GEOLOGY and HYDROCARBON POTENTIAL of THE JAN MAYEN RIDGE

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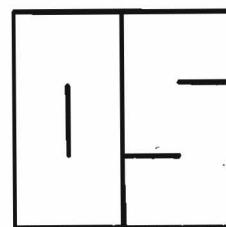
GEOLOGY and HYDROCARBON
POTENTIAL of
THE JAN MAYEN RIDGE

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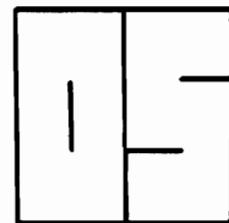Karl Gunnarsson,
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ABSTRACT/EXECUTIVE SUMMARY

In 1981 Iceland and Norway agreed upon the partition of the continental shelf in the area between Iceland and Jan Mayen. A joint project of geological mapping of the sub-sea resources of the Jan Mayen Ridge was included in the agreement. This mapping has been executed in close cooperation between Orkustofnun (National Energy Authority - Iceland) and Oljedirektoratet (Norwegian Petroleum Directorate). This report describes the work done, and gives an interpretation of the geological history of the area, including an evaluation of the hydrocarbon-potential. The work has concentrated on the acquisition of seismic data, and the interpretation of these data integrated with other existing geophysical and geological information.

Important conclusions drawn are:

- Reflections from pre-Tertiary strata are locally observed. These may represent Mesozoic sediments that could satisfy the basic conditions for hydrocarbon-generation and accumulation, but they could also partly be basaltic lavas with no hydrocarbon potential. There is no information available about the lithology of these rocks except by comparison with the geologically related areas of East Greenland and the Norwegian shelf.

- The Tertiary history, which is dominated by the plate tectonic opening of the Norwegian-Greenland Sea, is outlined in some detail. Both the tectonics and the sedimentation of the area can now be considered fairly well known. The Tertiary sediments are not likely to satisfy the conditions necessary to form hydrocarbon accumulations. For a better evaluation of this, more information on vertical movements and heat-flow at the ridge through time is needed. Information about the lithology of the early Tertiary sediments is also lacking, source-levels may be present, and stratigraphic traps caused by facies changes

may possibly occur.

- In general the hydrocarbon-potential of the area must be considered low - but all geological conditions necessary for hydrocarbon generation could be present - so at the existing level of knowledge it can not be ruled out.

- Production of possible hydrocarbons can not be expected in the near future because of the deep waters, remoteness and harsh weather condititons of the area.

- The interest of the oil-companies is for the time being low. The seismic data acquired were offered for sale to relevant companies in late 1987, but have until now only been bought by Statoil.

Concluding the report is a set of recommendations. Some further activity in the area is advised. Different levels of activity in terms of cost are defined. Continued interpretation of the existing dataset is the minimum option. Acquisition of more seismic data, shallow drilling and ultimately a deep bore-hole are escalating possibilities. Lack of lithological information from drilling presently makes it impossible to give a final answer to the question of the hydrocarbon-potential of the area, so drilling is the logical next step from a geological point of view. We present for discussion different arrangements for the continued exploration; whether to continue with exclusive governmental work, or to try to obtain participation from oil-companies by opening of the area for geophysical data acquisition or by awarding production licenses in the area.

GEOLOGY AND HYDROCARBON POTENTIAL OF THE JAN MAYEN RIDGE

ABSTRACT/EXECUTIVE SUMMARY

1 INTRODUCTION

1.1 PROJECT DESCRIPTION

In 1981 an agreement (included as Appendix 1) was reached between the governments of Iceland and Norway delimiting the continental shelf between Iceland and Jan Mayen. The agreement implies Norwegian acceptance of the Icelandic 200 nm economic zone and continental margin in the area (Fig.1.1). In addition to this clear definition of the national boundaries, the agreement defines a subsea area to be explored by the two nations in company (Fig.1.1). This area is delimited by latitudes $N68^{0}$ - $N70^{0}35'$ and longitudes $W10^{0}30'$ - $W6^{0}30'$. It covers a total of 45 470 km^{2} , of which 32 750 km^{2} is in the Norwegian sector, and 12 720 km^{2} in the Icelandic sector. The two parties also have specified rights to shares in possible hydrocarbon-production from the national subareas of this defined common interest subground. The agreement stipulated a joint survey program, to carry out a systematic geological mapping of the area. For this purpose a geophysical survey with emphasis on acquisition of multi-channel seismic reflection data was considered the most appropriate starting point. The survey was planned and executed in close cooperation between representatives of the relevant governmental bodies; the National Energy Authority (NEA) of Iceland, and the Norwegian Petroleum Directorate (NPD). The aquired dataset was to be considered common Icelandic/Norwegian property and treated confidentially. The Norwegian goverment was to carry the cost of acquisition and processing of the data. Possible profits from the sales of the data were to be split between the two parties, after costs had been covered. Funds for the acquisition, processing and interpretation of the data have been provided from 1985 and onwards.

This report contains a short description of the acquisition and processing of the geophysical data acquired during the

project. The main part is a description of the geology of the Jan Mayen microcontinent, including an evaluation of its hydrocarbon potential. Also included is a short description of follow-up projects in progress, continuing the regional geological mapping of the area, and recommendations for future exploration activities in the area.
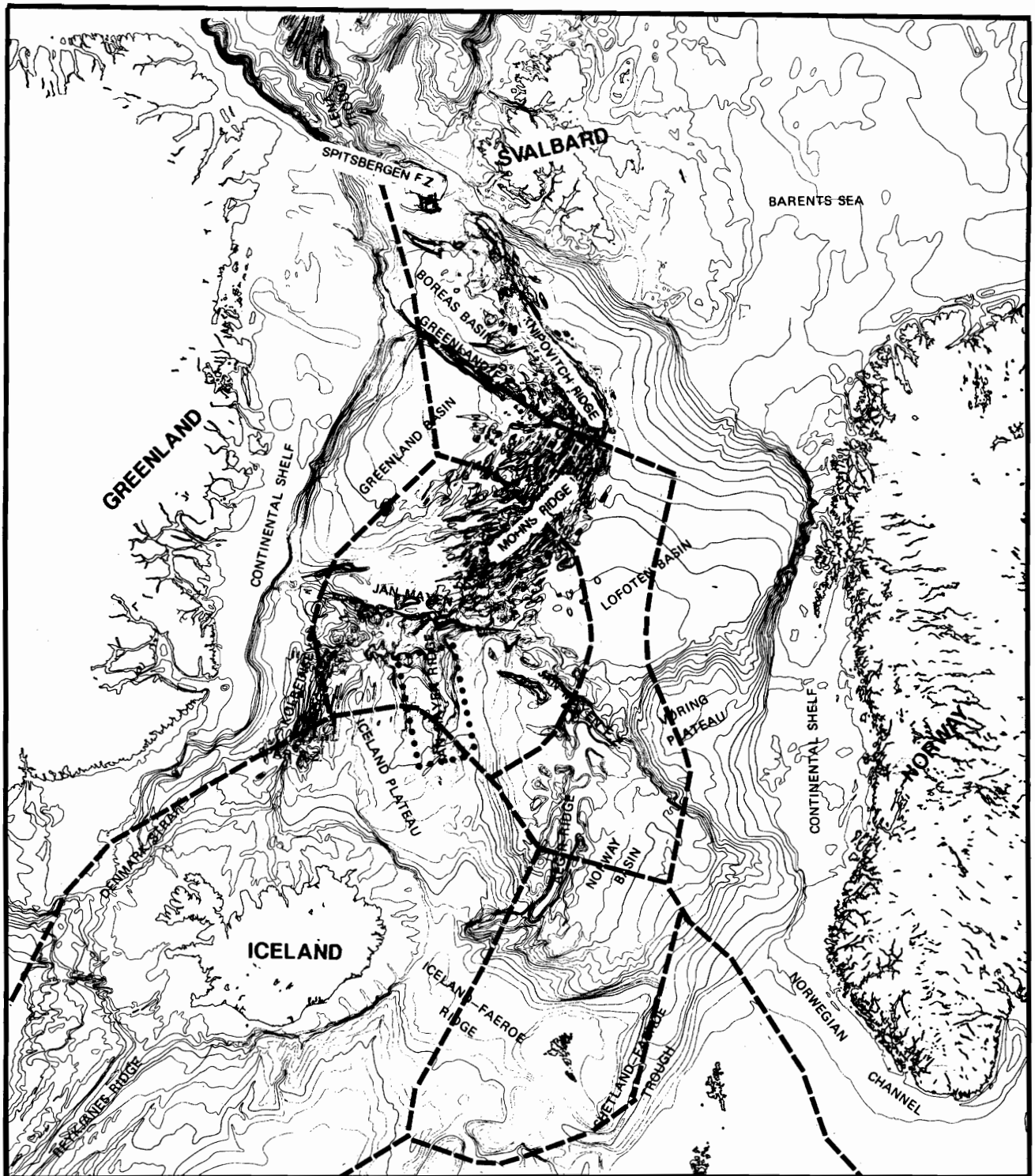
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------ 200 nm. & median lines

•••••• Icelandic - Norwegian Treaty - area

Fig. 1.1 . Bathymetry and political boundaries in the Norwegian - Greenland Sea.
Approximate continental shelf boundaries are shown with broken lines.
Location of the Icelandic - Norwegian treaty area on the Jan Mayen Ridge stippled.
Bathymetry from Perry et al (1980).

1.2 THE JAN MAYEN RIDGE 1985 SEISMIC SURVEY

1.2.1 DATA ACQUISITION

A survey plan was set up by NPD and NEA early 1985. In anticipation of weather and technical problems lines on three priority-levels were planned, totalling some 5000 km. Most lines were planned with normal 7-8 seconds recording time and shot-intervals of 25 m. Some lines with 15 seconds recording time and shot-intervals of 50 m were included in order to increase the understanding of basement-structure and the deeper crust. A number of seismic companies were invited to submit bids for the acquisition of data according to this plan which was incorporated into NPD's total data-acquisition programme for the season. It was decided to use GECO's vessel Malene Østervold for the survey.

The survey lasted from July 17 to August 31, with a break in the period 13-18 August for crew-change and shooting of a proprietary survey for NEA north of Iceland. A total of 4236 profile-km were shot, out of which 247 km were reshot because of faulty control of shot intervals. Figs. 1.2 and 1.3 and App. 4a show the location of the lines.

The navigation used during the survey was primarily LORAN-C, backed up by GPS and Transit satellite navigation when available. The seismic equipment included an airgun-array with a total volume of 3564 cubic inches, a 3 km long 120 channel streamer, and a DFS-V recording system. A more thorough description of the acqusition parameters is given in Appendix 2.

Gravity and magnetics were recorded during the whole survey. A Lacoste-Romberg gravimeter was used. The recovery of gravimetric measurements was 100 %. Magnetics were recorded with a Geometrics G801 instrument. It did not function during shooting of lines 19, 20, 21 and 22.
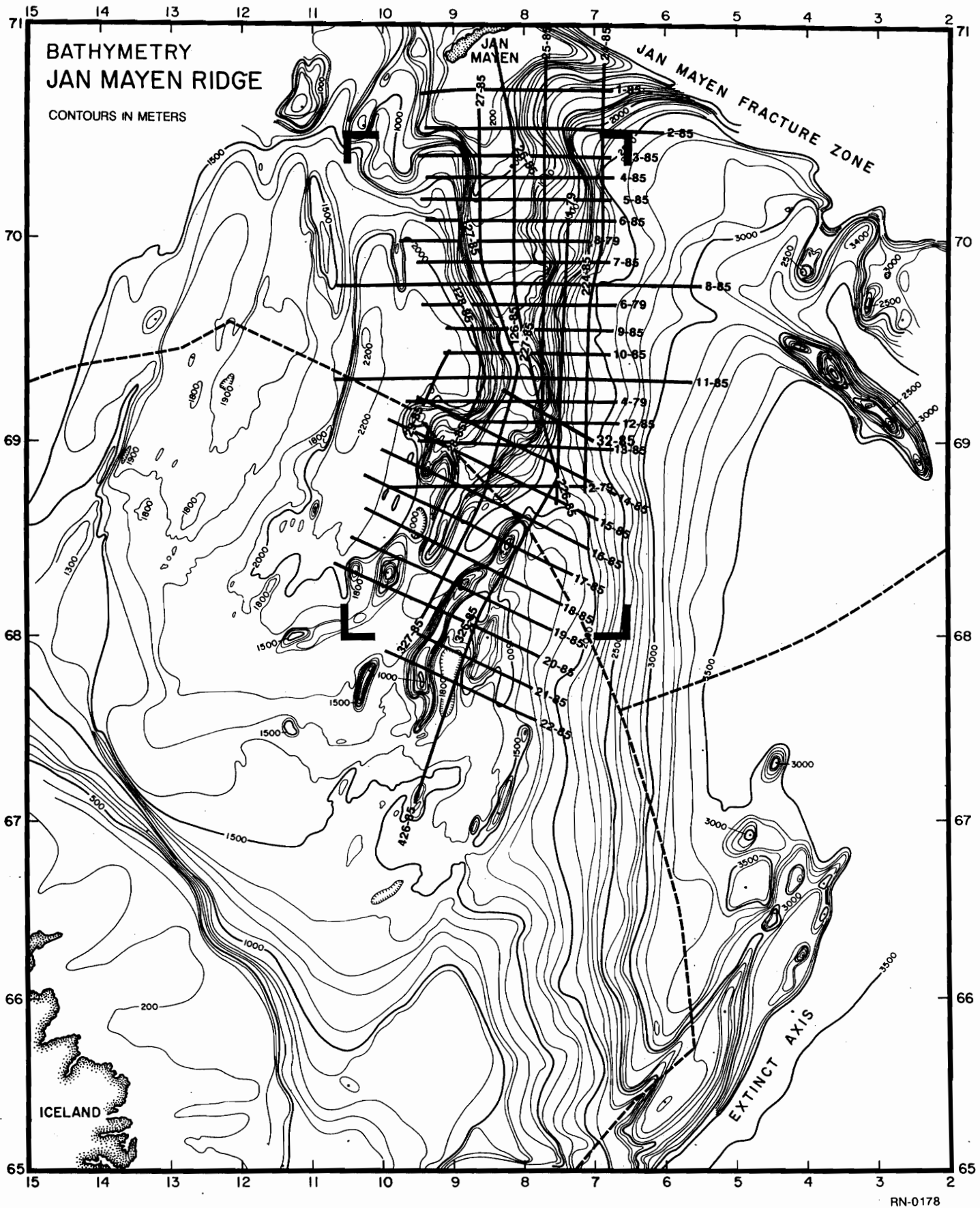
Fig. 1.2 Geophysical survey grid on the Jan Mayen Ridge acquired by NPD and NEA in 1985, and by NPD in 1979. Bathymetry from Richardson et al. (1981).
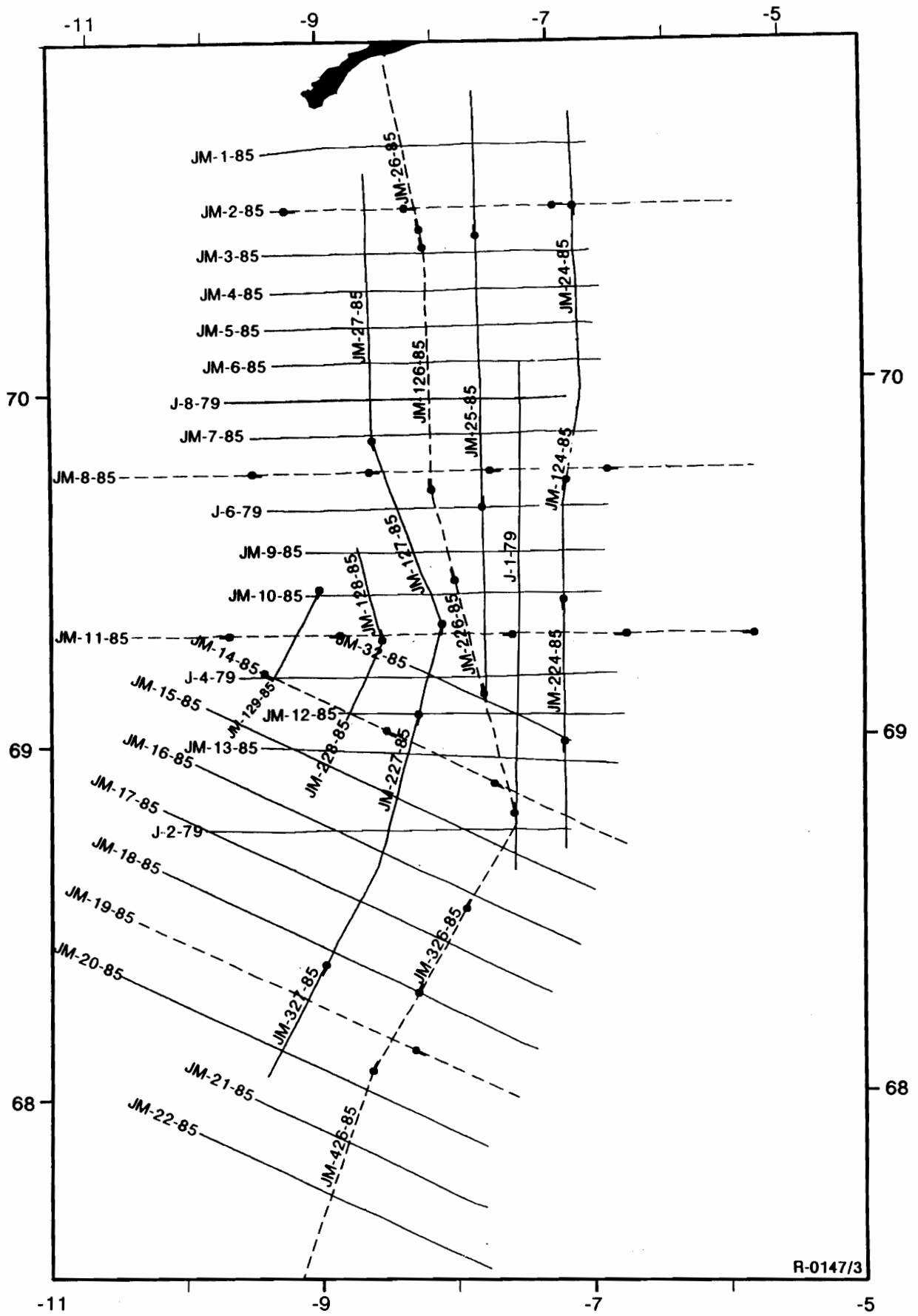
Fig. 1.3 Seismic reflection grid and sonobuoys acquired on the Jan Mayen Ridge by NEA and NPD in 1985, and by NPD in 1979.

Of 44 sonobuoys that were deployed for refraction seismic
registration during the survey, 38 worked satisfactorily.
They were all recorded both in analog and digital form.
Their location is shown in Fig. 1.3 (App. 4a).

The Final Field Operation Report from GECO, and the
Supervision Report from the hired client's representative
(Delph Management Ltd), are both available, and give full
information on technical equipment, and on the daily
operations.

1.2.2 DATA PROCESSING

Seismics

The seismic companies were invited to submit bids for
processing of the acquired seismic data. After evaluation
of prices, six companies were invited to do processing
tests on the data-set. Based on the results, GECO A/S,
Sandvika, was awarded the processing contract. An initial
timeschedule for the processing agreed on by both parties
was set up in February 1986. According to the schedule the
work was to be completed in September 1986. GECO proved to
be unable to comply with the schedule, causing delay also
of the interpretation of the data. Delivery of the final
seismic sections took place in October 1987.

The objective of the processing was to obtain good overall
data-quality. No specific horizons or levels were
optimized at the cost of others. Suppression of multiples
was the most difficult problem to cope with. FK-multiple
attentuation and weighted stack proved necessary. For
noise-reduction and data-reduction nmo-corrected summation
of every two adjacent traces in the shot gathers was
carried out. Remnant noise was attenuated with a post-stack
FK-filter. Seismic data from the area acquired and
processed by NPD in 1979 were post-stack reprocessed to
make them more comparable with the 1985-vintage data.

Generally the final data-set is of good quality, giving better resolution and penetration than earlier seismic investigations in the area.

Appendix 2 gives a description of the processing sequence. The available Processing Report gives full information on tests and evaluations during the processing.

Gravity/Magnetics

The gravimetric and magnetic data were processed by GECO A/S. No specific problems arose during the processing. Digital recordings at a temporary landbase (Tjørnes) in northern Iceland were used as a control of the variability of the magnetic field. The data were all integrated with the dataset acquired by NPD in the area in 1979. The final product consists of profiles in horizontal scale 1:50.000, plotted to match the migrated seismic sections (in 1/2 scale), and maps (contoured and annotated) in scales 1:500.000 and 1:250.000 of waterdepth, free-air-anomalies, Bouguer-anomalies and magnetic anomalies.

1.2.3 SALES OF DATA

All data have been offered for sale to relevant companies/institutions. The offer includes filtered and migrated seismic sections in full, half and squashed scales, together with gravity/magnetics profiles and maps. Both 1979 and 1985 vintages are included in the sales. In order to keep the companies entry costs relatively low the data-set was divided into two parts. The basic package, intended to give a regional overview of the area, consists of 1800 profile-km and is priced at NOK 995.000,-. The other package contains the rest of the data, 2800 profile-km, priced at NOK 1.450.000,-. The letter offering the data for sale is included as Appendix 3. Till October 1989 only Statoil has bought the basic package.

2 GEOLOGY OF THE JAN MAYEN RIDGE

2.1 BACKGROUND

2.1.1 PHYSIOGRAPHY OF THE JAN MAYEN RIDGE

The Jan Mayen Ridge (JMR) is a bathymetric ridge complex
extending southwards from the Jan Mayen island (Fig. 2.1).
The ridge complex is thought to be composed mainly of
continental crust, but can be transitional in nature where
it is broken up and subsided. We also loosely use the
term JMR to denote this geological entity, the Jan Mayen
microcontinent.

The ridge can be divided into two main structural elements,
a northern and a southern part. The northern part, here
referred to as the North Ridge, is a prominent flat-topped
ridge that extends southwards from the young volcanic
island Jan Mayen. Water-depth over the top of the North
Ridge increase towards the south, and is close to 1000 m
over much of its southern half. This ridge is terminated by
a NE-SW trending depression, the Jan Mayen Trough.
Oceanographers often use the term Jan Mayen Ridge for this
northern ridge only.

To the south of the trough is a complex of minor ridges,
that becomes subdued and indistinct towards the south. This
part of the ridge is referred to as the Southern Ridge
Complex. The ridges rise up to 1000 m depth from the
surrounding plain that is some 1500 to 2000 m deep. These
ridges gradually disappear to the south, and are buried in
young sediments and lava as Iceland is approached.

