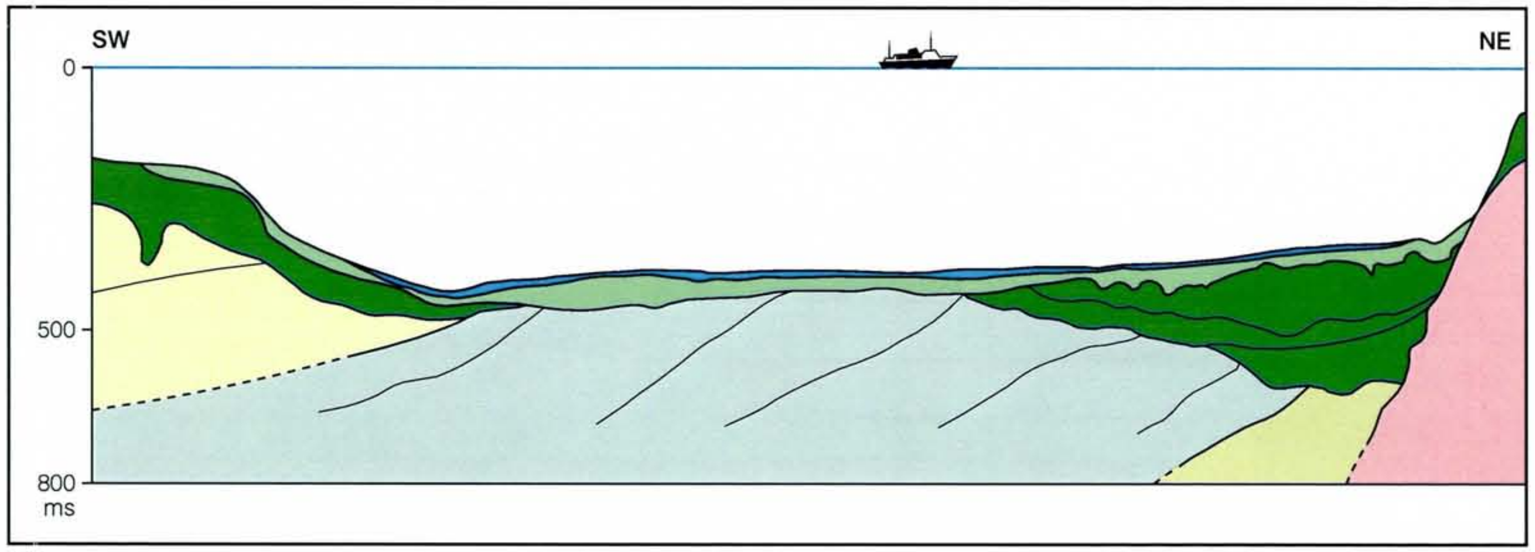
IV



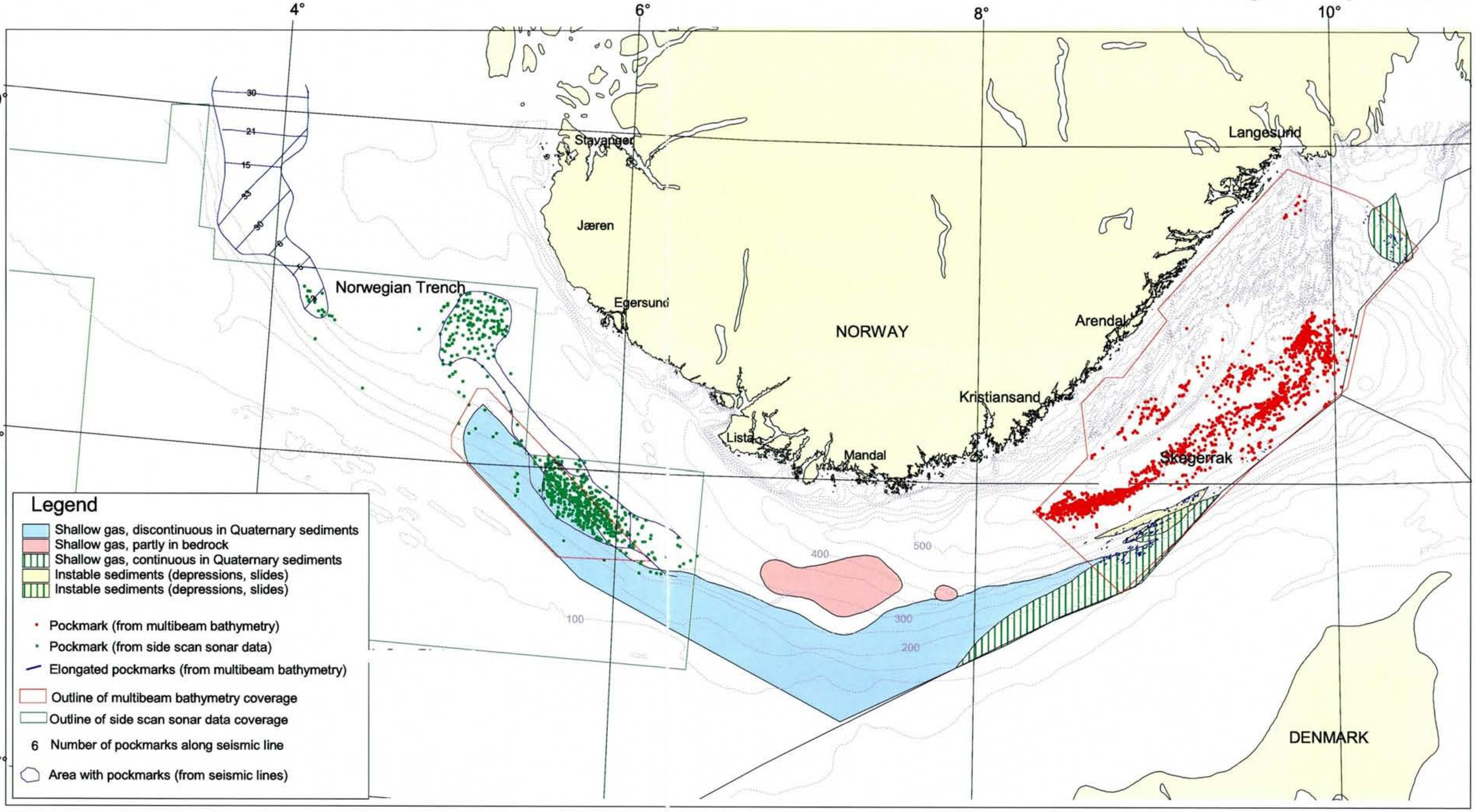
V



VI