On the east side of the JMR is the Norway Basin, about 3500
m deep, extending to the continental margin of Norway. The
area to the west of the ridge is generally called the
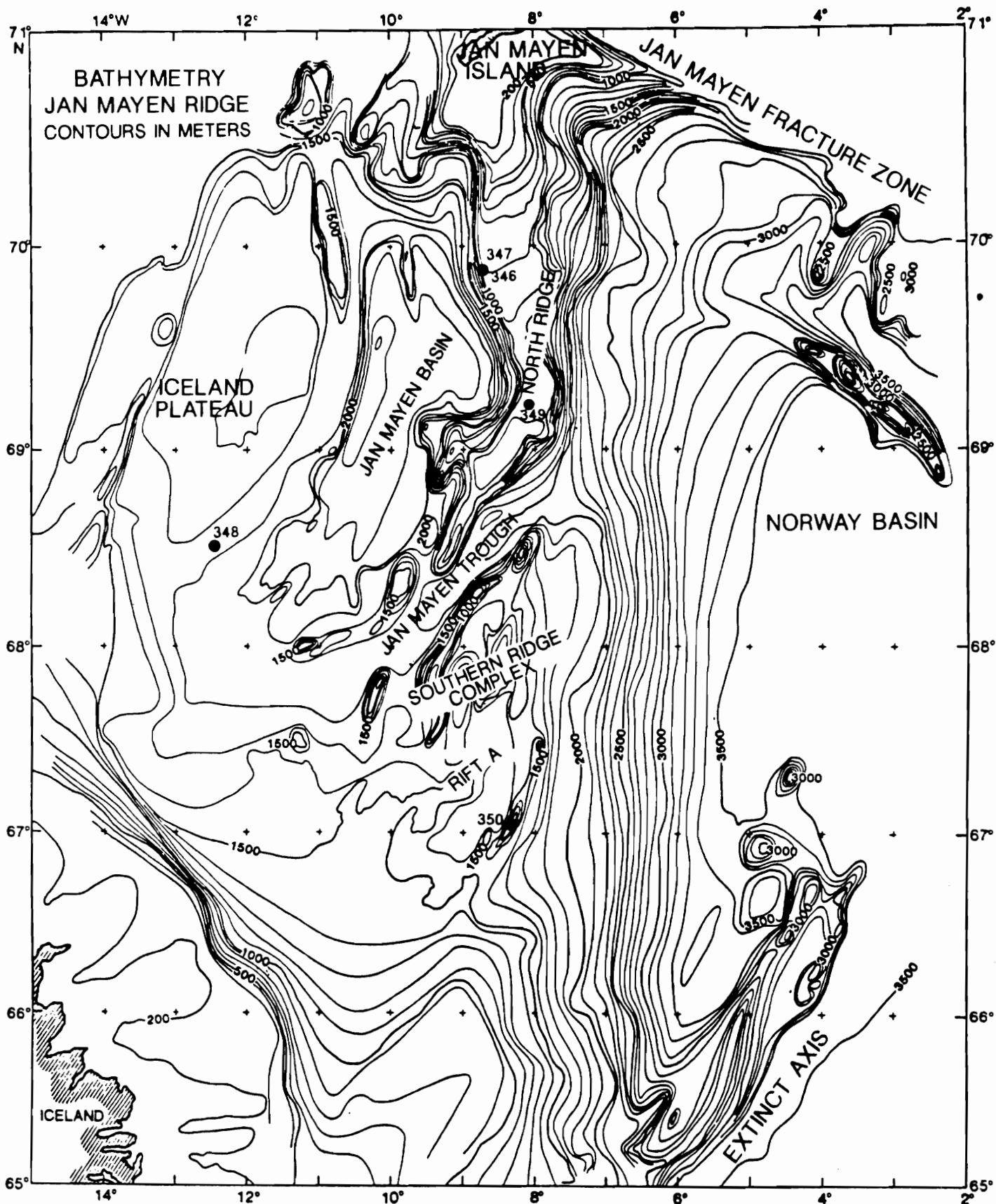
FIG. 2.1 Bathymetry of the Jan Mayen Ridge (from Richardson et al. 1981)

DSDP sites shown by dots and numbers.

Iceland Plateau, and is considerably shallower than the eastern basin, typically some 1500 m deep. The area just west of the North Ridge forms a distinct flat-bottomed depression, called the Jan Mayen Basin, with depths just exceeding 2000 m. The Iceland Plateau terminates to the west at the active spreading ridge called Kolbeinsey Ridge, but some writers use the term Iceland Plateau for a wider area extending westwards to the continental shelf of Greenland and including also the southern JMR area.

2.1.2 EARLIER GEOPHYSICAL INVESTIGATIONS

The Jan Mayen Ridge has been rather extensively studied compared to the rest of the North-east Atlantic. The academic interest in this area has been truly multi-national. American, German, Soviet, French, British and Norwegian institutions and universities, have conducted surveys and experiments in the area. In the early phase of investigation, considerable amounts of single channel seismic data were aquired, together with magnetic and gravity data (see e.g. Johnson and Heezen, 1967, Talwani and Eldholm, 1977, Grønlie and Talwani, 1978). Especially the cruises of the Vema and Conrad from the Lamont-Doherty Geological Observatory contributed a great deal to the understanding of the area.

The second phase of investigation of the JMR and the surrounding ocean basins consisted principally of a number of regional surveys, using the multi-channel seismic reflection method. The multi-channel cruises or projects that have included the JMR are (Fig 2.2):

- Cepan 1 Cruise 1975: A cruise by French institutions, also referred to as the CNEXO-data (Gairaud et al. 1978). A considerable amount of fair quality data in and around the entire JMR area. Includes magnetics.

- <u>Bundesanstalt fur Geowissenschaften und Rohstoffe 1975 and 1976 surveys</u>: The project is referred to as "Geoscience Studies in the North Atlantic" (see Hinz and Schluter, 1979, and Garde, 1978). A few lines of relatively good quality. Access to the data is not open.
- <u>Shackleton 1977 cruise</u>: University of Durham (see Nunns 1980 and Pelton 1985). Later reprocessed by Institute of Oceanographic Sciences.
- <u>University of Bergen 1978 survey</u>: A cruise of the Håkon Mosby, mainly on the northernmost part of the JMR (see Sundvor et al, 1979).
- <u>Conrad 1978 cruise(C2114)</u>: A project of the Lamont-Doherty Geological Observatory. This cruise included an expanding spread seismic experiment on the northern JMR. (See Olafsson, 1983, and Johansen et al, 1988)
- <u>NPD 1979 survey</u>: A reconnaisance survey of the North Ridge. This survey was the first step by the NPD to investigate the area by the seismic reflection method (see Eggen, 1984)
- <u>NPD-NEA 1985 survey</u>: The Norwegian-Icelandic survey which forms the main database for this report.
- <u>University of Oslo 1987 survey</u>: A cruise of Håkon Mosby, concentrated on areas east of JMR, but with two profiles located on the eastern part of the North Ridge.

Surveys in the area using other methods than multi-channel seismics are:

- <u>Project Magnet Aeromagnetic survey</u>: This large scale survey by the US Naval Oceanographic Office of the entire Iceland Plateau includes the southern and western parts of the JMR area. Line spacing are 5.5 and 11 km (see Vogt et al., 1980).
- <u>NPD aeromagnetic survey 1976</u>: Commisioned by the NPD and carried out by Compagnie Generale de Geophysique. Consists of a 5 by 15 km grid on the main JMR, totalling 11 620 km. (See Navrestad and Jørgensen, 1979).
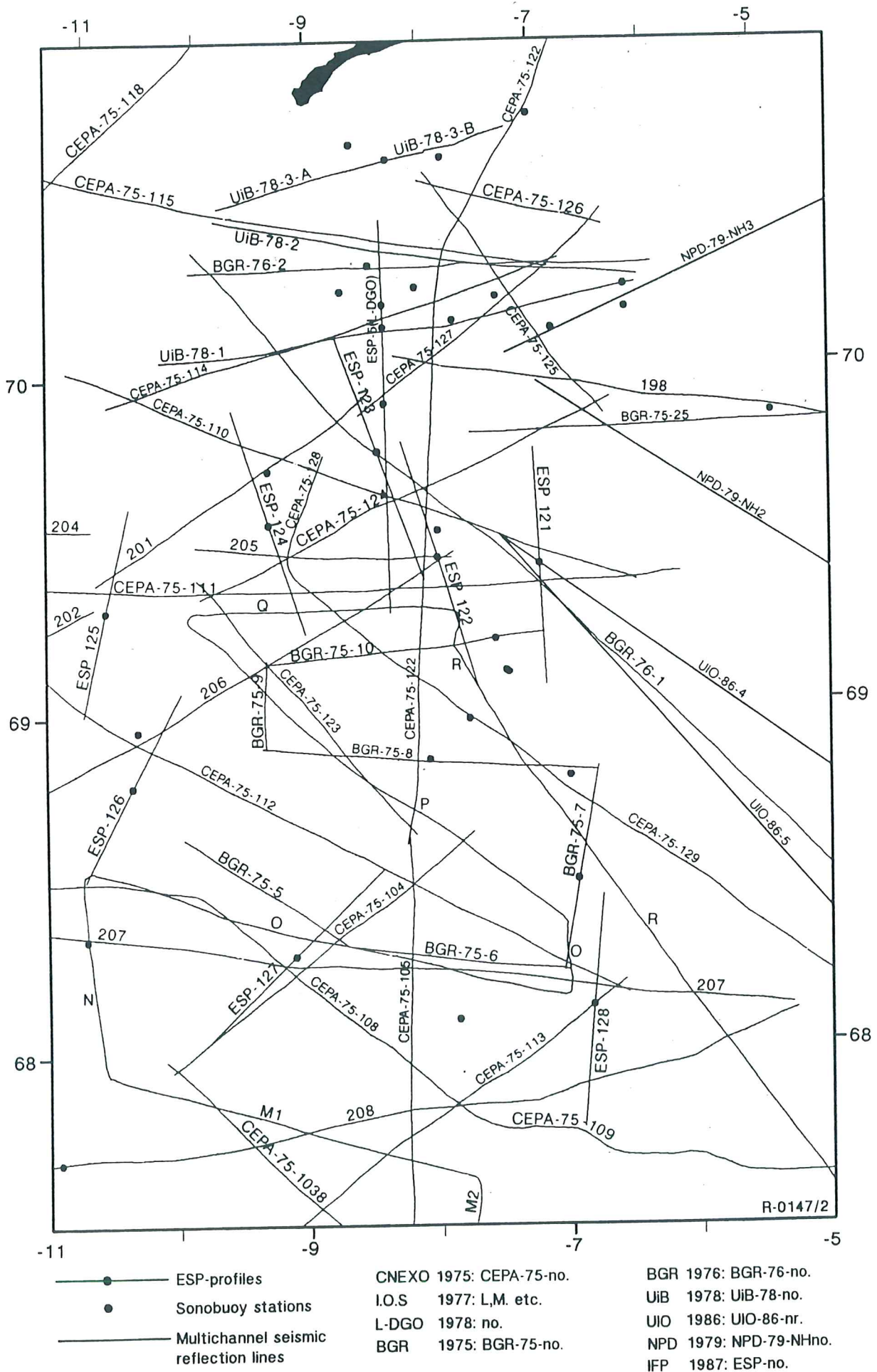
Fig. 2.2 Multichannel seismic reflection and refraction data acquired on the Jan Mayen Ridge by academic institutions 1975-87

- University of Hamburg, 1984 (Arktis II/5): A seismic
refraction study of the JMR, employing ocean bottom
seismometers and explosives (Weigel et al. 1986)
- University of Hamburg, 1987: A continuation of the 1984
project based on use of ocean bottom seismometers.
- IFP 1987 survey: Institut Francais du Petrole carried out
a seismic refraction study. A series of Expanding Spread
Profiles were measured, to obtain better understanding
of the crustal structure by velocity observations.
The data are being interpreted at the University of Oslo.

The earlier data represented a combined data base of
considerable quantity. It was anyway evident that the
uneven distribution of lines and variable and often
unsatisfactory quality of the data required a systematic
reflection survey of the most likely hydrocarbon
exploration area. This was the basis for the NPD-NEA survey
in 1985.

2.1.3 RESULTS OF DSDP-DRILLING

The only boreholes on Jan Mayen Ridge and its vicinities
were drilled during leg 38 of the Deep Sea Drilling Project
(DSDP) in 1974 (Talwani, Udintsev et al. 1976). 18 holes
were drilled in the Norwegian-Greenland seas, of which 5
holes, numbered 346-350, were drilled at or near the Jan
Mayen Ridge (Figs 2.1 and 2.6). Sites 346, 347 and 349 were
drilled on the North Ridge, site 350 was drilled in the
Southern Ridge Complex, and site 348 on oceanic crust on
the Iceland Plateau. Table 2.1 lists the positions,
waterdepths and penetration of the boreholes.

Table 2.1: DSDP boreholes in the Jan Mayen Ridge area
drilled during leg 38 in 1974.

Hole	Latitude		Longitude		Water-depth	Penetration
	Deg	Min	Deg	Min	(m)	(m)
346	69	53.35N	08	41.14W	732	187
347	69	52.31N	08	41.80W	745	190
348	68	30.18N	12	27.72W	1763	544
349	69	12.41N	08	05.80W	915	320
350	67	03.34N	08	17.68W	1275	388

The lithologies and inferred ages of the penetrated rocks
are summarized in Fig 2.3. Holes 347 and 348 are not
included because they were respectively drilled very close
to hole 346, and relatively distant from the Jan Mayen
Ridge. Hole 348 penetrated 527 m of sediments, before
bottoming in basalts. The sediments were mainly mudstones,
partly sandy mudstones containing mainly cold-water fauna.
Age determinations show Pleistocene at the top, to the
Miocene/Oligocene transition at the bottom. The age of the
tholeiitic basalts seems to confirm this age for the
creation of the basaltic basement. Hole 350 at the
southeastern rim of the Jan Mayen area also bottomed in
basalts after penetrating 346 m of mainly mudstones and
sandy mudstones. A relatively thin Pleistocene-Miocene
section is underlain by Oligocene and Late Eocene
sediments, with well developed turbidites towards the base.
The basalts bottoming the hole were normal tholeiites with
an indicated age of 40-44 m.y. - in accordance with the
paleontological dating of the overlying sediments.

The three holes drilled on the North Ridge proper (346,347
and 349) have important common traits. They were
(unintentionally) all drilled shortly west of a main down
to the west normal fault, and thus not optimally positioned

to reach as deep stratigraphic levels as was technically
feasible (Fig 2.4). Accordingly they all penetrate only
sediments of a Pleistocene - Late Eocene age, and
encountered a main unconformity at depth about 120 m below
seabottom. The top sediments of the holes 346 (347 was
drilled close to 346) and 349 are of Pleistocene/Pliocene
age, and have "glacial" origin, containing supposedly
icerafted material. A second unit, of Middle Miocene -
Late Oligocene age is identified. Its main lithologies are
muds and sandy muds with occasional layers of volcanic ash.
Below the main unconformity at 120 m depth Late Eocene
sediments are found, consisting of bioturbated mudstones
and sandy mudstones. In lower parts turbidites are
abundant.

In hole 346 the sandcontents of the lower unit is generally
about 30%. Above it sandcontents are generally below 20%.
In hole 349 an interval right above the main unconformity
has sandcontents above 50%. So has an interval at about
150 m depth. All other samples show sandcontents below 20%
in this hole. In hole 350 relatively few measurements of
sandcontents was done, giving results in the interval
0,5-35% sand (Cameron 1978).

Additionally some analyses of the organic geochemistry of
the cores from DSDP leg 38 have been done. These are
reported on in chapter 3.1.1.

Fig 2.3   Lithostratigraphy of DSDP-sites 346, 349 and 350.
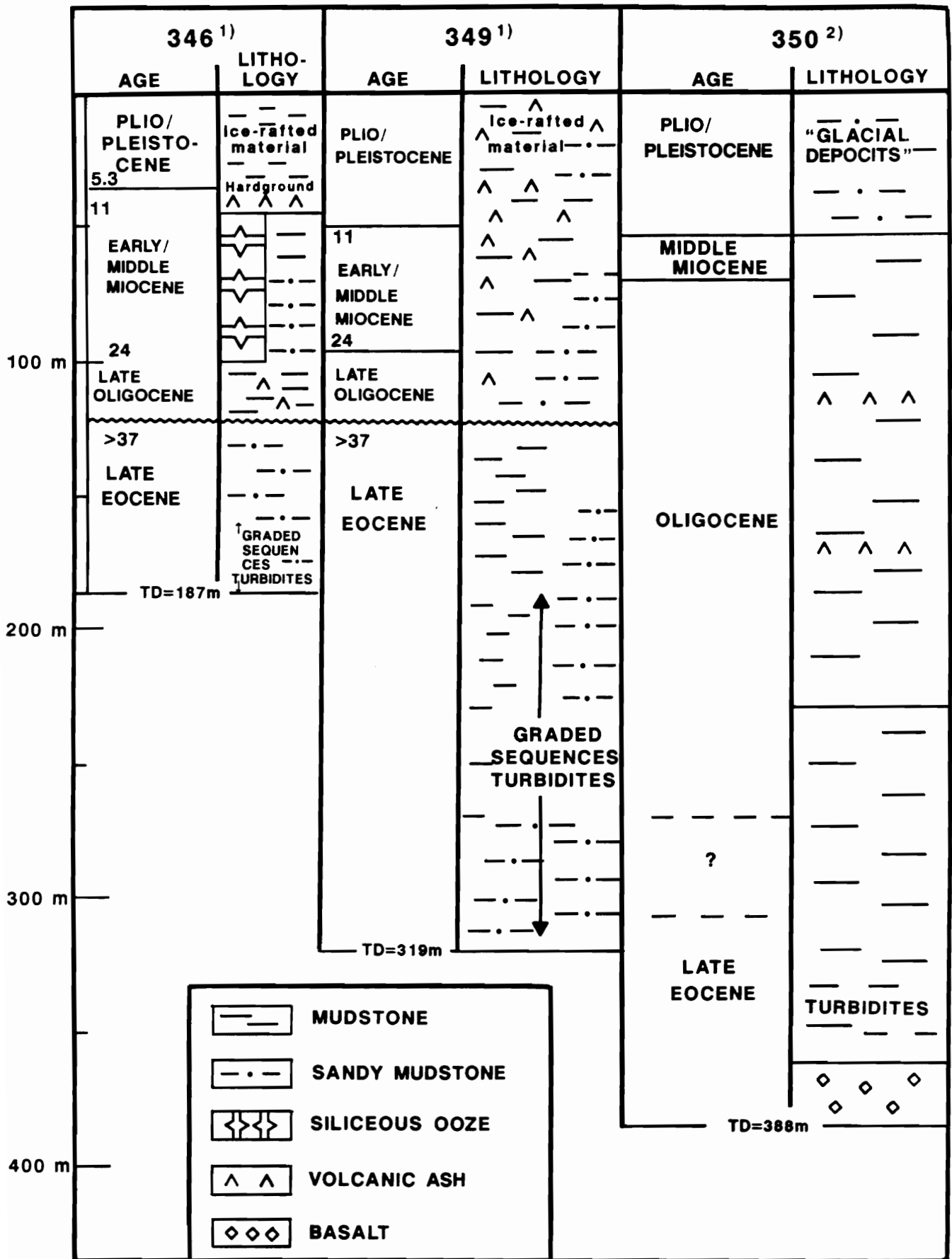
1) Haak & van Hinte (in press)

2) Talwani, M., Udintsev, G. et. al., 1976

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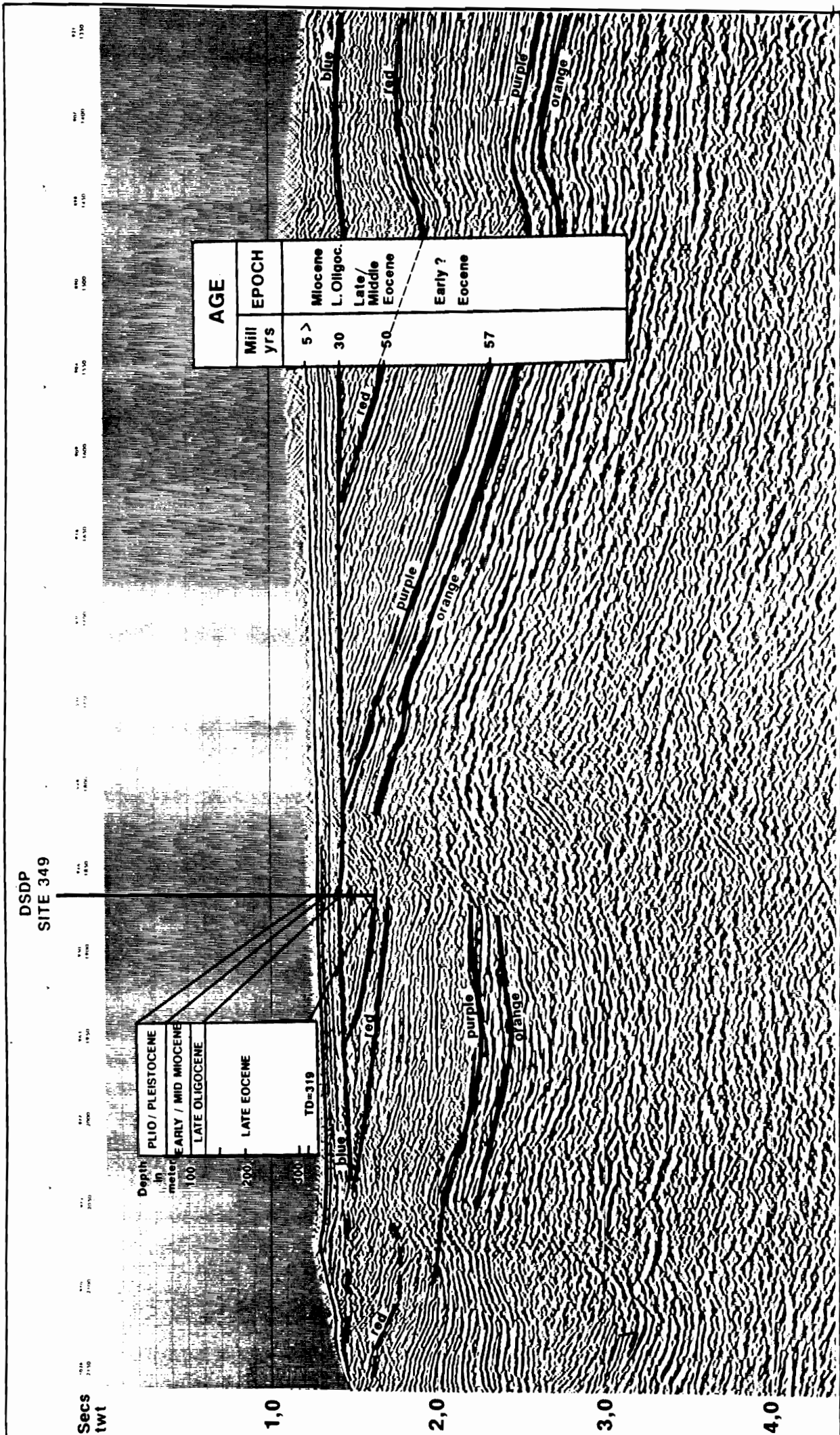
Fig 2.4   Interpretation of a part of seismic line JM-32-85, through DSDP site 349, showing stratigraphic correlation.

2.1.4 PLATE TECTONICS AND GEOLOGICAL REVIEW

Previous studies of the area have concluded that the Jan
Mayen Ridge is likely to be a microcontinent. The Jan Mayen
island and its immediate surroundings is supposed to be of
volcanic origin created by extrusion of abnormal amounts of
volcanic material, while most of the ridge is believed to
be of continental origin, split off and isolated by the
intricate opening history of the Norwegian-Greenland sea.
This is based partly on the geophysical properties of the
ridge (see e.g. Myhre et al. 1984): Gravity modelling on
traverses across the ridge indicates relatively light
material in the ridge, the ridge and its immediate
surroundings are magnetically relatively quiet, and seismic
refraction studies give velocity profiles similar to
measurements made on the East Greenland and Norwegian
margins. Studies of the Tertiary plate tectonic history of
the area also support the assumption that the Jan Mayen
Ridge is a microcontinent. The basic pattern of spreading
history affecting the JMR was already established by
Johnson and Heezen (1967). Talwani and Eldholm (1977)
established a comprehensive model for the opening of the
entire Norwegian-Greenland Sea, that has later only been
modified or challenged in regard to details.

The initial opening of the Norwegian-Greenland sea took
place east of the Jan Mayen Ridge about the time of the
transition Paleocene/Eocene, probably at the time of the
reverse magnetic epoch between the normal anomalies 24 and
25. This age is about 57 Ma according to the time scale of
Berggren et al. (1985), which is consistently used in this
report. After a phase of normal parallel spreading until
the time of anomaly 22 (52 Ma) according to Skogseid and
Eldholm (1987) or anomaly 20 (45 Ma) according to Nunns
(1983a), during which the Jan Mayen Ridge only existed as
the outermost part of the continental margin of East-
Greenland, a phase of irregular spreading began. A new rift
or spreading axis was activated west of the Ridge, and

sliced it off from the Greenland margin, while the older axis to the east (the Aegir Axis) remained active. Figure 2.5 illustrates the spreading history.

When these two rifts had formed east and west of the JMR, a small crustal plate consisting of the Jan Mayen microcontinent and the attached western half of the oceanic crust of the Norway Basin, began to rotate counterclockwise, causing spreading rates in the Norway Basin to be greater in the north than the south. This phase of two spreading axes continued until the time of anomaly 7 (26 Ma). Evidence for this period is found in the Norway basin, where the magnetic anomalies show a fan-shaped pattern, widening out to the north. Rigid plate geometry demands a similar fan-shaped pattern to the west, opening up to the south, to compensate for this irregularity. Such anomalies have not been observed, and the area formed by this spreading is not well defined. It is assumed that the

Figure 2.5 (see next page)
Reconstruction in four stages of the opening of the NE-Atlantic in the vicinity of the Jan Mayen Ridge (modified and simplified from Nunns 1983a). a) At the time of the beginning of anomaly 24 (56 Ma), which is the oldest detectable magnetic anomaly between Greenland and Europe. Spreading began shortly before this time. b) End of anomaly 20 time (45 Ma). At this time the spreading on the Aegir axis in the Norway Basin, originally normal, had developed into fan shaped spreading, complementary spreading was beginning between Greenland and the Jan Mayen Ridge. This led to counterclockwise rotation of the Jan Mayen microcontinent away from Greenland. c) End of anomaly 7 time (26 Ma). Spreading in the Norway Basin is finally extinct, and regular spreading being established on the Kolbeinsey Ridge west of the Jan Mayen Ridge. d) Present. Note that anomaly 5 (10 Ma) is indicated on the Kolbeinsey and Reykjanes Ridges.

Legend:

JMR: Jan Mayen Ridge
- - - spreading axis
——— transform fault

⣿ oceanic crust
from anomly 24 to 20

▨ oceanic crust
from anomaly 20 to 7
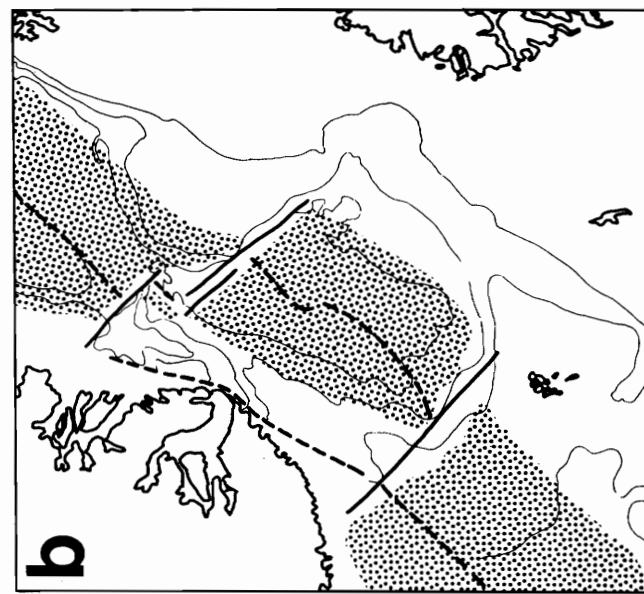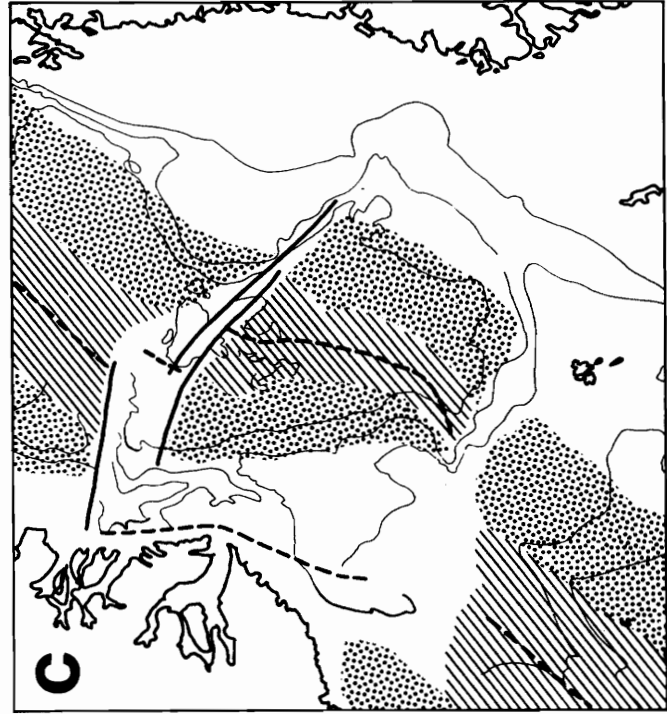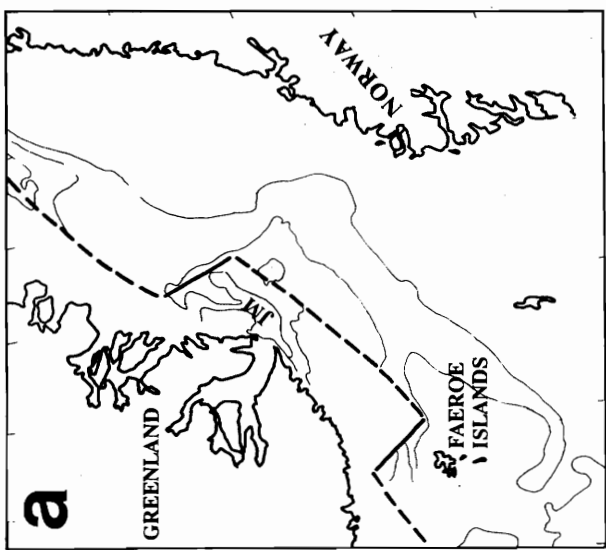
Fig 2.5

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mode of spreading in this area did not give rise to
identifiable anomalies. Talwani and Eldholm (1977) point to
parts of the Southern Ridge Complex. Nunns (1983 a,b)
considers that the complementary spreading took place to
the west of the ridge. Larsen (1988) expresses a similar
view, and suggests a northwards propagation of the
Kolbeinsey Ridge spreading axis over a period of time,
together with a parallel termination of spreading on the
Aegir Ridge. Crustal extention in the Jan Mayen Ridge area
could also have taken up some of the spreading, but this is
less well understood.

This abnormal phase ended when spreading ceased in the
Norway basin, and only the western spreading axis remained
active. According to Talwani and Eldholm (1977) this
happened at the time of anomaly 7 (26 Ma), when a now
extinct spreading axis, the Iceland Plateau Axis, took over
all spreading activity, until a further westward jump of
the axis initiated the now active Kolbeinsey Ridge. Vogt
et al. (1980) are of the opinion that this intermediate
axis did not occur but that the Kolbeinsey Ridge has been
active from the start. The above mentioned variations in
opinion of the detailed spreading history of these oceans
do not lead to basically different models for the
tectonic history of the JMR.

A geological map of the area (Fig 2.6) shows the areas of
assumed continental origin surrounded on all sides by
oceanic crust of varying age. On both sides of the ridge
are strips of crust that are of uncertain composition.
Interpreted seismic lines (Fig 2.7) show typical cross-
sections of the Ridge in two locations. The North Ridge has
a characteristic cross-section, tilted down to the east,
and with distinctly asymmetric flanks. The eastern flank is
only mildly affected by faulting, and the Tertiary
sedimentary wedge and the accoustic basement bear witness
of progressive eastward tilting. The western flank of the
ridge is by contrast formed by extensive normal faulting,

where the movement is down on the western side. Bathymetric maps and seismic sections show a complex pattern of fault blocks that have subsided to varying degree into the Jan Mayen Basin.

The ridges of the Southern Ridge complex (Fig 2.7) are mostly NNE-trending, partially surrounded by the flatlying opaque basement reflector of the western volcanic region, which is found in structurally low areas. Many attempts have been made to unravel the structural complexities of this part of JMR. Talwani and Eldholm (1977) recognized 6 ridges, partially on the basis of gravity anomalies, and denoted them as R1-R6. They considered some of them to be continental in origin, but the SE-corner of the area to be oceanic.

Horizon O (Fig. 2.7) represents a reflector at the base of the Tertiary sedimentary succession that is supposed to be composed of lava extruded shortly before the ocean-basin started to form. It was opaque on all vintages of seismic data up to the NPD 1979-survey (Eggen 1984), so previous authors have not discussed the pre-Paleocene/Eocene history of the ridge based on seismic reflection data.

2.1.5 THE CONJUGATE MARGINS

The post-Caledonian history of the area beetween Greenland and Norway is generally speaking characterized by tension. A rifting process was initiated in Late Carboniferous/ Early Permian and ended with seafloor-spreading and the creation of a deep ocean basin - the Norwegian-Greenland Sea - in Early Eocene. The accompanying faulting and vertical movements have created lateral facies changes and hiati/erosional phases that are not known in detail. As we have no direct observations of pre-Palecene/Eocene lithology
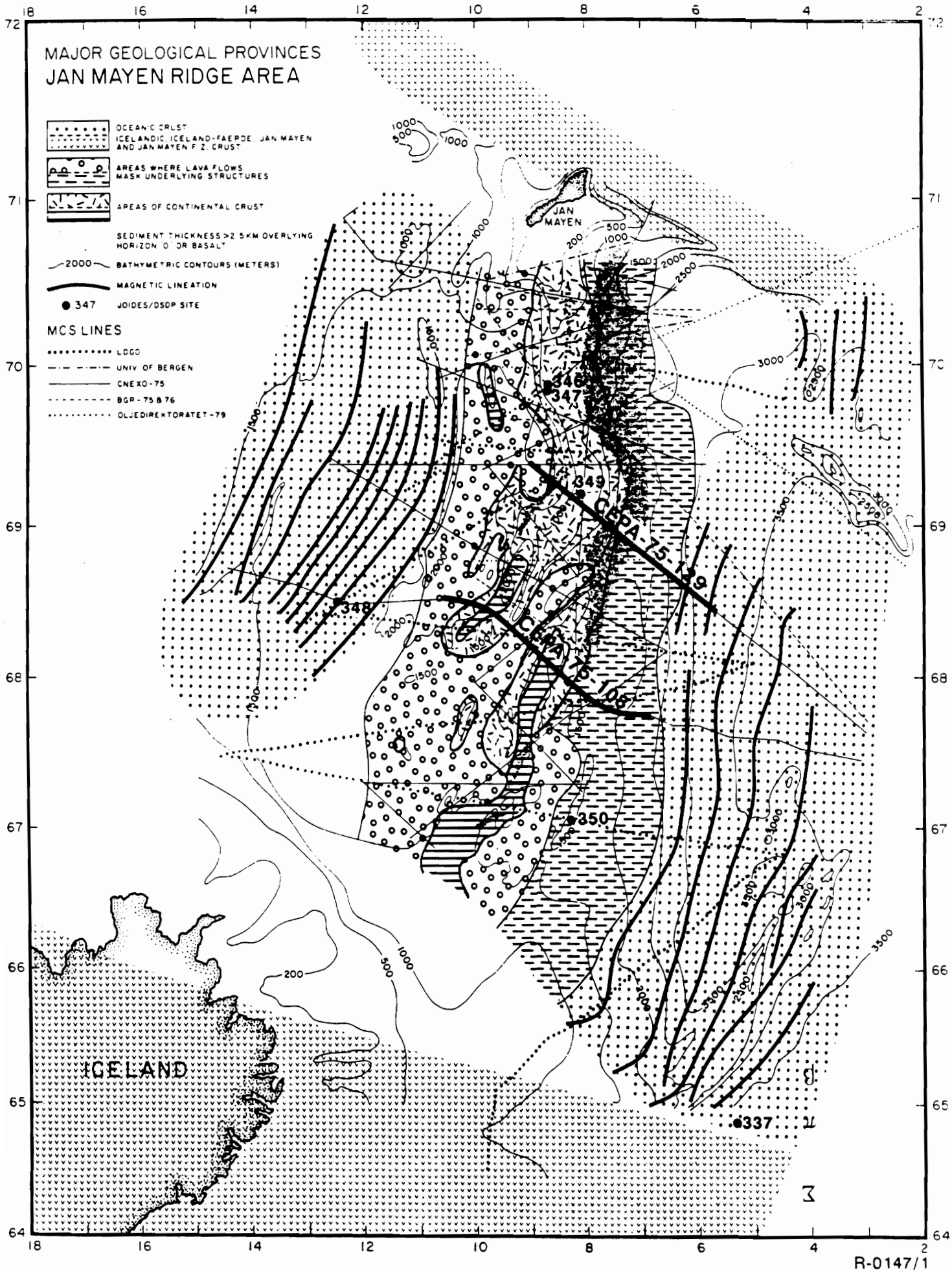
Fig 2.6 Geological map of the Jan Mayen Ridge area. From Richardson et al. (1981).
An interpretation of profiles CEPA-75-108 & 129 is shown in Fig. 2.7
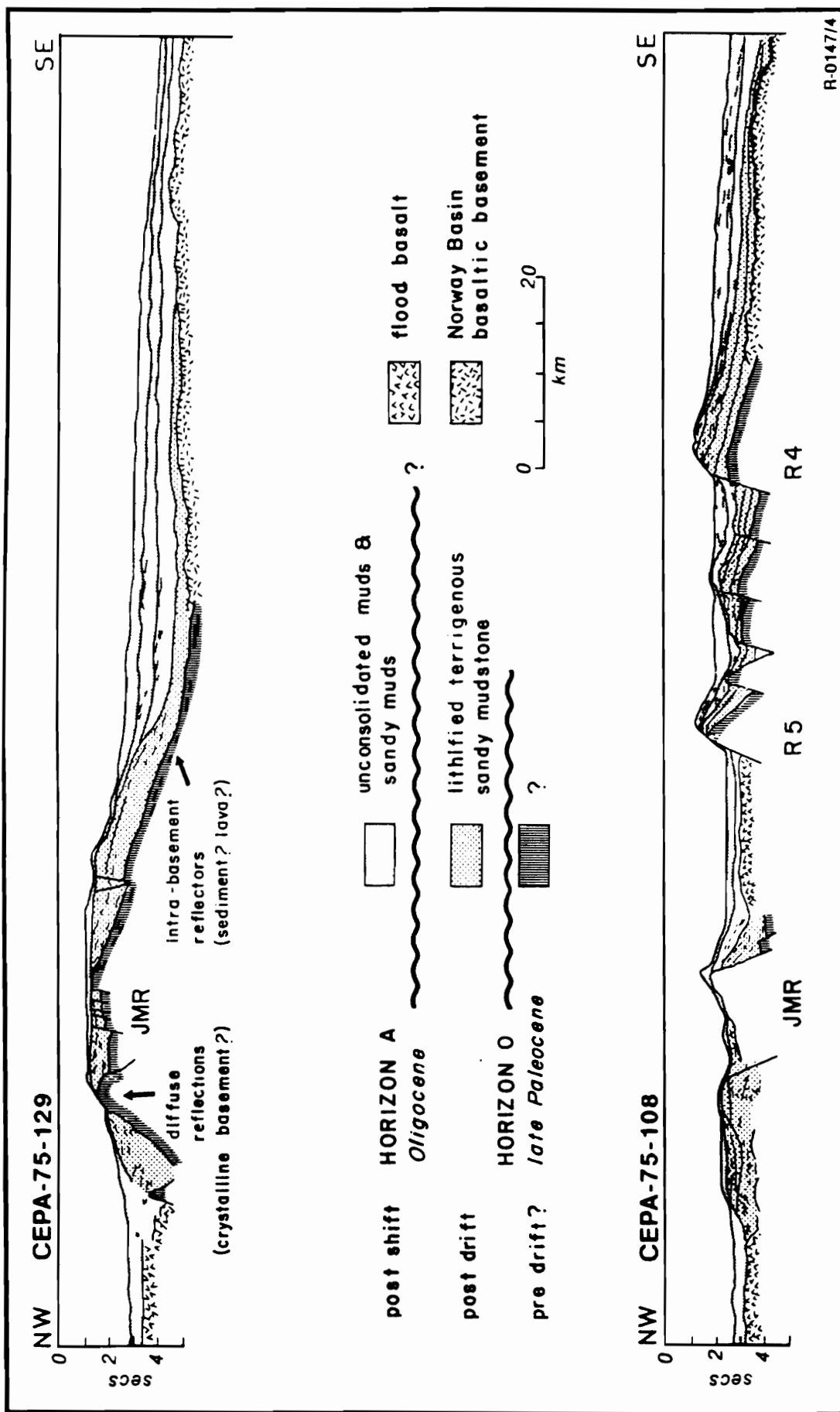
Fig.2.7 - Interpreted seismic profiles CEPA-75-108 and 129 crossing the North Ridge (JMR) and the Southern Ridge Complex. Profile locations in figures 2.2 and 2.6. The sediment lithologies and ages are based on drilling at DSDP Sites 346, and 349 on the North Ridge . (Nunns 1983b, modified from Gairaud et al 1978).

lithology in the area between Haltenbanken and East-Greenland the best we can do is to assume a sedimentary sequence with parallells to the flanking shelf- and on-shore sediments.

Palinspastic reconstructions show the pre-rift position of the Jan Mayen microcontinent. There are slight differences in the positioning suggested by different authors, but the general picture is agreed upon (Figs. 2.5 and 2.8).

On the Greenland side (for a geological review see e.g. Surlyk et al. 1981, 1984 and 1986, and Larsen 1984) the microcontinent was lined up along the Blosseville Coast and Liverpool Land. On the Blosseville coast early Tertiary subaerial lavas of thickness up to several km cover a thin, patchy layer of sediments of Late Cretaceous/Paleocene age resting upon Precambrian basement. Liverpool Land is a horst containing Precambrian rocks, lying just seaward of an extensive area of the post-Caledonian Jameson Land basin, containing Devonian-Cretaceous sedimentary rocks. This basin continues further north along the Greenland coast (Fig 2.8). Larsen (1984) interprets seismic data offshore Liverpool Land, and concludes that fault-blocks of Mesozoic or older age underlie large accumulations of Tertiary sediments.

On the Norwegian side (for a geological review see e.g. Bøen et al. 1984, Brekke and Riis 1987, Bukovics et al. 1984 and Skogseid and Eldholm 1989) the microcontinent was bordered to the north by the Jan Mayen Fracture Zone and Vøring Basin, to the east by the Faeroe-Shetland Escarpment and the Møre Basin. Both these neighbouring basins were subjected to large-scale Cretaceous subsidence. Sediments have been mapped in patches on the Norwegian mainland (Devonian basins in Western Norway), and on Andøya, while extensive mapping offshore based on seismics and borehole information, has uncovered that the shelf is totally covered with post-Caledonian sediments (Fig 2.8). Very

little is known about the pre-Early Triassic stratigraphy on this part of the Norwegian shelf.

This results in three basic alternatives for the lithostratigraphy of the pre-opening rocks at the Jan Mayen Ridge:

1) a thick Paleocene, mainly volcanic, deposit as on the Blosseville Coast
2) thick deposits of Cretaceous age as on the outer parts of the Norwegian shelf
3) mainly a Jurassic and Triassic sequence with a stratigraphy comparable to the inner parts of the conjugate margins.

The seismic reflectivity and velocity structure of the deeper parts of the ridge established in this study indicates that at least parts of the ridge contain a pre-Cretaceous sedimentary section. It is however impossible to predict with any certainty the lithologic column below the Early Tertiary basalt. The stratigraphy and main tectonic phases of the relevant parts of the conjugate margins are shown in Fig 2.9, to indicate probable pre-Tertiary sediments, and thereby source/reservoir combinations that could be found on the JM-microcontinent.
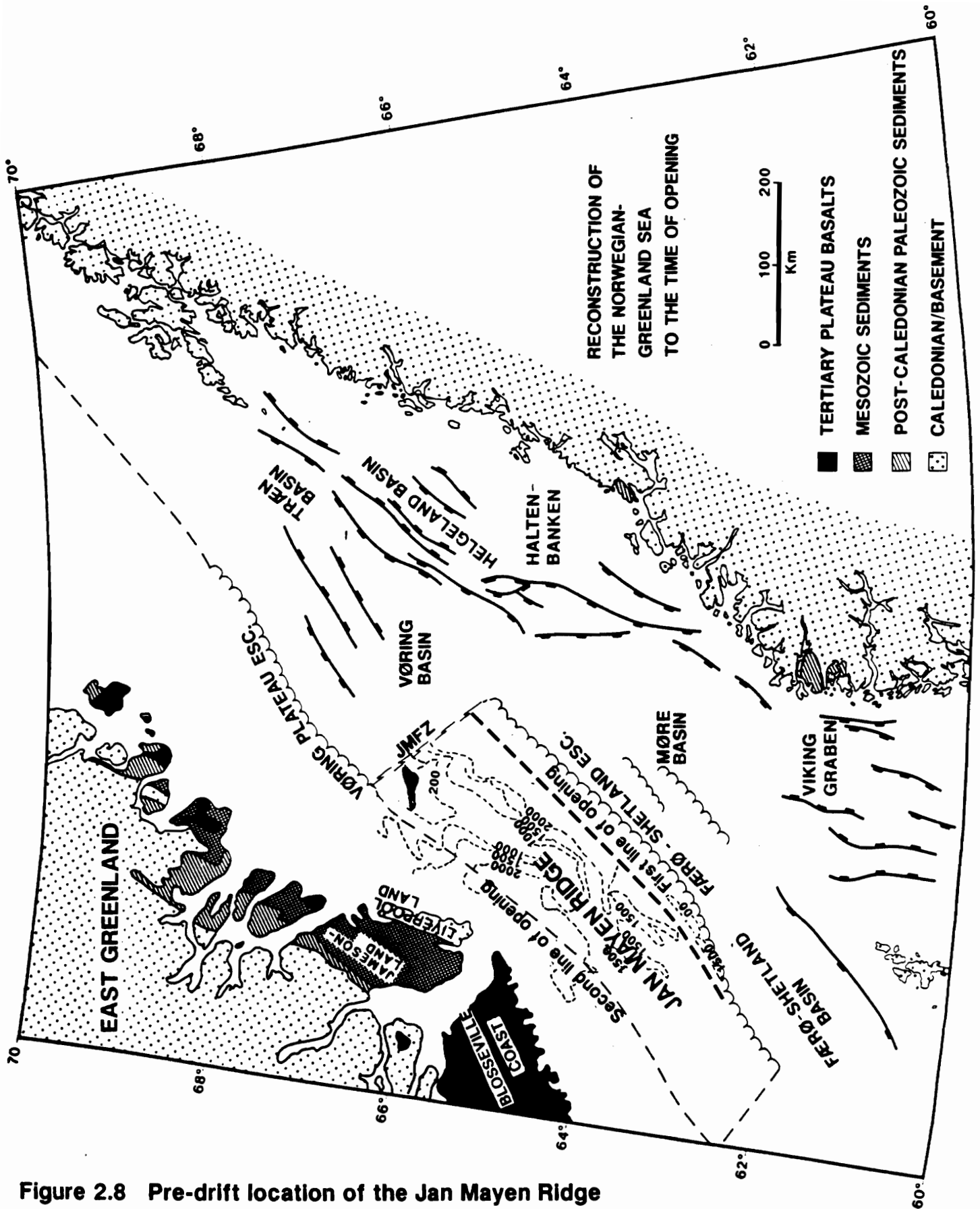
Figure 2.8 Pre-drift location of the Jan Mayen Ridge relative to Greenland and Norway. Onshore geology and structural elements offshore shown schematically.

RECONSTRUCTION OF
THE NORWEGIAN-
GREENLAND SEA
TO THE TIME OF OPENING

■ TERTIARY PLATEAU BASALTS

▨ MESOZOIC SEDIMENTS

▨ POST-CALEDONIAN PALEOZOIC SEDIMENTS

☐ CALEDONIAN/BASEMENT

0   100   200
Km

EAST GREENLAND

TRÆNA BASIN

HELGELAND BASIN

HALTEN-BANKEN

VØRING BASIN

VØRING PLATEAU ESC.

JMFZ

MØRE BASIN

VIKING GRABEN

FÆRØ-SHETLAND ESC.

FÆRØ-SHETLAND

BLOSSEVILLE COAST

JAN MAYEN RIDGE

JAMESON LAND

LIVERPOOL LAND

First line of opening

Second line of opening

200

1500

1500

1000

1500

2000

2000

2000

R-0147/5

Fig 2.9

Generalized litostratigraphic columns for the Haltenbanken area offshore Mid-Norway and Jameson Land in Central East Greenland. Major tectonic events and potential source and reservoir levels are indicated.

Table: Chronostratigraphy / Main Tectonic Phases / Generalized Lithostratigraphy

CHRONOSTRATIGRAPHY				MAIN TECTONIC PHASES		GENERALIZED LITHOSTRATIGRAPHY			
				HALTEN-BANKEN 3)	E.GREENLAND 2)	HALTEN-BANKEN NORWEGIAN SHELF 1)		SOURCE/RESERVOIR INTERVALS	JAMESON LAND EAST GREENLAND 2)
TERTIARY		MIOCENE				NORDLAND	KAI		
		OLIGOCENE				HORDALAND	BRYGGE		
		EOCENE							
		PALOCENE				ROGALAND	V-JARE V / TANG		
CRETACEOUS	LATE		MAASTRICHT			SHETLAND	SPRINGAR		
			CAMPANIAN				NISE		
			SANTONIAN				KVITNOS		
			CONIACIAN						
			TURONIAN			CROMER KNOLL	LYSING	(R)	
			CENOMANIAN						
	EARLY		ALBIAN				LANGE		
			APTIAN						
			BARREMIAN						
			HAUTERIVIAN				LYR	(R)	HESTEELV
			VALANGINIAN						
			RYAZANIAN		T			(R)	RAUKELV
JURASSIC	LATE		VOLGIAN			VIKING	SPEKK	S	HAREELV
			KIMMERIDGIAN				FROGN	R	OLYMPEN
			OXFORDIAN						
	MIDDLE		CALLOVIAN				MELKE		VARDE
			BATHONIAN			FANGST	GARN	R	KLØFT
			BAJOCIAN		T		NOT	S	
			AALENIAN				ILE		
	EARLY		TOARCIAN			BAT	TOFTE ROR	R	NEIL KLINTER
			PLIENSBACHIAN				TILJE		
			SINEMURIAN				ARE	S	KAP STEWART
			HETTANGIAN					R	
TRIASSIC	L		RHAETIAN				GREY BEDS		FLEMING FJORD
			NORIAN				RED BEDS		
			CARNIAN				UPPER SALT		
	M		LADINIAN				LOWER SALT		GIPS DALEN
			ANISIAN		T			S	PINGO DAL
	E		SCYTIAN					R	
PERMIAN	LATE						?	R/S	
					T			R	
	EARLY				T				
					T				GURREHOLMDAL / MESTERS VIG
CARBON.	LATE								

Legend:

- MUDSTONE/SHALE
- HIGHLY RADIOACTIVE SHALE
- SILTSTONE
- SANDSTONE
- CONGLOMERATE
- DOLOMITE
- LIMESTONE
- MARL
- GYPSUM
- SALT
- VOLCANIC ASH
- COAL

R-0068:2

1) Dalland, Worsley & Ofstad. 1988
2) Surlyk, Piasecki & Rolle. 1986
3) Brekke & Riis. 1987

2.2 TECTONIC PHASES

The short outline of the tectonic history of the Jan Mayen Ridge presented here, is based on the new results obtained in this study integrated with earlier results.