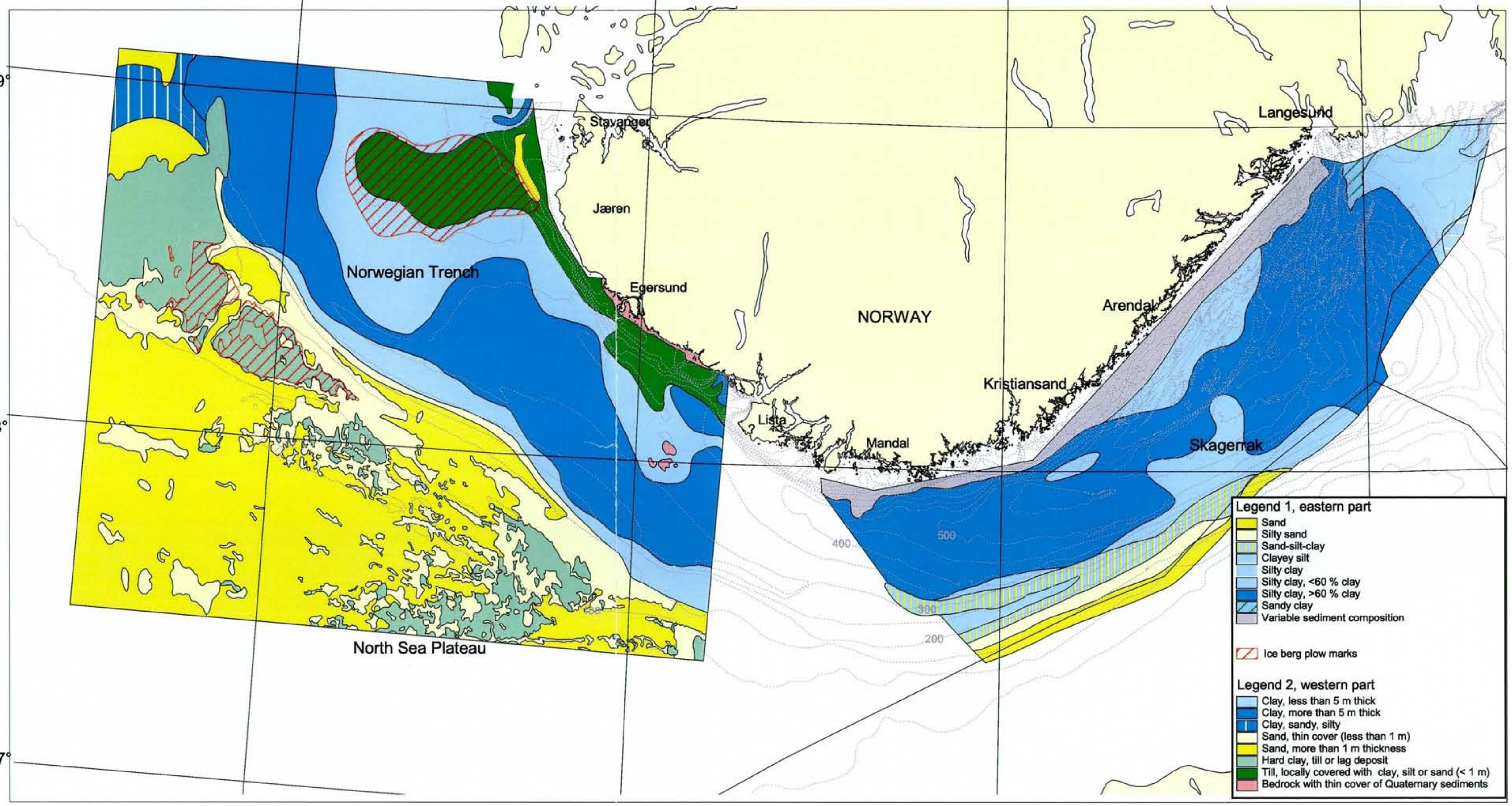
Shallow gas and pockmarks



Map 14

I

Sea bed sediments



Map 15

I