In Late Paleozoic and Mesozoic times, the Jan Mayen Ridge was located in the western part of the regional system of post-Caledonian rift basins between Greenland and Norway (Fig. 2.8). The ridge was established as a separate structural entity in the Tertiary as a result of two main tectonic events (Figs. 2.5 and 2.10):

1) The opening of the Norway Basin in the earliest Eocene, when the ridge still remained as a part of the Greenland continental margin, and

2) The separation of the ridge from Greenland through rifting and formation of a new spreading centre on the Greenland margin in the period from middle Eocene to the end of Oligocene.

Both events led to the formation of a passive rifted margin (Figs. 2.11 and 2.12). In the first event, a volcanic margin was formed on the eastern side of the ridge. In the second, a blockfaulted margin, to a lesser degree affected by volcanism, was formed on its western side. As the margins developed, each went through a rift phase, characterized by crustal extension, magmatism and initial isostatic adjustment, followed by breakup and a drift phase characterized by thermal subsidence and sediment loading. Because of the short time interval between the two events, the thermal structure and vertical movements resulting from the first event were strongly modulated by the second event.

The syn- and post-opening history may be divided into four phases of tectonic development by rift onset and breakup at

the two margins (Figs. 2.10 and 2.19)

First rift phase

The eastern volcanic margin was formed as the continent rifted on the Greenland side of the wide Jurassic/Cretaceous rift. There is remarkably little evidence for brittle deformation of the upper crust in this phase. The extension, which was accompanied by uplift and regional tilting, was apparently concentrated on a few widely spaced faults. The late rift and early drift stages were accompanied by the emplacement of basaltic dike swarms and subaerial eruption of a voluminous suite of basaltic lavaflows which now covers the ridge.

First drift phase

Breakup was followed by parallel seafloor spreading on the Aegir axis, and thermal subsidence of the margin and the spreading centre beneath sea level as the Norway Basin was formed. Sediments derived from Greenland accumulated at the margin and a paleo-shelfedge was built from the west.

Second rift phase

The western block-faulted margin was formed when a new rift, contemporaneous with the later stages of the Aegir Axis spreading centre, opened from the Iceland hotspot into the Greenland margin and gradually separated the ridge from Greenland. The Jan Mayen microplate was partly rotated anticlockwise and partly deformed between the competing spreading centres. The rifting process broke the earlier continental margin into a complex of rotated fault blocks. Magmatic activity was renewed and a sill complex was emplaced beneath the slope of the eastern margin.

CENOZOIC				STRATIGRAPHIC MARKERS	TECTONICS		
AGE (Ma)	PERIOD	EPOCH	AGE		ICELAND PLATEU	JMR	NORWAY BASIN
	QUATER-NARY	PLEISTOCENE	CALABRIAN			⑤	
		PLIO-CENE L	PIACENZIAN				
5		E	ZANCLEAN		SEAFLOOR SPREADING (PARALLEL)	SUBSIDENCE	
	NEOGENE	MIOCENE	MESSINIAN				
10			L TORTONIAN				
			M SERRAVALLIAN				
15			LANGHIAN				
20			E BURDIGALIAN				
			AQUITANIAN				
25		OLIGOCENE	L CHATTIAN	PINK GREEN BLUE	SEAFLOOR SPREADING (FAN-SHAPED?)	BREAKUP ④	ÆGIR AXIS EXTINCT
30	TERTIARY						
35			E RUPELIAN	TURQUOISE YELLOW		UPLIFT EXTENSION BLOCKFAULTING	FAN SHAPED SEAFLOOR SPREADING
	PALEOGENE	EOCENE	L PRIABONIAN				
40			BARTONIAN				
45			M LUTETIAN		PROPA-GATING? RIFT		
50				RED		③	
55			E YPRESIAN			SUBSIDIENCE	SEAFLOOR SPREADING
		PALEOCENE	SELANDIAN THANETIAN	PURPLE ORANGE		② VOLCANISM RIFTING	BREAKUP
60			L UNNAMED			①	
65			E DANIAN		PRE-OPENING PERIOD		

R-0175

Fig.2.10 Stratigraphy and tectonism at the Jan Mayen Ridge. The chart shows the correlation between phases of seafloor spreading in the Norway Basin and on the Iceland Plateau, tectonic phases at the Jan Mayen Ridge, and the main seismic stratigraphic markers.

As the incipient rift subsided, sediment input to the ridge from the Greenland side was shut off. Parts of the eastern rift flank, which now constitutes the JMR, were uplifted above sea level and eroded extensively. Shortlived submarine fans developed on both flanks of the ridge in response to sediment supply from its exposed top. As the local provenance areas were submerged some time prior to breakup west of the ridge, the ridge complex became sediment starved. At breakup, the basin plains west of the ridge, which lay several hundred meters below sea level, were covered with flatlying basalts. These were either emplaced as voluminous lava flows or as an extensive complex of sills just beneath the seafloor.

Second drift phase

After breakup the JMR continued to subside, driven by cooling and thermal contraction. Sedimentation became increasingly pelagic, but due to the steep slopes created in the second rift phase, gravity flow of sediments continued onto the basin plains from both the eastern and the western slope.

2.3 STRUCTURE

2.3.1 STRUCTURAL STYLE

The Jan Mayen Ridge is a sliver of continental crust bounded by passive rifted margins on both sides. The two margins are markedly different from a structural viewpoint (Figs. 2.11 and 2.12).

The ridge structure is illustrated with a structural map (Fig. 2.13, App. 4B), an isochrone map of reflector Purple, which marks the top of the extrusives covering the ridge (Fig. 2.14, App. 4C), an isopach map of total sediment thickness above the reflector (Fig. 2.15, App. 4F) and a series of interpreted seismic sections (Figs. 2.16 and 2.17, Apps. 5A and 5B).

The eastern margin exhibits few fault defined structures. Pre-opening strata are uniformly tilted or monoclinally flexured towards the Norway Basin. An extensive cover of volcanic extrusives is found west of the oldest seafloor spreading anomaly. A well developed morphological rise is present along the entire margin.

The western margin is characterized by normal faults with large throw down to the west that divide the margin into structural highs and rift basins arranged en echelon. A complex of sills or submarine lava flows covers most of the basins and masks the transition to normal oceanic crust on the Iceland Plateau. The margin is sediment starved and lacks a morphological rise.

Because of the proximity of the lines of breakup of the two margins, the structures formed at the eastern margin are partly overprinted by the structures formed at the western margin. The combination of eastwards tilting and flexuring of the eastern margin with down-to-the-west normal faulting

Legend (on map):

- Transfer fault zone
- Fracture zone
- Magnetic sea-floor spreading anomaly
- Normal fault
- Reverse fault
- Active volcano
- Intrusions
- Pseudo-escarpiment
- Dipping reflector sequence

Geological provinces:

1 Oceanic crust in the Norway Basin
2 Eastern volcanic province
3 Eastern margin continental crust
4 Western margin continental crust
5 Western volcanic province
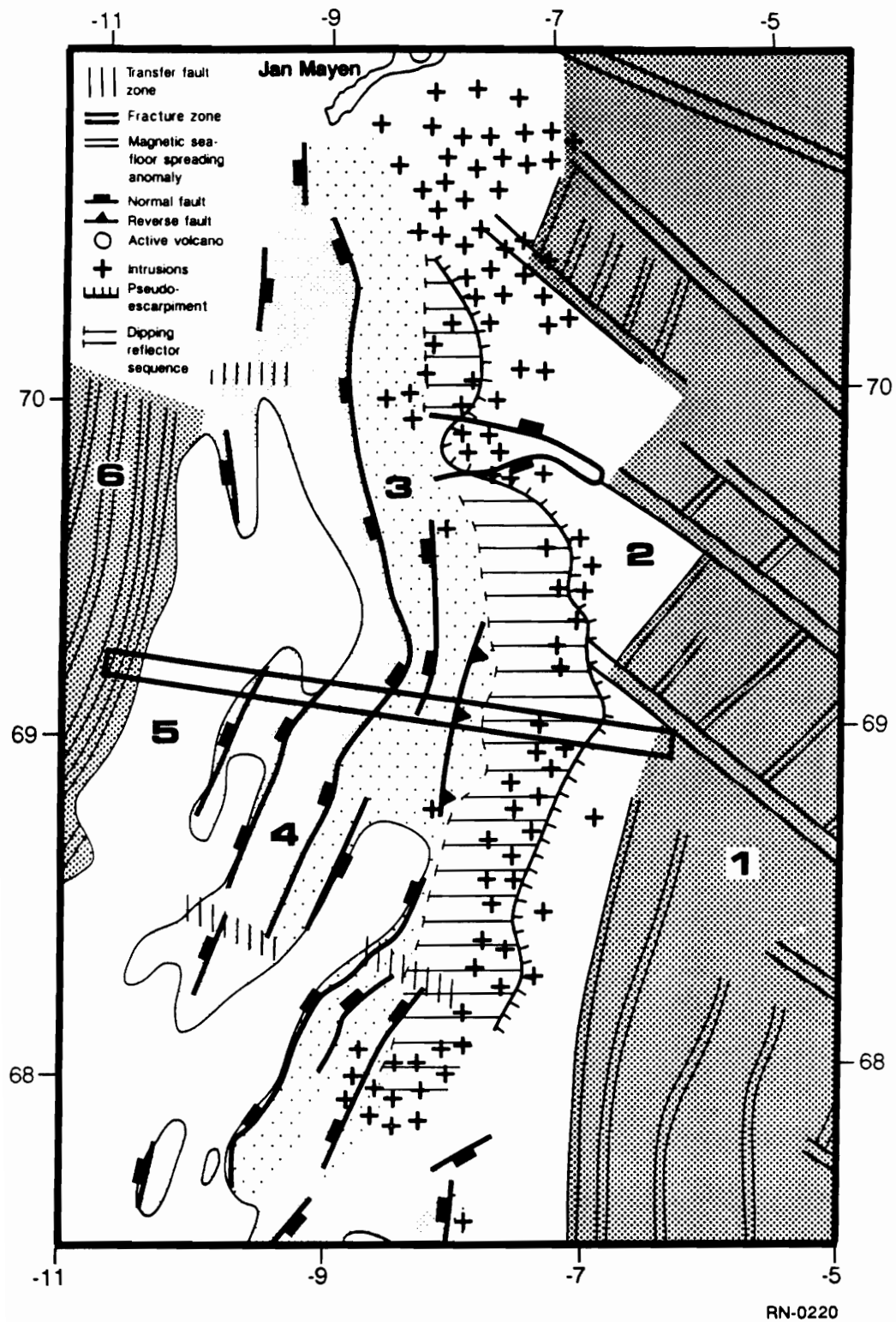6 Oceanic crust on the Iceland Plateau

RN-0220

Figure 2.11 Main geological provinces and structural features of the Jan Mayen Ridge. Bar shows location of generalized cross section in fig 2.12.

Generalized cross section of the Jan Mayen Ridge

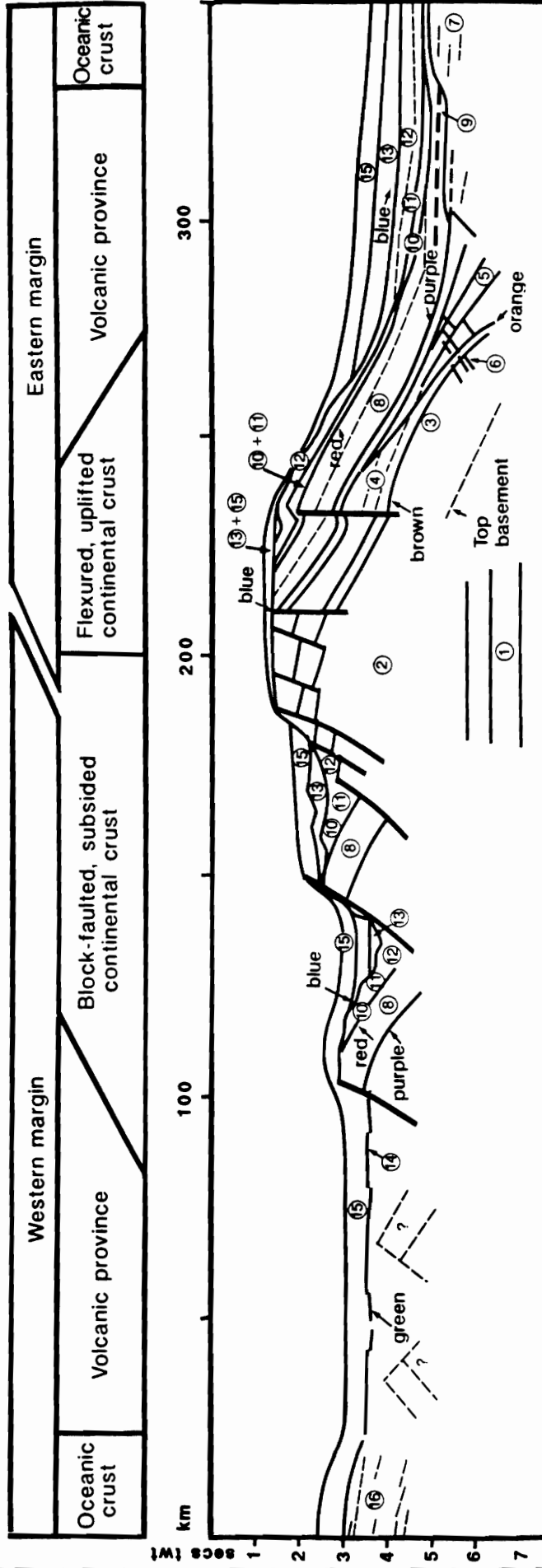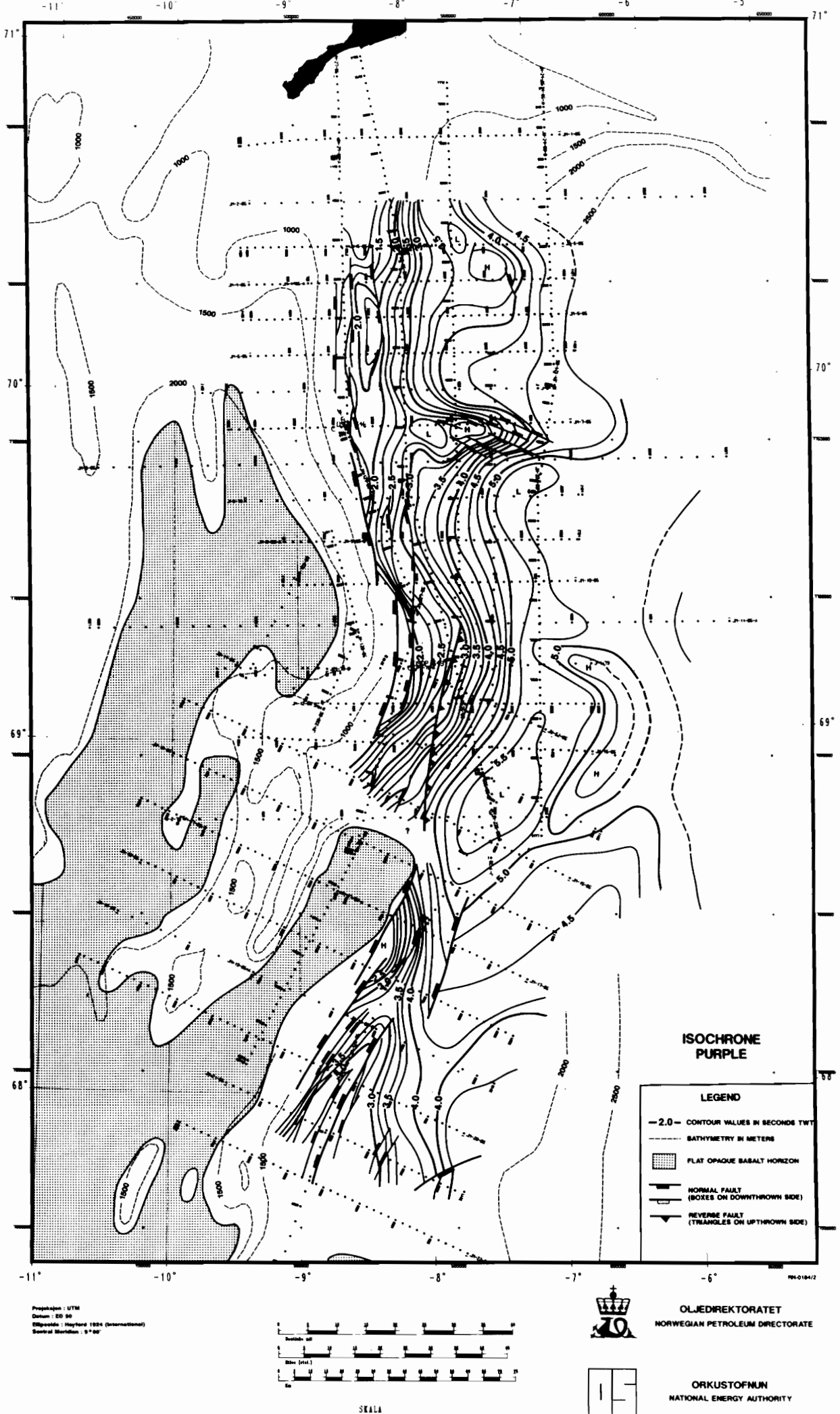Fig 2.12 Generalized cross section of the Jan Mayen Ridge. Location in fig 2.11.

Fig 2.13 Main structual and volcanic features of the JMR.
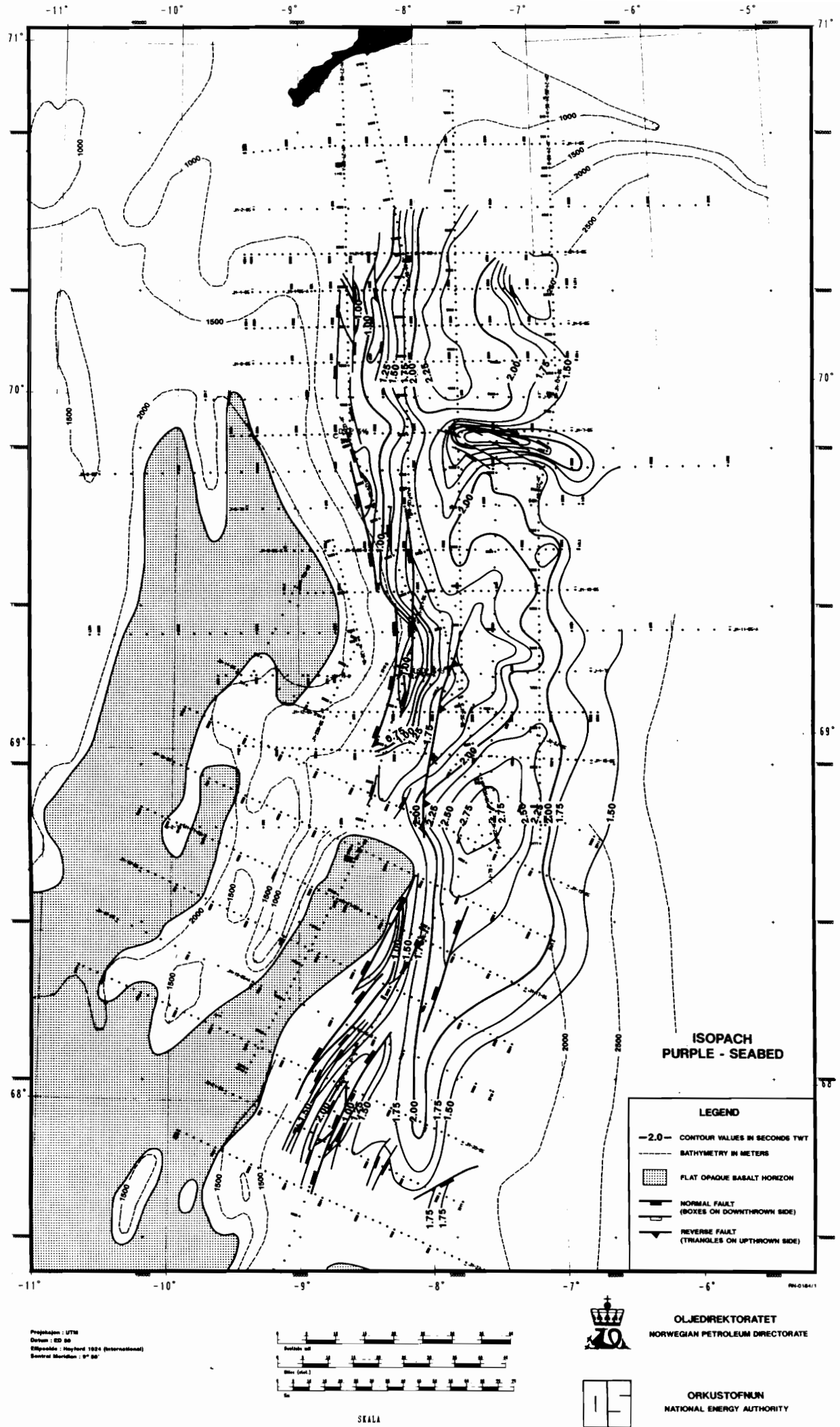
Fig 2.14   Isochrone map reflector Purple

Fig 2.15   Isopach map of total sediment thickness above reflector Purple

and eastwards rotation of faultblocks at the western
margin, imparts a fundamental asymmetry to the cross-
sectional geometry of the ridge.

The complex of faultblocks that make up the ridge defines a
structural axis with a northerly trend. There are
systematic changes in structure from north to south along
this axis. The width of the passive margin doublet, as
defined by the oldest seafloor spreading anomalies on both
sides of the ridge, increases towards the south. This is
also true of the depth to the top of the ridge, the degree
of fragmentation into faultblocks and the amount of
structural overlap between the two margins.

An abrupt change in the orientation of the structural
fabric of the ridge occurs at a prominent bend in the ridge
at 6915N. North of the bend, the average strike of faults
and geological units is about N7W, whereas south of the
bend it is N23E.

Figure 2.16 (see next page)
*Line drawings of four seismic dip lines (JM-4-,-10-,-12-and
-17-85) across the Jan Mayen Ridge. Location of lines shown
on index map.*

Figure 2.17 (two pages ahead)
*Line drawing of a composite seismic strike
line (composed of lines JM-25-, 1226- and 326-85) along the
eastern flank of the Jan Mayen Ridge. Location of line
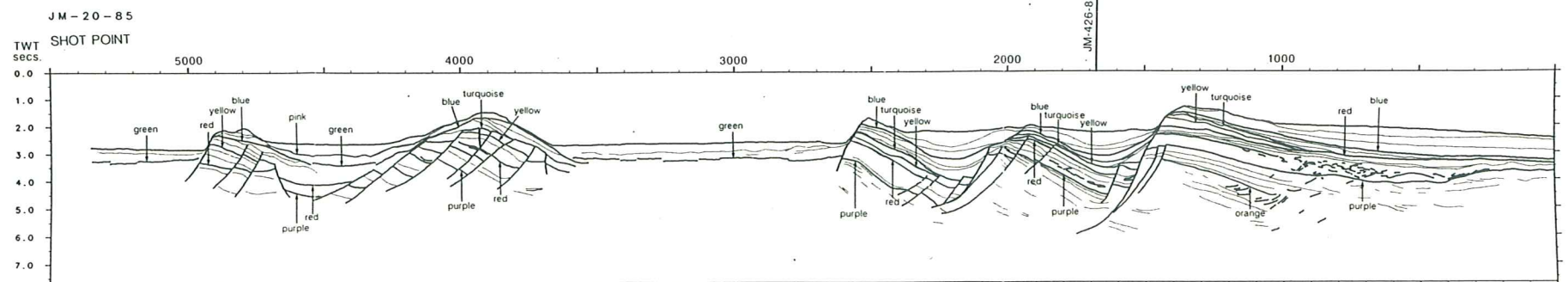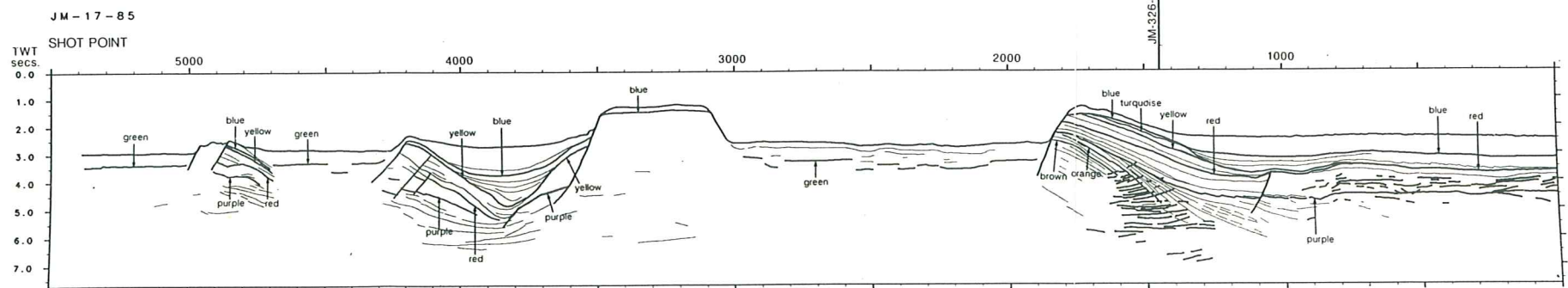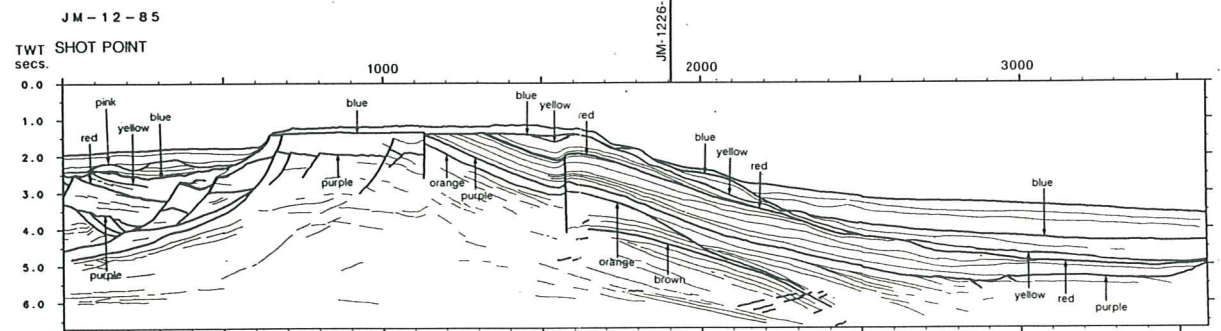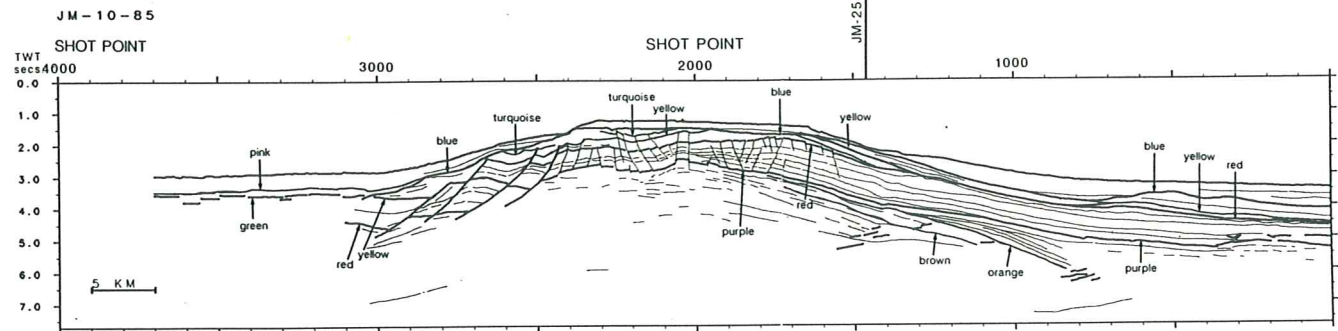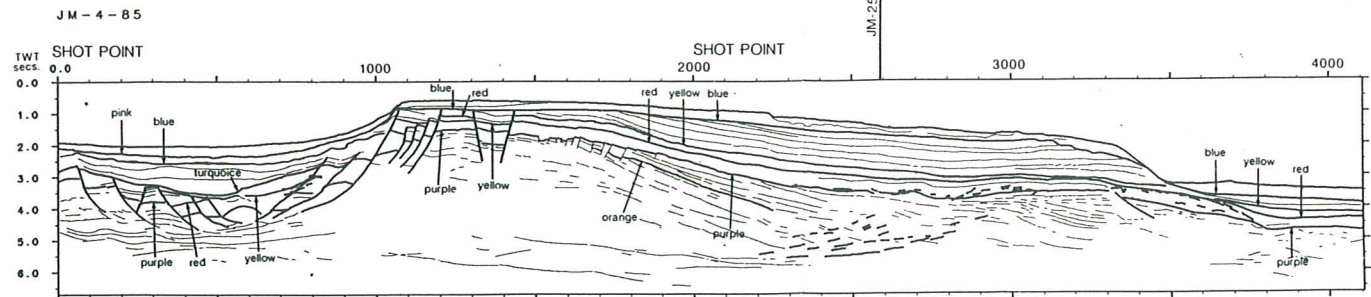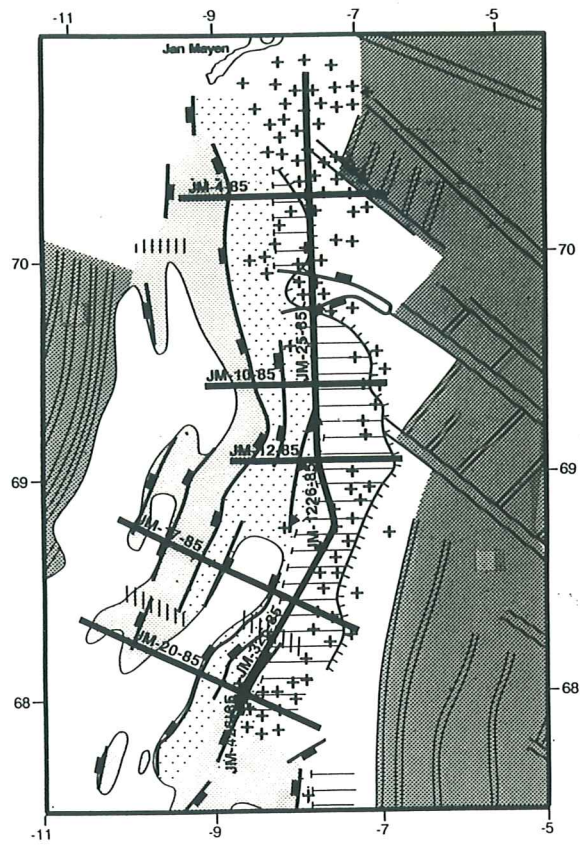shown on index map, Fig. 2.16.*

Fig 2.16

Fig 2.17

R-0197
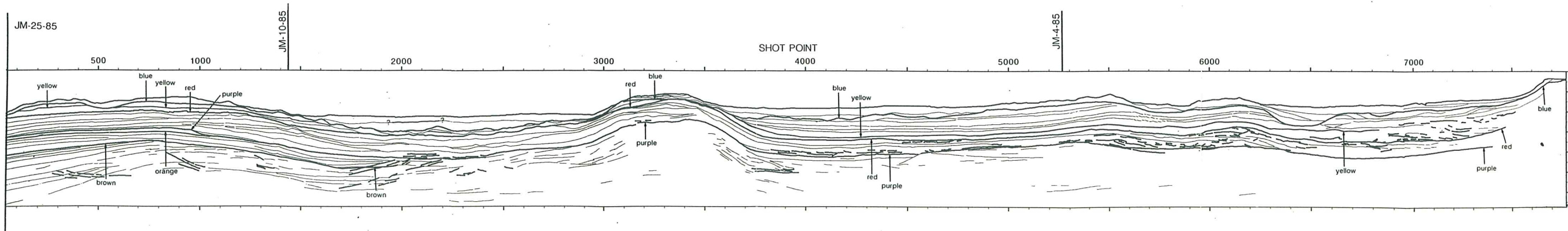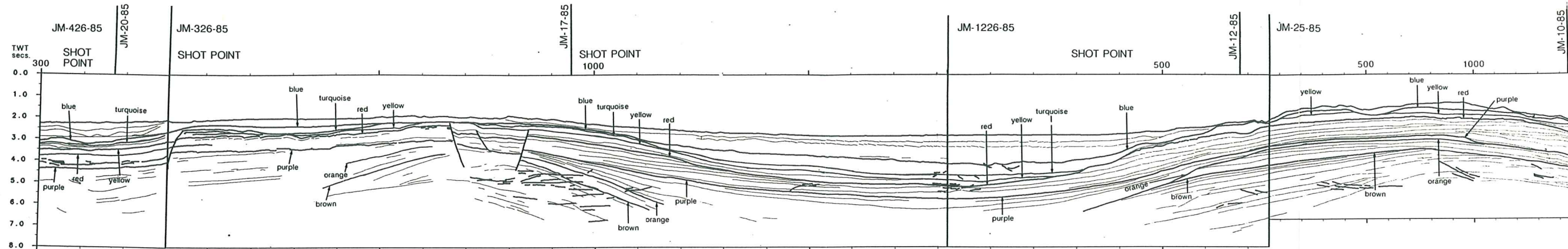
2.3.2 THE EASTERN MARGIN

The most striking characteristic of the eastern margin is the presence of an extensive complex of igneous rocks at a shallow structural level, comprising both volcanic rocks and intrusives (Figs. 2.11, 2.12, 2.13, 2.16, 2.17 and 2.18, Apps 4B, 5A and 5B). The volcanics overlie continental pre-opening rocks as a thin layer which thickens towards the continent-ocean boundary and merges with oceanic crust in the Norway Basin. The presence of a well developed sequence of seaward dipping and diverging reflectors beneath a smooth and extensive volcanic basement places the margin within the class of volcanic margins.

Talwani et al. (1983) divided the Norwegian volcanic margin into four structural zones: Zone I of inner lava flows, landward of the Vøring and Færøy-Shetland Escarpments; zone II, a subhorizontally stratified volcanic high seaward of the escarpments; zone III of seaward dipping reflectors; and zone IV of oceanic basement. This zonation has since been shown to characterize many other volcanic margins. Skogseid and Eldholm (1987) identified zones II, III and IV at the eastern margin of the Jan Mayen Ridge, but zone I and the corresponding escarpment were apparently lacking. They tentatively divided zone III into two subzones, IIIA and IIIB, on the basis of differences in cross-sectional geometry. The present study confirms this structural zonation (Fig. 2.18). The identification in the new data of an extensive complex of dikes and sills associated with the seaward dipping reflector sequence and continental crust beneath its inner part sheds further light on the structure and evolution of the margin.
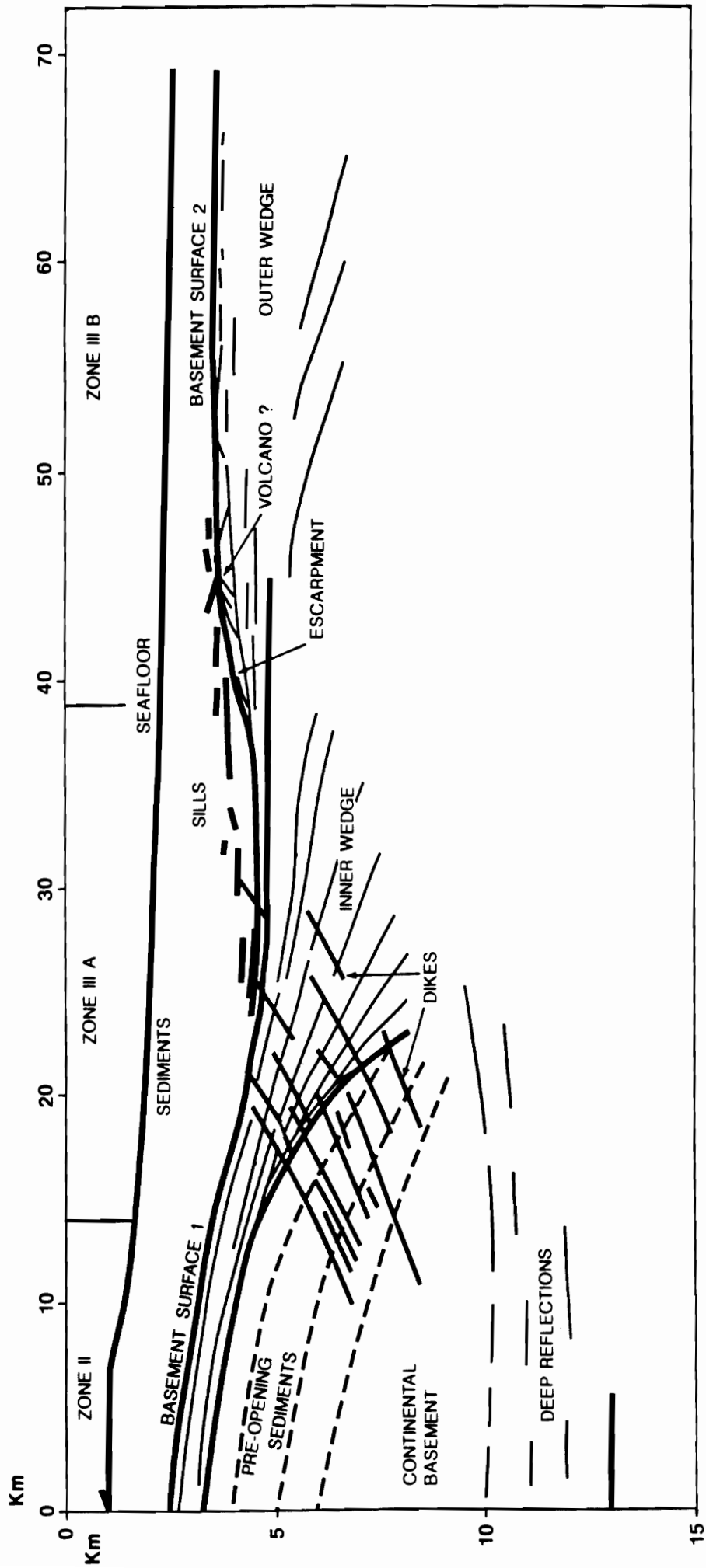
Fig 2.18 Structure of the volcanic megasequence at the eastern margin of the North Ridge.

Zone II

A zone of high-standing continental crust, largely
unaffected by faulting in the first rift phase, uplifted
and tilted eastwards in the second rift phase, is present
in a narrow strip along the central axis of the North
Ridge. Beneath a thin layer of plateau basalts, continuous
with the sequence of seaward dipping reflectors in zone
III, a stratified sequence of sediments, possibly
containing some volcanics, overlies continental basement.
The zone continues into the Southern Ridge Complex broken
by the system of normal faults formed in the second rift
phase.

Zone IV

Oceanic crust in the Norway Basin extends some distance to
the west of the oldest seafloor spreading anomaly at the
eastern margin, anomaly 24b. A number of fracture zones are
present, the main ones being, from north to south, the
Western, Eastern and Central Jan Mayen Fracture Zones and
the Norway Basin Fracture Zone (Fig. 2.13, App. 4B).
Adjacent to the margin the basement surface is generally
only slightly hummocky and much smoother than normal
oceanic basement. An exception is the area north of the
Central Jan Mayen Fracture Zone, where the basement is
highly fractured and uneven.

Zone III

The main geological units in this zone are the sequence of
seaward dipping reflectors, subsided continental crust
beneath the inner part of the sequence, and a complex of
intrusives (Fig. 2.18).

Seaward dipping reflectors have been mapped in a 20-40 km

wide zone beneath the slope of the eastern margin from 68N to 7025N, and may continue further south. In a transect across the margin, systematic changes in the cross-sectional geometry of the volcanic sequence define two juxtaposed and partly overlapping wedge-shaped units, the inner and the outer wedge. The inner wedge, closer to the ridge, has an overall divergent reflector pattern. The outer wedge marks a transition to a more offlapping pattern. It is characterized by a subhorizontally stratified top layer that oversteps the inner wedge upslope and terminates at westfacing escarpments.

Continental crust continues some distance from zone II eastwards into zone III beneath the sequence of seaward dipping reflectors.

A complex of intrusives is present within zone III along the margin. A series of west-dipping reflector segments, interpreted as a dike swarm, crosscuts the stratification of the inner wedge as well as the underlying continental rocks. A number of short horizontal high-amplitude reflectors, interpreted as sills, are found within the post-opening sediments.

Structural changes along the margin

The two main structural trends characteristic for the Jan Mayen Ridge as a whole are clearly evident at the eastern margin. North of the Norway Basin Fracture Zone, the dipping reflector sequence and underlying continental units have a northerly strike. Both the fracture zones and the seafloor spreading anomalies in the Norway Basin make an oblique angle with the margin trend and the isochrons are displaced sinistrally across the fracture zones. Thus, the initial oceanic rift was left-stepping at this part of the margin. There is evidence that the geometry was inherited from the continental rift in that two clear offsets are

observed in the margin landward of the oldest seafloor spreading anomalies. The Transverse Ridge, an east-west oriented structural high beneath the slope (Fig. 2.13, App. 4B), offsets the dipping reflector sequence and associated escarpments and intrusives left-laterally by some 20 km. It lies in direct continuation of the southern strand of the Central Jan Mayen Fracture Zone, and probably corresponds to a short shear margin segment. A similar shear segment may be present further north.

South of the Norway Basin Fracture Zone, the margin strikes east of north in a direction more parallel with the seafloor spreading anomalies. It is divided into two structural segments by Rift "A" west of DSDP site 350 (Figs. 2.1, 2.11 and 2.13). A continuous sequence of seaward dipping reflectors is present beneath the flank of the easternmost faultblocks north of the rift. With the available data we cannot determine whether the sequence continues southward across the rift. If it does and is found at the flank of the easternmost fault blocks, as indicated by Pelton (1985), this implies a structural offset in the margin at the northern termination of the rift at the time of opening of the Norway Basin. The rift itself was formed in the second rift phase, but cannot have created such an offset because faulting of the required magnitude is lacking on the eastern margin north of the rift. Alternatively, the dipping reflector sequence was broken by faulting in the second rift phase and now lies partly within the rift.

The Jan Mayen Trough reaches the outer continental margin, but there is no apparent offset in the dipping reflector sequence across its mouth.

Rift phase structures

A remarkable feature of the eastern margin is the lack of prominent rift structures associated with the first rift phase. Along most of the margin pre-opening strata are traceable, without apparent faulting or syntectonic sedimentary features, a horizontal distance of approximately 10 km beneath the inner wedge (Fig. 2.18).

Tectonic overprint

Tectonic overprint by the second rift phase is recognized along the entire eastern margin in the form of uplift of the eastern ridge flank and emplacement of the sill complex within the post- opening sediments. The eastwards tilting of the outer continental margin is in places taken up by a flexure or westfacing normal faults at the base of the slope. The faultblock bounded by the reverse fault on the southeastern corner of the North Ridge and the Transverse Ridge are apparently compressional structures resulting from the second rift phase.

2.3.3 THE WESTERN MARGIN

Despite its position at the edge of a narrow microcontinent, the western margin (Figs. 2.11, 2.12, 2.13, and 2.16, Apps. 4B and 5A) is in many respects a typical block faulted passive margin. Due to the thin sedimentary cover, the rift structures are unusually well imaged. Three structural zones are recognized in a transect from east to west across the margin: A terrain of blockfaulted continental crust, deep rift basins covered by flatlying sills or lavas and oceanic crust on the Iceland Plateau dated by seafloor spreading anomalies.

Blockfaulted terrain

The width of the blockfaulted terrain increases from 50 km
at 70N to more than 100 km at 6740N. With few exceptions,
the larger normal faults exhibit downthrow to the west and
divide the microcontinent into a complex of eastwards
rotated fault blocks. The dimensions of the blocks, as
measured by cross-strike bedlengths within the hanging
walls, range from a few hundred meters to approximately 15
km. On the larger blocks throw on the boundary faults
reaches 1.5-2 km and stratal dips up to 10 degrees have
been measured.

The crustal extension that caused the fault system divided
the western margin into a series of faulted ridges
separated by rift basins (Fig. 2.13): The Jan Mayen Basin;
the North Ridge; the Jan Mayen Trough; and a complex of
faultblocks, the Southern Ridges, divided by Rift "A"
west of DSDP site 350. This is reflected in the bathymetry
(Fig. 2.1).

The North Ridge is a 50 km wide block, structurally
coherent from the island of Jan Mayen a distance of 300 km
towards the south. The block is asymmetric in cross-
section, flat-topped, with an eastwards tilted eastern
flank and a steep faulted western flank. The high-standing
central part was uplifted and truncated by erosion in the
second rift phase but only to a minor degree affected by
faulting. The ridge is bounded on the west by a listric
master fault zone (Fig. 2.11, 2.13, 2.16, Apps 4B and 5A)
which separates the main ridge block from the blockfaulted
terrain further west. The fault zone is composed of two
main segments which intersect at an angle of 30 degrees at
the ridge bend. The faults sole out in the Jan Mayen Basin
beneath a series of fault blocks forming a listric fan in
the hanging wall. At the northern segment, the fan consists

of a few narrow riders, wheras a wider terrace of larger fault blocks is present at the southern segment. Nearly all the fault planes dip to the west except furthest to the north where a system of antithetic faults has resulted in a grabenlike geometry (Fig. 2.16, App. 5A line JM-4-85).

Although there are strong similarities in structural style between the Southern Ridge Complex and the North Ridge, there are also some important differences. In the Southern Ridge Complex, the blockfaulted terrain reaches into zone III of the eastern margin and a single master fault zone bounding it on the east is lacking. Instead, several narrow fault blocks on the outer continental margin are bounded by shorter left stepping normal faults. Generally, the faults are steep and planar as deep down as they are imaged and direct evidence of sole faults is lacking. The relatively uniform width, rotation and depth to the top of the faultblocks, shows that a near horizontal shear zone must exist at depth, either as one or more discrete decollement surfaces or a zone of ductile deformation.

Along the entire western margin, abrupt lateral offsets of faultblocks (Figs. 2.11 and 2.23, App. 4H) are commonly observed showing that transversely oriented structural discontinuities exist within the fault system. The seismic grid spacing and the paucity of strike lines is such that none of the inferred discontinuities between individual blocks are imaged directly, but at about 6745N a number of small faultblocks with discordant strikes define a broad east-west trending zone linking the northern tip of the unnamed rift with the southern end of the Jan Mayen Trough (Fig. 2.11). The zone is interpreted as a zone of accomodation transferring extension towards the west.

Thus, many of the fundamental structural characteristics of extensional terrains in continental crust are found at the western margin of the Jan Mayen Ridge. Compressional structures formed coevally with the extensional structures

add another dimension to this picture. The clearest
examples are found as tectonic overprint on the eastern
margin. On the southeastern corner of the North Ridge, a 65
km long NNE striking fault with a near vertical faultplane
and maximum throw to the west of some 600 m marks the
western boundary of a large faultblock (Figs. 2.13 and
2.16, Apps. 4B and 5A). This fault and similar steep faults
in zone III south of the Jan Mayen Trough were interpreted
by Skogseid and Eldholm (1987) as a system of dextral
strike slip faults. We find no indications of a significant
strike-slip component and interpret them as reverse faults.
In either case a compressional regime is indicated. The
Transverse Ridge further north, the elongated domal uplift
on trend with the southern strand of the Central Jan Mayen
Fracture Zone, is another feature belonging to the same
phase of structuring and indicating compression. Two small
thrust faults are observed immediately south of the
Transverse ridge.

Rift basins

The rift basins are elongated, oriented along the
prevailing structural trends with their longitudinal axes
arranged en echelon and their northern tips shifted
successively towards the north and west. A flatlying opaque
reflector covers the largest basins and masks the
underlying structure. The fact that they widen towards the
south and apparently coalesce indicates that they are rift
arms protruding from a larger rift system in the south. At
their northern end, where the opaque reflector is absent
and the deep structure can be studied, they are seen to be
faulted troughs structured in the same style as the higher-
standing terrain with eastwards rotated faultblocks bounded
by westvergent normal faults and occasional antithetic
faults.

Igneous complex

The opaque reflector covering the rift basins is flatlying
at a depth of 0.4-0.6 s twt beneath the basin plains. In
cross-section it is composed of numerous horizontal
segments at slightly different stratigraphic levels giving
it a stepped character. Detailed analysis has shown the
reflector to represent the top of a sill complex or a
series of submarine lava flows. The reflector is completely
opaque except at the edges close to the ridge where on a
few lines the continental rocks of the blockfaulted terrain
are traceable a short distance underneath it. On line JM-8-
85, sedimentary layers continue below the reflector halfway
across the Jan Mayen Basin to an isolated fault block (the
Middle Axis) rising above the basin plains (Fig. 2.13, App.
4B). The implication is that a considerable part of the
basins masked by the reflector may be underlain by
continental crust.

Oceanic crust

Magnetic seafloor spreading anomalies on the Iceland
Plateau show that oceanic crust is present immediately west
of the Jan Mayen Basin. The oldest anomaly identified with
certainty on the Iceland Plateau is anomaly 6C, but there
is some indication of anomaly 7 (Vogt et al., 1980).
Oceanic basement on the plateau is characterized by a
smooth opaque reflector (Eldholm and Windish, 1974; Talwani
and Eldholm, 1977; Olafsson, 1983) not much different in
character from the igneous marker covering the rift basins
to the east.

North of about 69N, the Jan Mayen Basin is separated from
the magnetically lineated oceanic basement on the Iceland
Plateau by an eastfacing scarp. The oceanic crust
immediately west of the scarp is composed of a suite of
subbasement layers beneath a strongly reflective upper

surface. The layered basement has an interval velocity in its upper part of 4 km/s twt derived from CDP stacks and is interpreted to consist of a sequence of submarine lava flows. South of 69N, the igneous marker covering the rift basins can be traced onto oceanic crust on the Iceland Plateau without marked discontinuity or change in character.

2.4 STRATIGRAPHY

2.4.1 Stratigraphic framework

The cross-sectional images of the Jan Mayen Ridge provided
by the new seismic reflection data (Figs. 2.16 and 2.17,
Apps. 5A and 5B) contain wealth of new geological
information. Sixteen geological units, ranging from
continental and oceanic basement to sedimentary and
volcanic layers and igneous intrusives, were studied in
order to unravel the structure and history of the ridge.

The stratigraphic framework proposed here is based mainly
on seismic analysis. It is illustrated with the generalized
cross-section in Fig. 2.12 and a schematic crustal column
(Table 2.2). The section runs through a type locality on
the southeastern corner of the ridge where the stratigraphy
is exceptionally complete.

A top basement surface divides the crustal column into
continental basement rocks and a cover of volcanic and
sedimentary strata.

Continental basement

Beneath the basement surface, the crust is divided into two
units on the basis of a difference in reflectivity.

The lower unit is characterized by horizontal reflectors
observed in an average depth range of 5.5-6.5 s twt beneath
the North Ridge and parts of the Southern Ridge Complex
(unit 1, Table 2.2 and Fig. 2.12). On lines registered to
more than 7 s twt there is an apparent lowering of
reflectivity below this unit.

Stratigraphic marker	Geological unit	Mega-sequ-ence
⊢ Seafloor ───		
	Hemipelagic and pelagic sediments (15) oceanic basement (16)	(4)
⊢ Pink ───	─── Breakup marker 2 ───	
⊢ Blue ───	Syn-rift megasequence locally derived; divided by several rift-related uncon-	
⊢ Turquoise───	formities. Early syn-rift (10), (11), late syn-rift (12), (13),	(3)
⊢ Yellow ───	sill complex (14)	
⊢ Red ───	─── Rift unconformity 2 ───	
	Post-opening sedimentary sequence derived from Greenland (8), sill complex (9)	(2)
⊢ Purple ───	─── Breakup marker 1 ───	
	Volcanic megasequence with seaward dipping reflectors (5), dike complex (6), oceanic basement (7)	(1)
⊢ Orange ───	─── Rift unconformity 1 ───	
⊢ Brown ───	Pre-opening sediments (4) Mesozoic or Paleozoic unconformity Pre-opening sediments (3)	
⊢ Top basement ─		
	Continental basement rocks, non-reflective (2)	
	Reflective deep crustal layer (1)	

Table 2.2 Main seismic stratigraphic markers and geological unit

The upper unit (unit 2) is characterized by low
reflectivity. The occurrance of a few reflections in some
cases gives the impression of weak layering, but in general
it is difficult to discriminate between real reflections
and artifact. Because strong reflections are returned from
below the unit, the lowering in reflectivity is interpreted
to be real.

An integrated analysis of the available geological and
geophysical data back up the interpretation of the basement
rocks as being continental in origin.

Cover strata

The volcano-sedimentary cover is divided into a lower
series of pre-opening strata and an upper series of syn-
and post-opening strata by reflector Orange. The reflector
is interpreted to mark the onset of the rift phase which
led to breakup of the continent between Norway and
Greenland and the opening of the Norwegian- Greenland Sea.

Lower series

At the type locality on the southeastern corner of the
North Ridge, the lower series occurs as a thick and well-
stratified sedimentary succession on an upthrust faultblock
bounded on the west by a prominent reverse fault (Figs.
2.11 and 2.12). The series is bounded at its base by a
narrow band of strong reflections from the top of the less
reflective basement beneath and has a maximum thickness of
about 2.5 s twt. A marked unconformity, Reflector Brown,
divides it into two sequences (units 3 and 4). Outside the
type locality, a distinct basal reflector is observed only
sporadically. An estimated average thickness ranging from
0.4 to 1.2 s twt therefore represents a minimum.

Upper series

A major result of the stratigraphic analysis of the upper
series is the identification of the rift onset and breakup
markers of the two rift phases: Reflectors Orange, Purple,
Red and Pink divide the series into four megasequences
corresponding to the major phases in the plate tectonic
evolution of the ridge (Fig. 2.10).

Reflector Orange represents an unconformity at the base of
the eastern margin volcanics. Beneath the inner wedge of
dipping reflectors the unconformity is clearly erosional
and truncates the underlying lower series strata. Signs of
synrift sedimentation or emplacement of volcanic extrusives
are apparently lacking in the lower series. It therefore
probably consists of pre-rift sediments and reflector
Orange marks the onset of rifting at the eastern margin.

The Orange-Purple megasequence (unit 5) spans the volcanic
megasequence emplaced at the Greenland margin during the
rift and early drift phase. It includes the sequence of
seaward dipping reflectors and the thin volcanic layer
extending upslope from it and is interpreted to consist
mainly of subaerial basaltic lava flows.

Reflector Purple defines the top of the volcanic
megasequence. It is an amalgamation of surfaces which young
towards the ocean and merge with oceanic basement. At the
outer wedge, the youngest volcanic subsequences below it
are time-equivalent with the lower part of the Purple-Red
megasequence. Ridgeward of the outer wedge, where the
reflector marks the top of basalts which flooded the
continent, it is close to being a chronostratigraphic
boundary and is interpreted to correlate with or slightly
post- date breakup.

The dike complex (unit 6) observed within the volcanic

megasequence, the underlying lower series sediments and the
continental basement, is interpreted to have been emplaced
contemporaneously with the dipping reflector sequence.

The Purple-Red megasequence (unit 8) is the sequence of
drift phase sediments deposited on the Greenland margin and
in the Norway Basin after breakup and prior to the onset of
the second rift phase. It records thermal subsidence of the
margin and the initial development of a shelfedge facing
the Norway Basin.

The Red-Pink megasequence is the synrift sequence deposited
during the second rift phase when the ridge was separated
from the Greenland margin. Reflector Red represents the
onset of uplift and faulting associated with this phase.
Reflectors Yellow, Turquoise and Blue divide the
megasequence into four depositional sequences (units 10 to
13) recording different stages in the development of the
rift. The uppermost sequence, Blue-Pink, post-dates the
main phase of faulting and represents a period of thermal
subsidence prior to breakup.

The sill complex (unit 9) is largely confined to the
Purple-Red megasequence. A few sills are observed within
the abovelying sequence. It is interpreted to have been
emplaced in the second rift phase.

The Pink-seafloor megasequence of sediments deposited
during the second drift phase (unit 15) continues onto
oceanic basement west of the ridge and thus post-dates
breakup. Analysis of reflector Green, the opaque reflector
which covers the rift basins west of the ridge, shows that
the emplacement of the complex of sills or lavaflows it
represents (unit 14) was approximately coeval with breakup
and with the formation of Reflector Pink. Since reflector
Green is composed of a number of reflector segments at
slightly different stratigraphic levels it is not a
chronostratigraphic boundary. Reflector Pink is

therefore taken as the breakup marker.

Mapping of stratigraphic boundaries

The regional stratigraphic framework was established by
extending the stratigraphy of the type locality to other
parts of the ridge. In order to establish regional
correlations, reflectors Purple, Red and Blue, being the
most easily correlateable reflectors, were mapped first. We
are confident of the interpretation of these sequence
boundaries along most of the eastern margin, less so on the
western margin. Once the regional correlations were
established, the other markers (Top basement, Brown,
Orange, Yellow, Turquoise, Green and Pink) were introduced
and mapped more locally in an effort to understand
structuring and sedimentation at the ridge.

A major difficulty was the general lack of continuous
stratigraphic ties between the different subprovinces of
the ridge due to fault zones, masking by igneous rock
suites and erosional truncation. On the eastern slope, part
of the post-opening sedimentary cover is composed of a
multitude of laterally restricted local depositional units,
and stratigraphic boundaries are in many cases difficult to
follow along strike. The western margin is structurally
complex and few effective longitudinal tie-lines exist. Out
of several possible correlations, the one that minimizes
structural complexity and leads to a simple and plausible
history of tectonism and sedimentation has been chosen.

Isochrone maps of reflectors Purple, Red and Blue (Figs.
2.14, 2.20, 2.22, Apps. 4C, 4D and 4E respectively) and
isopach maps of the intervals Purple-Red, Red-Blue and
Blue-seafloor (Figs. 2.21, 2.23, 2.24, Apps. 4G, 4H and 4I
respectively) illustrate the stratigraphy of the
sedimentary cover. A total sediment isopach is shown in
Figure 2.15 (App. 4F). The maps do not cover parts of the

structurally complicated western margin. Reflector Blue was
chosen instead of the slightly younger reflector Pink,
because it can be mapped over a far larger part of the
ridge. As a result the two upper stratigraphic
intervals presented as isopachs do not correspond exactly
to megasequences.

2.4.2 AGE CALIBRATION

The new stratigrahic framework provides a relative
chronology of events and enables a more accurate analysis
of structure, tectonics and depositional systems than
previously possible. An absolute age calibration of the
framework is essential for further studies. Some of the
stratigraphic markers may be dated with the help of seismic
ties to biostratigraphically dated markers in the DSDP
holes. Downlap of post-opening sequences on dated oceanic
basement provides imortant additional constraints. For the
older part of the succession, however, tentative ages must
be assigned on the basis of correlations with the geology
of the conjugate margins.

Basement

Reconstructions of the plate movements that took place
between Greenland and Norway in Late Paleozoic, Mesozoic
and Cenozoic times (Ziegler, 1989) show that the Jan Mayen
Ridge must have been part of the province of Caledonian
deformation, irrespective of the magnitude of the Devonian
Arctic-North Atlantic megashear movements along the axis of
the Caledonides. We can therefore safely assume that the
continental basement beneath the ridge is Caledonian in
age.

Lower series

The reconstructions also show that the ridge has been
juxtaposed with the East Greenland sedimentary basin (Figs.
2.5 and 2.8) from Carboniferous times at least. We
therefore anticipate strong similarities between the pre-
opening sedimentary successions of the East Greenland basin
and the Jan Mayen Ridge.

Because of the large thickness of the lower series,
comparisons with the thick Jameson Land succession (Fig.
2.9; Surlyk et al., 1981, 1984; Ziegler, 1989, his Fig.50)
are particularly relevant. Elements of the stratigraphy of
the lower series which might be used to establish
correlations between the two successions, are mainly the
unconformities, associated phases of faulting and
stratigraphic thicknesses of subunits. For two reasons,
such correlations are difficult to establish:

1) The East Greenland basin was affected by a number of
tectonic phases in Late Paleozoic and Mesozoic times
(Surlyk et al., 1981). Most of the resulting unconformities
are subtle and not identifiable on the basis of geometry
alone.

2) The Jameson Land basin is separated from the shelf by a
coastparallel basement high, Liverpool Land, which was
active during several of these phases (Surlyk et al.,
1981). The North Ridge probably constituted a separate
fault block with potentially different history of vertical
movements. Sequence thicknesses and gaps in the
stratigraphic record may therefore differ between the two
successions.

Thus, correlation of unconformities is non-unique and
relative thickness of subsequences is not a reliable
criterion on which correlations can be based.

Reflector Brown is a prominent reflector and represents an erosional unconformity caused by a tilting of the fault block at the type locality. Assuming that the reflector represents one of the strong late Mesozoic tectonic phases and noting the strong reflection coefficient, we suggest that the reflector corresponds to the base Cretaceous unconformity above the Jurrassic sandstones. It follows that a part of the Cretaceous and Paleocene succession, missing in Jameson Land, but preserved as scattered remnants to the north and south, is preserved at the ridge. This may be explained by the large uplift and erosion which affected the East Greenland margin in late Tertiary times.

Upper series

The volcanic megasequence at the Jan Mayen Ridge exhibits strong stratigraphic and structural similarities with the volcanic sequences observed on the Norwegian and Greenland volcanic margins. The dipping reflector sequence at the Outer Vøring Plateau was drilled during ODP leg 104 and found to have been erupted mainly in the period of reverse magnetic polarity between anomalies 24 and 25, the youngest and possibly the oldest subsequences belonging to the periods of normal polarity above and below. This corresponds to an age of approximately 56-59 Ma. On the basis of a temporal correlation of the main igneous and pyroclastic units in the North Atlanic Volcanic Province (Eldholm et al., 1989), a similar age is indicated for the other dipping reflector sequences observed on the conjugate margins.

More direct evidence for the age of the volcanic megasequence at the Jan Mayen Ridge comes from its relation to the oldest seafloor spreading anomalies in the Norway Basin and a correlation with the Blosseville Coast plateau basalts of East Greenland. According to our interpretation, the second rift phase split the East Greenland volcanic margin along a breakup line which left zone III and part of

zone II on the Jan Mayen side. The volcanic megasequence at the ridge was originally continuous with the Blosseville Coast plateau basalts. Age constraints may therefore be obtained from the exposed basalts in Greenland.

Biostratigraphic ages constrain the eruption of the Blosseville Coast lavas to the time period from 55 to 59 Ma. Combined with the fact that the entire sequence is reversely magnetized, this indicates emplacement during the period of reverse magnetic polarity between anomalies 24 and 25. But, due to erosion, the upper part of the Blosseville sequence is missing. On the Jan Mayen Ridge, the volcanic sequence escaped erosion. Ridgeward of the outer wedge, reflector Purple is a conformable chronostratic surface marking a shift from continent-flooding plateau basalts to younger and more restricted sequences at the outer wedge. It probably corresponds to the uneroded top of the Blosseville lavas. Because the dipping reflectors lie ridgeward of anomaly 24B, this inner surface of reflector Purple probably predates the anomaly, but normal polarity of the top layer of the outer wedge cannot be excluded. Thus, the Orange-Purple megasequence probably spans the time period from 59-56 Ma.

Age constraints on reflector Blue are provided by seismic ties to the DSDP holes 346, 347 and 349 (Talwani and Udintsev et al., 1976). The holes are located on the western part of the North Ridge and bottom out beneath the reflector. It represents an angular unconformity separating late Eocene sediments below from a condensed sequence of late Oligocene to Pliocene sediments above. Thus, a hiatus of at least 7 Ma from 37 Ma (anomaly 15) to 30 Ma (anomaly 10) is present in this strongly eroded area. The boundary becomes conformable in the basins on both sides of the ridge and the hiatus associated with the reflector is probably much smaller.

The seismic lines crossing these sites show that, due to

ambiguous correlations across fault zones, it is uncertain
whether reflector Red was reached. They do show, however,
that at least a part of the late Eocene section found in
the holes overlies reflector Red. The reflector is
therefore late Eocene or older. It was traced on several
lines to its point of downlap onto oceanic crust in the
Norway Basin. This point is not well determined, but occurs
within a strip of seafloor defined by anomalies 20 to 22.
Assuming that the basement was covered by sediments soon
after its formation, which seems likely in view of the
small width of the ocean basin at that time and the high
rate of sediment input to the eastern margin, this gives an
age of 45- 52 Ma correspondig to the middle Eocene or the
end of early Eocence.

Reflector Pink is defined on the western flank of the North
Ridge. It cannot be followed across the boundary faults
onto the flat top of the ridge where holes 346, 347 and 349
are sited, but age constraints are obtained from hole 348
and the reflector's relation to oceanic basement west of
the ridge. The hole is sited on the Iceland Plateau and
penetrates a relatively continuous sequence of sediments
ranging in age from Pleistocene to early Miocene. An
uncertain Oligocene age at the bottom of the hole is in
conflict with the siting of the hole at anomaly 6A and must
be rejected. Line L-DGO 206, which runs from site 348 to
the North Ridge, shows that the sedimentary sequence can be
followed from the site across anomaly 6C (24 Ma, Olicocene/
Miocene boundary) into the Jan Mayen basin where it is
continuous with the sequence above reflector Pink in the
Jan Mayen Basin. This indicates that the reflector predates
Miocene. In Sections 2.5.6 and 2.5.7 we present arguments
for the correlation of reflector Pink with breakup at
approximately anomaly 7 (26 Ma, late Oligocene).

None of the new lines cross DSDP-site 350 in the Southern
Ridges. Due to steep stratal dips at the site,
navigational inaccuracy and poor quality of the older lines

it has not proved possible to utilize the results from this hole for age calibration of the stratigraphy.

With the age constraints imposed by the available data, the reflectors Orange, Purple, Red and Pink, divide the upper series into four megasequences corresponding to the major plate tectonic phases in the Tertiary development of the ridge (Fig.2.19, App. 5C).
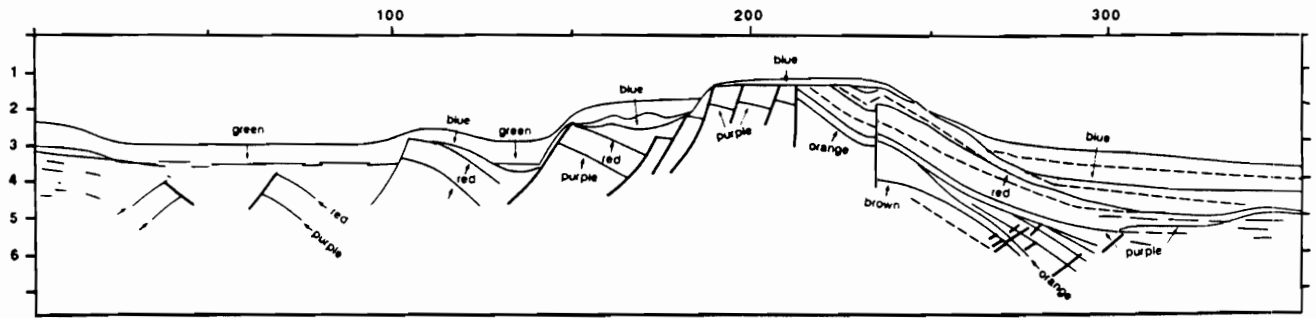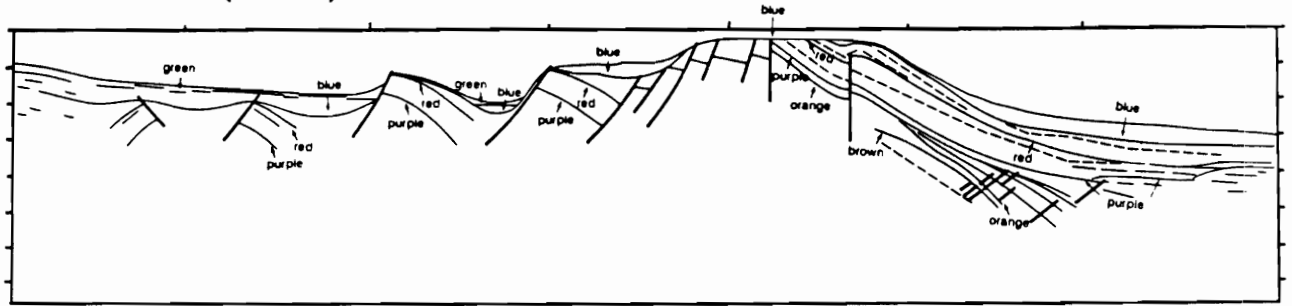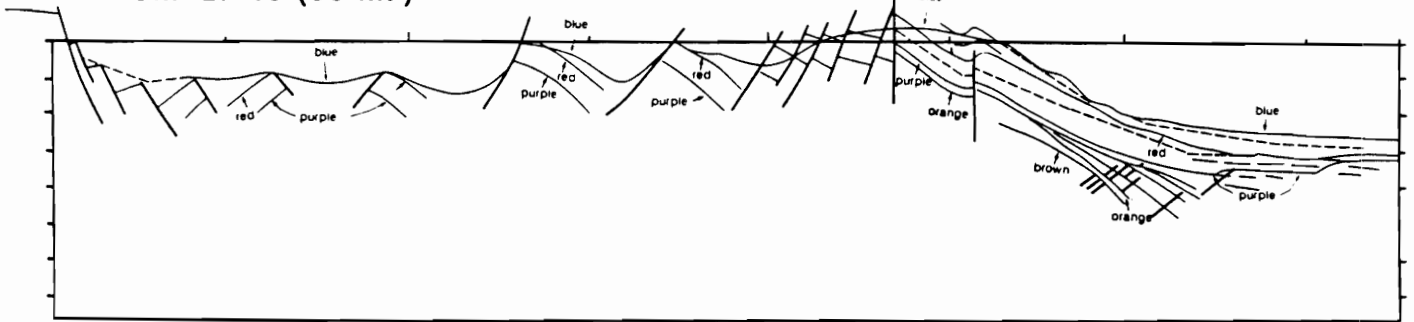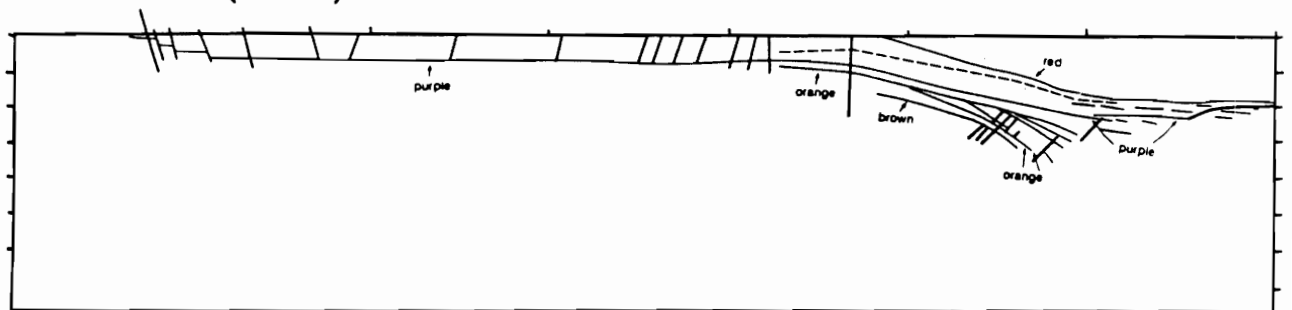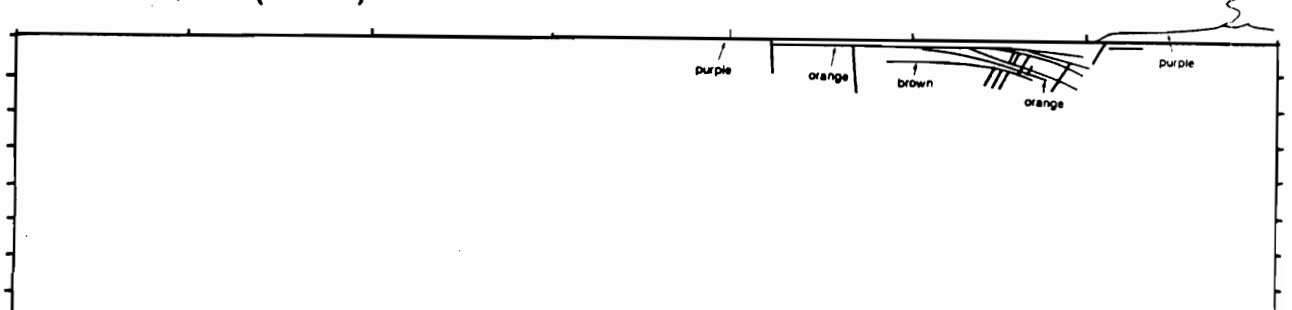
Fig 2.19   Evolution of the Jan Mayen Ridge.

R-0197/1

2.5 ANALYSIS OF THE COVER STRATA

2.5.1 LOWER SERIES: PRE-OPENING PHASE

Overall geometry

The stratified series observed beneath the volcanics at the type locality (Fig. 2.16, App. 5A, line JM-12-85; Fig. 2.17, App. 5B, lines JM-25- and 1226-85) reaches a thickness of about 2.5 s twt, corresponding to some 4-5 km. The series is identified with certainty and mappable only on the fault block east of the prominent reverse fault on the North Ridge. It exhibits internal reflectors with good or fair continuity defining uniform parallel or gently diverging layering. The whole series is tilted towards the Norway basin and dips beneath the inner wedge of dipping reflectors.

When the displacement is restored on the reverse fault, the abovelying volcanic layer can be traced across it without apparent change in thickness. None of the lower series strata observed east of the fault can be identified to the west of it, and they may be entirely lacking there. Yet, there is some layering west of the fault, so their presence cannot be excluded.

Lower boundary

The band of reflectors plunging eastward from 5 to 6.5 s twt on line JM-12 and southward in a similar depth range on lines JM-25 and 1226, defines the base of the series and the top of the continental basement.

Upper boundary

Reflector Orange forms the upper boundary of the series and
defines the base of the overlying volcanic megasequence.
The boundary was mapped as a continuous reflector in a
small region around the type locality on the southeastern
part of the North Ridge. In zone II the boundary is
conformable. In zone III, the following stratigraphic
relations are observed:

1) The boundary marks a change from subparallel layering
below to eastwards divergent within the abovelying inner
wedge.

2) Reflectors in the wedge are in some cases observed to
onlap the boundary updip.

3) The uppermost layers beneath the wedge thin in the
downdip direction. On several lines this is clearly due to
erosional truncation at the boundary.

Continuous mapping of reflector Orange outside this region
proved difficult. Extension to the regions further north
and south along the eastern margin is therefore based on
correlation between dip lines, using the criteria above.

Subsequences

Reflector Brown divides the lower series into two
sequences. Centrally on the fault block, the reflector
represents a nearly conformable boundary. Towards the
north, the underlying beds are truncated by the
unconformity. This is also seen near the western edge of
the fault block.

Tectonism and sedimentation

The parallel layering and good continuity of the internal reflectors, indicates a marine platform or basin margin sedimentary sequence. But continental sediments may also be present, and within the uppermost part of the series, the presence of volcanic layers cannot be excluded.

Reflector Brown and the associated erosional unconformity indicate slight tilting of the faultblock to the southeast. The uniform parallell stratification in the lower part of the Brown- Orange sequence indicates that these movements were followed by a period of stability. The uppermost part of the lower series thins downdip mainly as a result of erosional truncation at reflector Orange caused by uplift of the outer margin. A small part of the apparent downdip thinning may admittedly be caused by syntectonic depositional thickening towards the fault, but internal layering that might be used to determine this component is lacking.

Thus, the stratal geometry of the lower series differs markedly from the geometry expected if all or part of it was deposited in response to rifting at the eastern margin. The most reasonable interpretation is that the series predates the rifting. Alternatively, if all or part of the series was deposited during the rift phase which led to the opening of the Norway basin, the boundary faults of the rift must have been located well to the west of the reverse fault, but we do not consider this very likely.

2.5.2 MEGASEQUENCE 1: OPENING VOLCANISM

The megasequence spans the volcanic rock suite at the eastern margin and its westward extension across the ridge as a thin layer. A description of the overall geometry was given in Section 2.3.2 and is illustrated in Figure 2.18.

Upper boundary

Reflector Purple (Figs. 2.14 and 2.18, App. 4C) is the strong reflector marking the top of the volcanics. Detailed studies show that the reflector is composed of several surfaces at slightly different stratigraphic levels. As a first approximation, a division can be made into

1) a smooth surface defining the top of the volcanic megasequence over the ridge, including the inner wedge, and

2) a time-transgressive basinward-younging surface further downslope on the eastern margin. It is slightly rougher, continuous with the oceanic basement in the Norway Basin and oversteps the older surface upslope.

The two surfaces will be referred to as volcanic basement surfaces 1 and 2 repectively. The transition between the two occurs at the non-fault related westward facing escarpments along the eastern margin (Fig. 2.13, App. 4B), where basement surface 2 steps down to meet basement surface 1.

The reflector is a lithostratigraphic boundary separating volcanic rocks below from sedimentary rocks above. Basement surface 1, which forms the top of the inner wedge and the thin layer continuing upslope from it, is a relatively conformable boundary separating laterally extensive layers above and below. At the western escarpment there is a

transition to an increasingly offlapping reflector pattern in the sequence below. Thus, basement surface 1 is probably close to being a chronostratigraphic boundary, whereas basement surface 2 becomes increasingly younger basinward. Since basement surface 1 can often be traced some distance underneath basement surface 2 , the latter in fact defines the top of a volcanic subsequence, time- equivalent with the lower part of the abovelying sedimentary sequence. However, because of the marked difference in lithology and genesis, this subsequence is considered to be a part of the volcanic Orange-Purple megasequence. When reflector Purple is used in a time stratigraphic sense, its age is defined to be that of basement surface 1.

Stratigraphy of the dipping reflector sequence

In a typical cross-section orthogonal to the margin, the reflector pattern divides the sequence into basinward dipping and thickening subsequences that either pinch out in the updip direction or converge to a certain point before becoming parallel. The bounding surfaces are either planar or arcuate and convex upward in cross section. The subsequences build two basic types of sequence geometries, divergent and offlapping. In a divergent sequence, the subsequences are arranged in a vertical stack with the points of pinchout or maximum convergence approximately in the same location, referred to as the apex. The average dips decrease upwards from reflector to reflector, and the upper surface is close to being an isochrone. In an offlapping sequence, the subsequences are arranged in an oceanward prograding stack. No apex develops because of the successive oceanward shift of the pinchout points. The whole sequence, therefore, exhibits a general pattern of offlap from a relatively even, oceanward younging upper surface.

Inner wedge

The inner wedge exhibits an overall divergent reflector
pattern. Both divergent-planar and divergent-arcuate
geometries occur. A composite form with an arcuate lower
part and a planar upper part is commonly observed. Second
order departures from the regular divergent reflector
pattern of the inner wedge are common enough to constitute
a systematic shift in the westward extent of the
subsequences from the bottom to the top of the wedge. The
lower subsequences often onlap the basal surface of the
wedge and pinch out before reaching the apex. The main body
of the wedge does not pinch out in the updip direction.
Some part of it at least, converges updip only to a certain
degree at the apex, where it turns parallel and continues
westward across the ridge as a thin layer. This layer can
be followed to the western margin, where it is downfaulted
at the boundary faults. At the top of the wedge there is an
eastward shift and usually a change to an offlapping
pattern associated with the transition to the outer wedge.

Outer wedge and escarpments

The cross-sectional geometry of the outer wedge is less
regular than that of the inner wedge. Data quality and data
coverage are also poorer. Overprinting by sills sometimes
obscures the internal structure. Nevertheless, a distinct
outer wedge is recognized on the basis of one or more of
the following criteria:

1) A transition from a fanshaped to an offlapping pattern

2) Increased dips compared to the top layers of the inner
   wedge

3) A subhorizontal layer on top of the wedge rising above
   the upper surface of the inner wedge and overstepping
   it in the updip direction

The top layer thins updip as it oversteps the inner wedge.
The thinning is the result of downstepping of the upper
surface at the escarpments and other less prominent scarps.
The western escarpment marks the updip termination of the
top layer of the outer wedge and is a rather subtle
feature. The eastern escarpment is more prominent,
especially south of the CJMFZ, where it is developed as a
scarp reaching a height of several hundred meters. North of
the CJMFZ, it is more subdued and resembles a wedge-like
pinchout.

East of the eastern escarpment, the top layer of the outer
wedge attains an average maximum height above the top of
the inner wedge of 1.3 km. Its structure varies from
subhorizontally stratified to irregular or opaque. The
escarpment itself also varies in structure. Two basic forms
are recognized: A steeply sloping surface onlapped by
sediments; and a featheredge caused by the updip
termination of horizontal reflectors interfingering with
sedimentary layers. On some profiles, both forms are
present. In neither case is there any sign of faulting or
erosion. The escarpments therefore are depositional
features.

East of the northern termination of the Jan Mayen Trough,
several mound-like structures have been observed within the
top layer of the outer wedge, just east of the eastern
escarpment. The mounds are 7-8.5 km across and rise 900-
1300 m from a horizontal base. They exhibit upward convex
tops and internal reflectors that downlap the base.

Thin layer

The thin volcanic layer extending upslope from the inner
wedge is characterized by high amplitude reflectors, smooth
and continuous in the upper part. The thickness of the

layer is not well determined due to the uncertainty in the picking of the base (reflector Orange), but is estimated to be 380 ms twt on the average, corresponding to approximately 750 m. Although belonging to basement surface type 1, the top of the layer is not an entirely consistent chronostratigraphic surface. On the southern part of the North Ridge, it lies at a higher stratigraphic level than in the region immediately to the north and east. It steps down to the lower level at a northeastfacing scarp, some 400 m high, observed on several lines.

Depositional features and environment

The volcanic nature of the megasequence follows from the close stratigraphic and structural similarity with the volcanic sequences confirmed by drilling at other volcanic margins and the correlation with the plateau basalts at the East Greenland margin. Several stratigraphic and morphological features of the megasequence itself indicate a volcanic origin and provide further insights into the mode of emplacement.

A general feature of the dipping reflector sequence is basinward transition from a fanshaped to an offlapping pattern. Commonly, the thin upper edge of a subsequence oversteps the adjacent inner subsequence (or subsequences) and rises above it to form a local step at its updip termination. This is observed on different spatial scales, the escarpments associated with the outer wedge being just such a phenomenon on a large scale.

Onlapping and offlapping patterns are common in sedimentary sequences. Oceanward shift of onlap produces updip overstepping subsequences. Updip overstepping sometimes occurs also within overall offlapping sequences. But, updip facing scarps are produced in neither case, at least not in terrigenous clastic sediments. In the sedimentary

environment of the Norwegian- Greenland Sea, the
combination of an overall offlapping sequence with
occational updip overstepping of individual subsequences
terminating at well defined scarps is thus incompatible
with a sedimentary origin, and strongly indicates a
basinward retreating volcanic source. In this context, the
westfacing escarpments associated with the outer wedge must
be interpreted as being formed by lava flows, and the
mounds observed within the top layer of the outer wedge
find an explanation as volcanoes.

Lava flows, whether subaerial or submarine, have limited
flow lengths and are bounded by marginal scarps. Flow
lengths are generally much larger on land than beneath the
sea due to lower cooling rates on land. Lavas flowing from
land into the ocean or a lake are quickly quenched at the
shoreline and a steep front often develops.

A basaltic volcanic zone that subsides beneath sea level
will go through three distinct phases of volcanism. Above
sea level, non- explosive volcanism will result in a
layered stack of areally extensive lava flows. As the zone
becomes submerged, the erupted magma will be torn apart in
steam explosions and laterally restricted pyroclastic
mounds will be formed together with extensive but
relatively thin ash layers. Eventually, a critical depth is
reached (several hundred m) at which the hydrostatic
pressure prevents steam explosions and lavas will flow
again as relatively restricted sheet or pillow flows.

A change from subaerial to submarine volcanism took place
at the eastern margin as Norway Basin gradually opened. The
transition from inner to the outer wedge is interpreted to
record this event. The irregular layering of the top layer
of the outer wedge, the increase in roughness associated
with the transition from basement surface 1 to basement
surface 2 and the formation of the escarpments are best
explained as being caused by a decrease in lava flow

lengths due to the submergence of the volcanic zone or the development of a marginal sea between the volcanic zone and the continent. It is possible that an increase in volcanic production could have caused the updip overstepping of the top layer and the formation of a flow front, but this should not by itself have resulted in more irregular layering or sharply defined composite escarpments.

Alternative explanations are less feasible. A chemical control would imply increasing silica content with time, which can be rejected as an overall trend in the transition to the formation of oceanic crust. A fall in eruption temperature large enough to alter the flow lengths and morphology of the lavas seems unlikely. A change in the surface gradient resulting from differential subsidence could restrict lava flows but would not lead to the formation of escarpments.

The northeast facing escarpment on the North Ridge (Fig.2.13, App. 4B) is a well defined scarp limiting an extensive uniformly layered extrusive unit of nearly constant thickness. The strata above and below the unit show no signs of erosion or faulting and the scarp is therefore depositional in origin. In view of its thickness of 400 m, the unit is clearly composed of multiple flows. It seems that no possible mechanism, other than quenching at a shoreline, could cause the abrupt termination of multiple subaerial lava flows in exactly the same position, producing a sharply defined scarp. This implies early subsidence of the margin and supports the interpretation of the westfacing escarpments as being caused by submergence.

2.5.3 INTRUSIVES AT THE EASTERN MARGIN

The two sets of reflectors interpreted as intrusives are found along the entire eastern margin. The areal distribution of the sill complex is shown in Figures 2.11 and 2.13 (App. 4B).

Sills

The reflectors interpreted as sills are short reflector segments observed within the sedimentary sequence above reflector Purple. They are single-reflector bright-spots with sharp edges that give rise to diffractions on unmigrated sections. Although most are subhorizontal and conformable with the sedimentary layering, some are clearly discordant. Commonly, the sedimentary strata above the reflectors are uplifted. There are cases where the strata are uplifted as a block with step-like margins exactly coincident with the position of the reflector edges, and the affected section has a well defined upper boundary above which there is no deformation. These characteristics identify the reflector segments as sills.

South of the Transverse Ridge, the sills are mostly found near the escarpments, which define the transition to the outer wedge. North of this ridge, they are more widely distributed. Most are found within the Purple-Red megasequence, but a few are found within the abovelying Red-Pink megasequence. They tend to cluster at certain stratigraphic levels, commonly at a level corresponding to the top of the outer wedge.

The most precise indicator of their relative age is the uppermost stratigraphic level of sediments deformed by the sills, which consistently gives an age corresponding to reflector Red or the lower half of the Red-Blue sequence,

except for a few sills at the northern termination of the Jan Mayen Trough, which are emplaced at the level of reflector Blue.

Dikes

The reflectors interpreted as dikes are found at the inner wedge, where they dip westward orthogonally to the margin and crosscut the stratification of the volcanic megasequence as well as the underlying strata. They occur as sets of closely spaced short reflector segments with an average dip of 25 degrees. Generally, the reflectors do not offset the bedding, but minor offsets may be present in a few cases. The reflectors are dimmer and fewer in number above reflector Orange than beneath it.

Possible interpretations of the reflectors are metamorphic layering, faults or dikes. Metamorphic layering is not expected to generate a number of closely spaced reflectors. Closely spaced small-offset faults could explain the geometry, but should by themselves neither generate such strong reflections nor brighten beneath reflector Orange. A dike swarm could have the observed geometry and would be expected to give rise to more prominent reflections within the sediments below reflector Orange than in the basaltic sequence above. Thus, a dike swarm seems to be the most satisfactory interpretation. It has the added attraction of providing feeder dikes for the extrusives of the inner wedge. The emplacement of the dikes could be controlled by fractures or minor faults.

The upper boundary of the dike swarm is diffuse, but almost invariably lies within the Orange-Purple megasequence. In rare cases, dikes are observed to intrude the sediments just above reflector Purple. The stratigraphic level of the upper edge of individual dikes provides a constraint on their maximum possible age. It ranges from pre-Orange to approximately Purple. The most reasonable interpretation is

that their emplacement was coeval with the formation of the inner wedge, although a younger age cannot be entirely excluded.

2.5.4 MEGASEQUENCE 2: FIRST DRIFT PHASE

The Purple-Red megasequence is the post-rift sedimentary sequence deposited on the Greenland continental margin and in the Norway Basin following the opening of the Norwegian-Greenland Sea. It comprises all sediments deposited between breakup and the onset of significant rifting on the Greenland margin.

Overall geometry

The sequence was disrupted post-depositionally by extensional faulting in the second rift phase. It is preserved, tilted to the east, along the eastern margin and on the fault blocks of the western margin. It is relatively uniform in thickness, but depocentres are present beneath both the eastern and the western slopes (Figs. 2.16 and 2.21, Apps. 5A and 4G). It can be followed to the edge of the westernmost fault blocks. Eastwards it thins into the Norway Basin. The upper boundary downlaps oceanic basement, whereas the lower part of the sequence interfingers with the volcanic top layer of the outer wedge.

Upper boundary

Reflector Red is a prominent unconformity marking a change in the pattern of sedimentation. Over most of the ridge it is relatively conformable with the underlying sequence. At the base of the abovelying sequence, a downslope thinning wedge of sediments downlaps the reflector towards the Norway Basin. At the northern end of the Jan Mayen Trough,

the boundary is clearly erosive in character. The slope
sediments are truncated at the boundary, which is in turn
overlain by a marine onlap sequence interpreted as a canyon
fill.

Sequence description

Systematic changes in external and internal geometry show
that two main depositional settings are present: shelf and
slope. The shelf sequence is found over much of the central
and western part of the ridge complex. It exhibits regular
parallel layering. Continuation of the sequence onto the
fault blocks of the present western margin is often
ambiguous due to the non-unique correlations across the
boundary faults. The simplest consistent interpretation of
the sequence in this western area (Fig. 2.16, App. 5A)
result in its continuation to the western edge of the
complex of fault blocks without large variations in
thickness. Nevertheless some differential subsidence is
indicated along the western margin. The subsidence seems to
be controlled by initial movements on some of the faults
that developed into the fault complex at the western margin
in the second rift phase.

A change to a gently diverging and converging reflector
pattern on the eastern margin, together with the occurrence
of progradational clinoforms, indicates the initial
formation of a shelfedge and slope facing the Norway Basin.
On the lower slope off the central part of the North Ridge,
the external form, as well as the internal structure of the
uppermost depositional sequences, indicates the presence of
a large submarine fan.
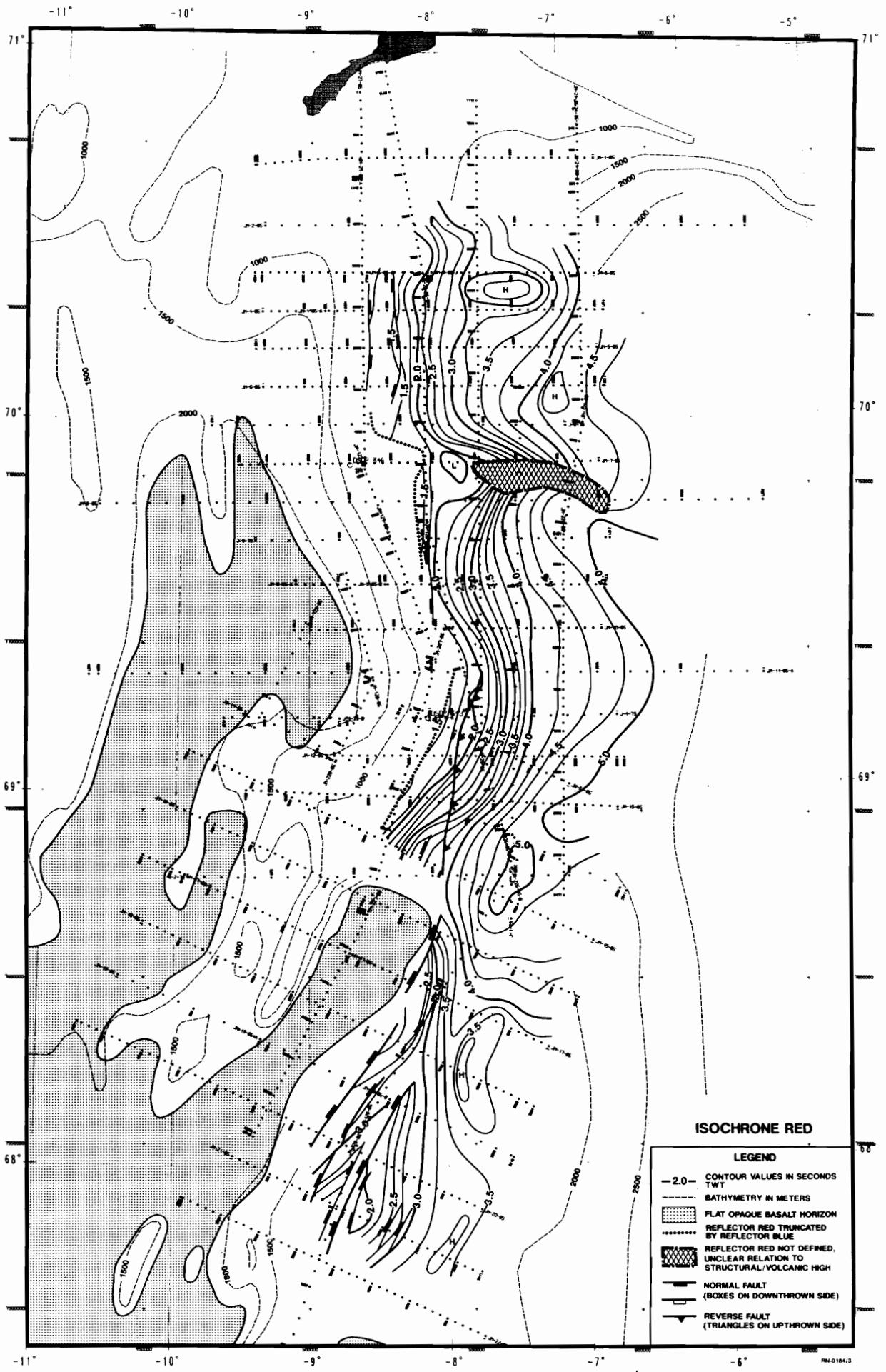
Fig 2.20   Isochrone map of reflector Red
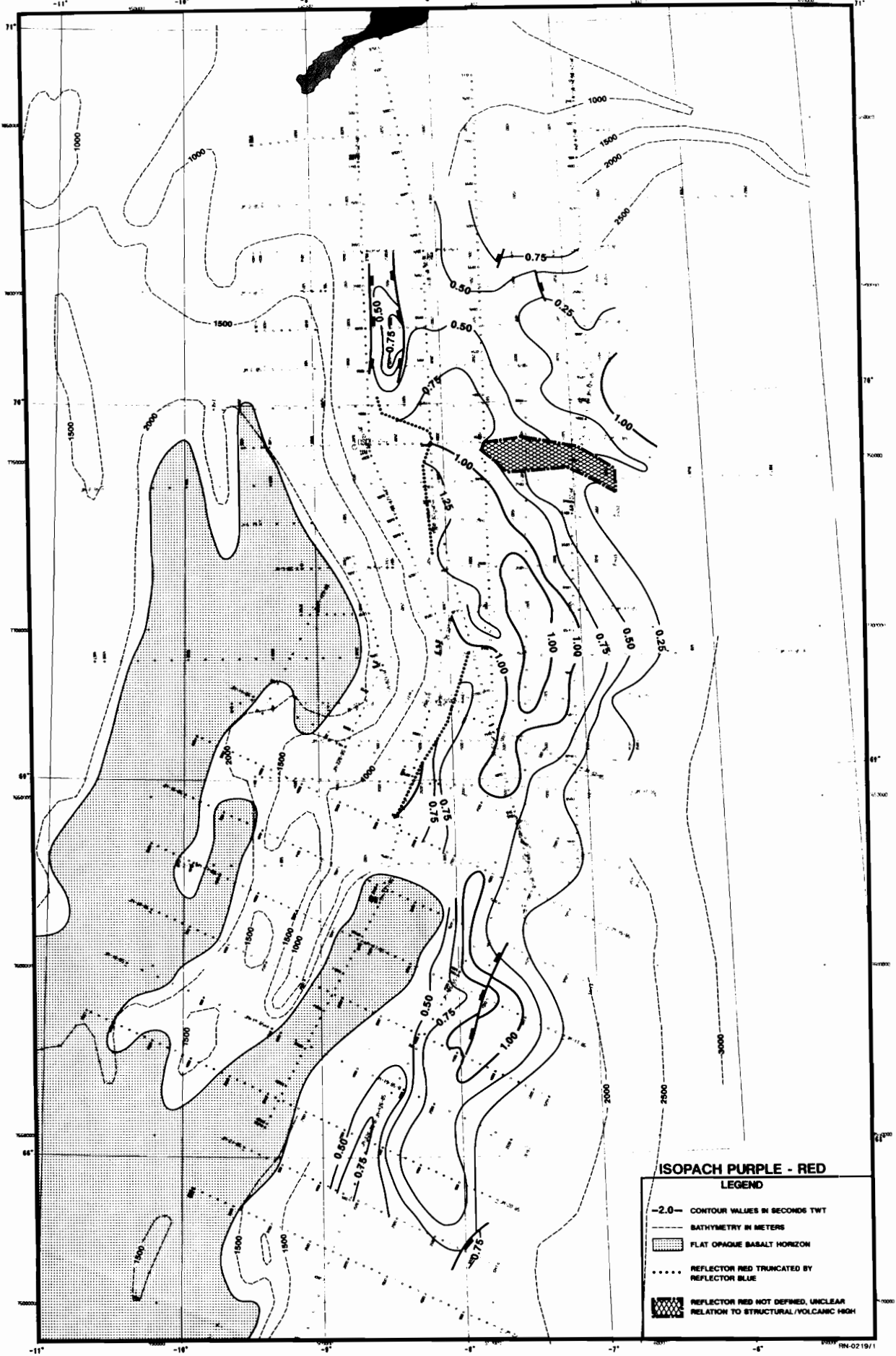
Fig 2.21   Isopach map of the Purple - Red megasequence

Tectonism and sedimentation

During the early drift phase, when the sequence was being
deposited, Norway Basin gradually opened and deepened and
the Greenland continental margin subsided beneath sea
level. Evidence for the marine conditions at the base of
the sequence comes from the northeast facing volcanic scarp
on the North Ridge, mapped at the level of reflector Purple
and interpreted as being caused by the quenching of lava
flows at a shoreline. This indicates that the outer
continental margin subsided below sea level soon after
breakup and that most of the sequence consists of marine
sediments. The lower part sequence was deposited coevally
with extensive volcanism at the outer wedge of dipping
reflectors in the Norway Basin.

A shelfedge was formed on the eastern margin of the Jan
Mayen Ridge. The geometry of the sequence indicates
abundant sediment supply to the margin from an eastern
source and implies erosion of an uplifted provenance area
in the Greenland hinterland.

Vertical aggradation of the shelf and outbuilding of the
slope, evident along the entire eastern margin, indicates
that, as the Norway Basin gradually opened and subsided,
the growth in the space available to accomodate sediments
beneath erosional base level outpaced sediment supply to
the margin. Subsidence of the margin was probably thermally
driven at this stage and mostly flexural in character. Yet,
there are clear signs of some faulting within the interval.
A rift basin was probably initiated on the shelf, but did
not develop to become a significant sediment trap, because
sediment supply to the eastern slope continued throughout
the Purple-Red interval at a high rate. On the southern
part of the North Ridge and on the the Transverse Ridge,
there are indications of an event in the middle part of the
sequence of much reduced vertical aggradation of the shelf

contemporaneously with continued outbuilding of the slope. This can be explained by a relative fall in sealevel and may be caused by the phase of extension indicated by the faulting.

2.5.5 MEGASEQUENCE 3: SECOND RIFT PHASE

The Red-Pink megasequence is the syn-rift sequence deposited during the second rift phase when the ridge was being separated from the Greenland margin.

Overall geometry

The sequence has an irregular geometry and exhibits a variety of depositional forms related to tectonic movements. The internal unconformities Yellow, Turquoise and Blue divide it into four subsequences which record different stages in the development of the rift along the western margin. The upper boundary of the sequence, reflector Pink, interpreted to mark breakup on the western margin, has not been identified with certainty on the eastern margin. An isopach map was therefore constructed for the Red-Blue interval (Fig. 2.23, App. 4H).

Sequence description

Sequence Red-Yellow exhibits variable thickness. South of the Transverse Ridge it defines a wedge of sediments downlapping reflector Red on the upper slope and thinning markedly into the Norway Basin. Although some faulting is associated with reflector Red, the sequence pre-dates most of the fault movements at the western margin.

Reflector Yellow is a tectonic unconformity marking the onset of the main phase of faulting and sequence Yellow-Turquoise spans the earliest sediments deposited syntectonically in response to this phase. On the eastern margin it forms the uppermost part of the downlap sequence, whereas on the western margin it defines restricted steep fans at some of the boundary faults.

Sequence Turquoise-Blue exhibits large thickness variations as a result of differential subsidence and syntectonic sedimentation. On the western margin, the sequence fills the rift basins and half-grabens. On the eastern margin, two different sequence morphologies are observed. South of the Transverse Ridge, the sequence is thin on the slope, but it thickens into the ocean basin at the foot of the slope. North of the ridge there is a thick stack of evenly layered sediments.

Reflector Blue (Fig. 2.22, App. 4E) is a marked unconformity over the entire ridge. It is truncated at some of the major boundary faults at the western margin, because of minor fault movements or erosion post-dating the reflector, but it clearly post-dates the main phase of faulting. On the North Ridge the reflector represents a prominent angular unconformity caused by uplift and erosion, which is estimated to have removed up to 1000-1500 m of sediments. On the western margin, it can be traced underneath the edge of the igneous marker, reflector Green.

Sequence Blue-Pink records the final infilling of the rift basins at the western margin and levelling of the seafloor to a plain.
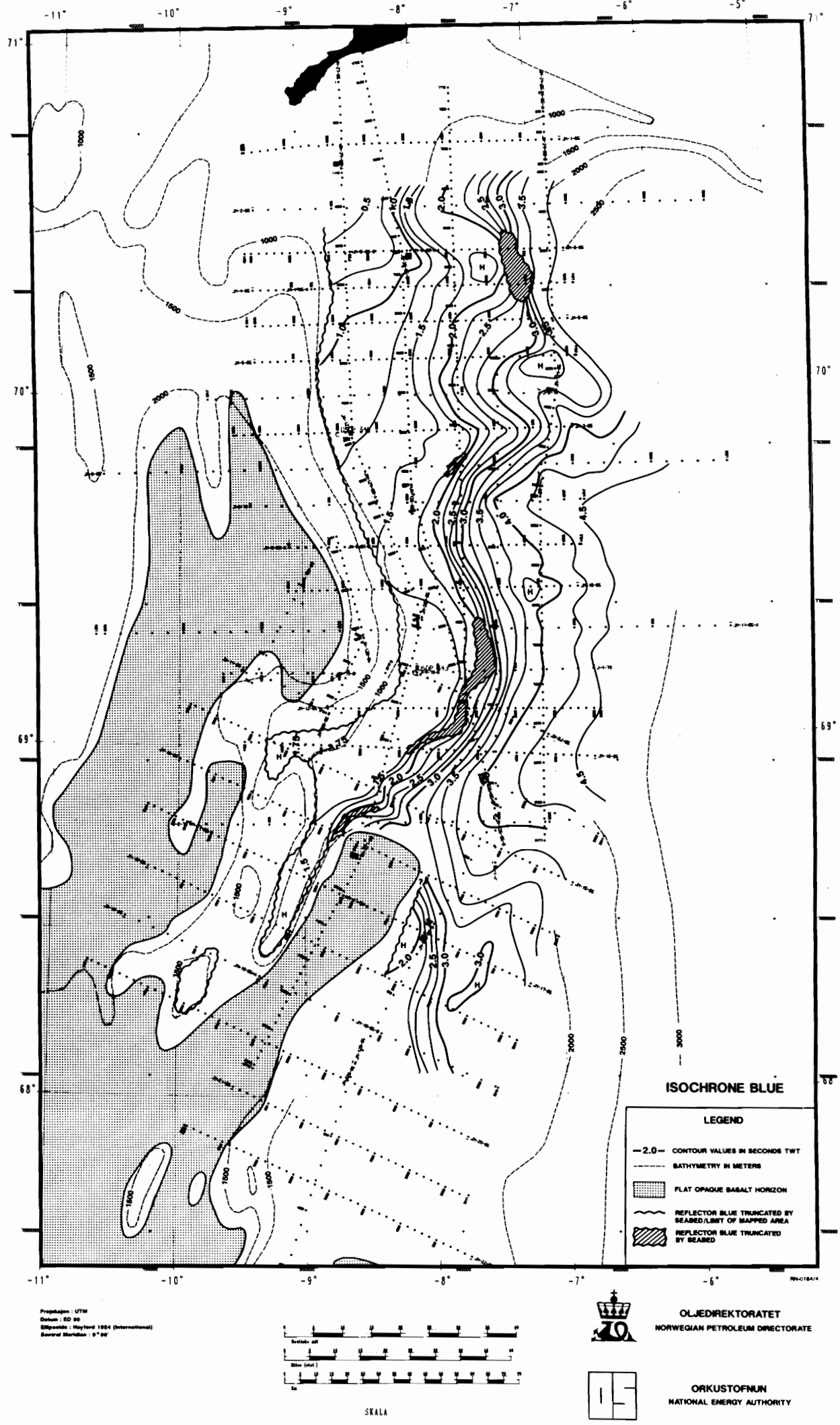
Fig 2.22   Isochrone map of reflector Blue

ISOPACH RED - BLUE

LEGEND

—2.0—	CONTOUR VALUES IN SECONDS TWT
— — —	BATHYMETRY IN METERS
	FLAT OPAQUE BASALT HORIZON
	REFLECTOR BLUE TRUNCATED BY SEABED
········	REFLECTOR RED TRUNCATED BY REFLECTOR BLUE
	REFLECTOR RED NOT DEFINED, UNCLEAR RELATION TO STRUCTURAL/VOLCANIC HIGH

Projeksjon : UTM
Datum : ED 50
Ellipsoide : Hayford 1924 (International)
Sentral Meridian : 9° 00'

SKALA

OLJEDIREKTORATET
NORWEGIAN PETROLEUM DIRECTORATE

ORKUSTOFNUN
NATIONAL ENERGY AUTHORITY

Fig 2.23   Isopach map of the Red - Blue megasequence

Tectonism and sedimentation

Contemporaneously with the development of the rift on the
Greenland shelf, the Jan Mayen Ridge, which formed the
eastern rift flank on the outer continental margin, was
fragmented into rift basins and faulted ridges. This was
accompanied by the emplacement of sills at the eastern
margin. The larger fault blocks were uplifted and tilted
eastwards. The North Ridge was uplifted above sea level and
eroded extensively. Following the main phase of faulting,
thermal subsidence set in over the whole ridge complex
prior to breakup, and the North Ridge was submerged.

The pattern of sedimentation underwent radical changes
during the deposition of the sequence as a result of
faulting and differential vertical movements. Four phases
of sedimentation are discernible, corresponding to the four
depositional sequences.

The sediments deposited in the first phase (sequence Red-
Yellow) record mild uplift and tilting of the faultblocks
which formed the eastern rift flank, coevally with
subsidence of the rift basins. The basins began trapping
sediments and, as a result, sediments deposited on the
slope towards the Norway basin were increasingly derived
from the eastern rift flank. South of the Transverse Ridge,
a basinward thinning and downlapping wedge was deposited on
the upper slope. A prominent submarine canyon was formed at
the mouth of the Jan Mayen Trough, probably as a result of
the steepening of the slope. A thin sheet of sediments
deposited on the eastern margin north of the Transverse
Ridge indicates that the uplift and tilting was less marked
there.

In the second phase (Yellow-Turquoise), the rift basins on
the western margin started to subside rapidly. Eastwards
rotation of the larger fault blocks caused their western
edges to be further uplifted coevally with subsidence of

the intervening half grabens. The North Ridge rose above
sea level, but none of the fault blocks in the Southern
Ridge Complex were exposed. At the same time as the North
Ridge was established as a strongly eroded local provenance
area, the deepening rift at the western margin began to
trap all sediments derived from the Greenland side. On the
eastern margin, south of the Transverse Ridge, the slope
steepened and to a larger degree the sediments were carried
into the basin and deposited as submarine fans. North of
the Transverse Ridge, a downlap wedge was deposited. The
wedge is similar to the wedge deposited south of the ridge
in the first phase and its presence indicates that the
uplift of the North Ridge propagated northwards.

At the onset of the third phase (Turquoise-Blue), the rift
basins were already established and many faults had become
inactive. Yet, extensional movements continued on many of
the major faults. There is clear evidence that the tectonic
regime acquired a coexisting component of compression.
Uplift and the rate of erosion culminated on the North
Ridge and a large amount of sediments was shed into the
surrounding basins. On the western margin the sediments
were transported by turbidity currents into the rift where
they accumulated as a stratified fan complex filling in the
many grabens and halfgrabens. On the eastern margin, the
sedimentation was dominated by massflow down the eastern
slope. Different depositional regimes continued to exist on
either side of the Transverse Ridge. South of the ridge,
overlapping fans initially built a slope front fill.
Towards the end of the phase, the sediment input to the
slope reached a near- catastrophic rate. A number of
transversely oriented channels were formed as turbitidy
currents eroded into the sediments deposited earlier as a
slope front fill. Between the closely spaced channels some
sediment was deposited on overlapping levees, but most of
it was carried further into the basin where coalescing fans
built a sedimentary apron on the rise and filled an
emerging depocentre at the mouth of the Jan Mayen Trough.

North of the Transverse Ridge, the slope was wider and much
gentler than further south. The sediments eroded from the
exposed top of the ridge accumulated as a thick and well
stratified stack of turbidites. At the end of the phase,
the top of the sequence was exposed to subaerial erosion
and a large canyon was carved into it by turbidity currents
carrying sediments deeper into the Norway Basin.

In the last phase (Blue-Pink), fault movements ceased and
thermal subsidence set in over the whole ridge complex. The
rift basins of the western margin were levelled to a plain
by sediments derived from the unstable western slopes.

2.5.6 INTRUSIVES AT THE WESTERN MARGIN

At an average depth of 350-500 m below the seafloor, an
extensive flatlying high-amplitude reflector, reflector
Green, covers the major rift basins at the western margin
and masks the underlying structure. No real energy is
returned from below the reflector except at its northern
and eastern edge in the Jan Mayen Basin.

Description

In cross section (Fig. 2.16, App. 5A) the reflector is
composed of a number of segments with sharply defined
edges. The individual reflector segments are straight and
horizontal and range in length from 1-25 km. The grid of
reflection lines available is too coarse to define the
planform of their edges.

Normally the reflection signature is just one cycle, but in
a number of cases several cycles are observed, indicating
some internal structure. In at least two cases a clear

double reflection is observed from the same segment.
Although individual segments are straight and horizontal,
they are not smooth on a horizontal scale of hundreds of
meters.

The areal extent of the reflector appears to be controlled
by the bathymetric relief at the western margin, which in
turn reflects the underlying structure. The reflector
covers the Jan Mayen Basin, the Jan Mayen Trough, part of
Rift "A" west of DSDP site 350 and the region to the
southwest of these basins. The total areal extent within
the study area is approximately 12 000 km^2 (Fig. 2.13,
App. 4B).

In each basin the larger reflector segments form extensive
flats with a well defined average depth level. Few segments
are found shallower than 100 ms twt (90 m) above this
level. Short deeperlying segments are common, the maximum
offset being 300 ms (250 m). The average depth to the
reflector ranges from 3.5 s twt in the Jan Mayen Basin to
3.2 s twt in the Jan Mayen Trough and in Rift "A". In view
of the large area covered by the reflector, this depth
range (corresponding to some 250 m) is remarkably narrow.

In the major rift basins, the reflector's boundary is an
easily mappable sharp edge, which either abuts against the
the raised tectonic relief or terminates abruptly on the
basin plain. At the western flank of the North Ridge,
sedimentary layers and faults in the listric fault complex
are occasionally traceable a few km beneath the reflector's
edge.

West and southwest of the Jan Mayen Basin, the Iceland
Plateau is covered by a smooth and opaque basement
reflector (Eldholm and Windish, 1974; Eldholm and Talwani,
1977; Olafsson, 1983). Although it is somewhat more rugged
and in places tilted by faulting, this reflector is similar
in appearance to reflector Green. It was reached by DSDP

hole 348, sited at anomaly 6A, and found to be basalt, probably a sill (Talwani, Udintsev et al., 1976).

North of approximately 69N, reflector Green terminates against the northerly striking basement high, which marks the western structural boundary of the Jan Mayen Basin and coincides roughly with the oldest seafloor spreading anomaly identified on the Iceland Plateau.

South of 69N, the Jan Mayen Basin lacks a structural boundary to the southwest and reflector Green can be followed onto undisputable oceanic crust on the Iceland Plateau where it merges with the opaque basement horizon without other discontinuity than the characteristic stepping. The only observable difference is that the opaque horizon on the Iceland Plateau is somewhat more irregular than reflector Green and the extensive flats defined by the latter in the rift basins are lacking. As the opaque reflector is followed towards Iceland it shallows by upward stepping, but retains its high reflectivity.

Stratigraphic position

Constraints on the age and origin of reflector Green are provided by its stratigraphic position within the sedimentary succession. Individual reflector segments lie at different stratigraphic levels but are conformable with the sedimentary succession. This follows from observations between the two edges of different segments, where a horizontally layered sequence is observed from above the edges down to the intervening segment at deeper level. Commonly, the two edges are joined by a sedimentary interface at exactly the same level. In the Jan Mayen Basin, reflector Blue dips underneath its eastern edge of reflector Green and reflector Pink continues into the basin within the sedimentary sequence above it. At the northern end of the Jan Mayen Trough, reflector Green lies 300 ms

twt above reflector Blue. In the eastern part of the Jan
Mayen Basin, reflector Pink typically lies some 100 ms twt
above reflector Green, but merges with it in the central
and western part of the basin. The stratigraphic position
of reflector Green is therefore high within the late rift
sequence above reflector Blue, a major part being at the
level of reflector Pink.

Origin and emplacement

Reflector Green is interpreted as being igneous in nature.
A sedimentary origin is not supported by the data. The fact
that the reflector is areally restricted to the basin
plains of the western margin and yet covers them only
partially, excludes pelagic deposits and airborne ash. A
sediment mass transport mechanism may explain the areal
configuration, but the large reflection coefficient rules
out most such deposits. Although submarine debris flows and
slides are commonly highly reflective and structureless,
they leave scars on the slope from which they derive. No
large scars are observed on the western margin. A gas
hydrate layer would not generate such a strong reflection.
Thus, we are left with submarine lava flows or sills, an
interpretation strongly supported by the reflector's
lateral association with and similar appearance to the
opaque reflector on the Iceland Plateau.

Reflector Green defines a horizontal surface high within
the postrift basin fill sequence of the western margin. The
basin plains must have been nearly horisontal at the time
of its emplacement. Significant fault related subsidence of
the basins with respect to the ridges, post-dating
reflector Green, can be excluded. Any later component of
differential thermal subsidence should have flexured or
tilted the reflector. This appears unlikely in view of the
present horizontal attitude of the reflector over the large
area it covers. Because of the smoothness of the erosional

surface defined by reflector Blue on the North Ridge and
lack of erosional channels at its edge, sea level cannot
have fallen significantly below the top of the ridge. Thus,
most of the present day level difference between the basin
plains and ridges had already been established when the
igneous complex was emplaced. A reconstruction to the time
of emplacement of reflector Green indicates that water
depths above the basin plains were of the order of 1000 m
and implies a submarine origin for the layered volcanic
basement at the western margin of the Jan Mayen Basin.

An examination of the sedimentary layering above the
reflector does not yield a single unambiguous case of a
step being caused by faulting. In one case, where the
reflector is transparent, a prominent offset can be shown
to be unrelated to faulting. However, up to a level just
above reflector Pink, the sediments above reflector Green
are commonly raised above individual segments and slightly
stepped or kinked over the edges. This phenomenon needs not
be explained by faulting, alternative interpretations being
uplift by sill intrusion or differential compaction over
sills or lava flows.

Although it is possible that the reflector's characteristic
stepping was caused by tectonic disruption of a previously
level and continuous surface, it is unlikely that the
igneous complex represented by the reflector was derived
from a single point or fissure source. The mechanics of
horizontal submarine and subterranean magma transport make
the possibility of a single source covering an area of more
than 12 000 km^2 highly unlikely. Therefore, reflector Green
is interpreted as being caused by locally derived igneous
units, either sills or submarine lava flows, imbedded at
different stratigraphic levels within the sedimentary
sequence. It follows that overlap between the individual
segments should be common, reflector Green representing
only the upper surface of the complex. The fact that no
gaps in the surface are found at the edges of different

segments indicates that this is the case.

There appears to be no unique way of discriminating between sills and lava flows with the available data. Sill complexes on the Norwegian Margin, in the Rockall Trough and on the eastern margin of the Jan Mayen Ridge all show examples of discordant sills. Large flats at approximately constant depth level, such as those defined by reflector Green are lacking, strongly indicating a different emplacement setting for this reflector. The narrow depth range to the reflector can be explained by emplacement at a horizontal surface where the magma pressure suddenly fell below the prevailing hydrostatic or lithostatic pressure. This in turn indicates emplacement at or just below seafloor where the pressure gradient is steepest. Additional evidence for emplacement close to the seafloor comes from the overlying megasequence.

The igneous nature of reflector Green, its areal distribution, similarity to the Iceland Plateau opaque horizon and lack of structural offset between the two reflectors at anomaly 7 south of 69N indicate that it formed at breakup west of the ridge, but this cannot be proven by seismic stratigraphic means.

2.5.7 MEGASEQUENCE 4: SECOND DRIFT PHASE

The sedimentary sequence above reflector Pink was deposited in the second drift phase when seafloor spreading was established on the Iceland Plateau.

Reflector Pink is defined on the western slopes of the North Ridge, where in places it defines submarine erosional channels. The abovelying sequence pinches out in the updip direction where the slope is steepest just beneath the flat top of the ridge, but its presence there cannot be

excluded. The sequence steps onto oceanic basement on the Iceland Plateau and therefore post-dates breakup, but because reflector Pink merges with reflector Green in the western part of the Jan Mayen Basin, this may not apply to the whole sequence. A thin unit at the base may be masked by reflector Green and possibly pre-date the oldest oceanic crust.

Assuming that reflector Green was emplaced just before or at breakup, the part of the sequence above reflector Pink which continues onto oceanic basement may be stripped away to reveal the situation at breakup (Fig 2.19, App. 5C). This shows that reflector Green lay at the seafloor in the western part of the Jan Mayen Basin and just beneath it further east and that reflector Pink was formed approximately at the same time.

The sediments in the sequence above reflector Pink, seem to have been derived from the slopes at the western margin. This may be explained by the steepness of the slopes which probably rendered them unstable. In the upper part of the sequence, the sediments are expected to become increasingly pelagic. A minimum estimate of this component is provided by the thickness of the thin layer covering the top of the North Ridge.

The stratigraphic position of reflector Pink at the eastern margin, indicated on Figure 2.12, is only tentative because firm ties from the western margin are lacking.

ISOPACH BLUE - SEABED

LEGEND

—2.0— CONTOUR VALUES IN SECONDS TWT

‑‑‑‑‑‑ BATHYMETRY IN METERS

▨ FLAT OPAQUE BASALT HORIZON

∿∿ REFLECTOR BLUE TRUNCATED BY
SEABED/LIMIT OF MAPPED AREA

▧ REFLECTOR BLUE TRUNCATED
BY SEABED

Projeksjon : UTM
Datum : ED 50
Ellipsoide : Hayford 1924 (International)
Sentral Meridian : 9°00'

SKALA

OLJEDIREKTORATET

NORWEGIAN PETROLEUM DIRECTORATE

ORKUSTOFNUN

NATIONAL ENERGY AUTHORITY

Fig. 2.24 Isopach map of the sequence above reflector Blue

3 HYDROCARBON RESOURCE POTENTIAL OF THE JAN MAYEN RIDGE

Two main sedimentary sequences on the Jan Mayen Ridge
should be investigated for possible hydrocarbon generation
and accumulation, the Tertiary post-rift sediments and the
older sediments below the early Tertiary basalts. The post-
rift sediments are transparent and easily detectable by
seismic reflection methods. Some information about their
nature is available from the DSDP-boreholes on the ridge
and in other locations in the Norwegian-Greenland Sea,
boreholes on the Norwegian shelf and a few onshore
localities on Greenland. Their hydrocarbon generating
potential must be considered uncertain, as is indicated by
the discussion of relevant data below.

Estimation of the potential of the sediments below the
basalts is hampered by lack of samples from these strata.
Our knowledge of their distribution, thickness and
stratigraphy is limited. The conjugate margins of the Jan
Mayen microcontinent, the Møre margin of Norway and the
central East Greenland margin, were adjacent to the
microcontinent in pre-rift times and were part of the same
sedimentary environment. In absence of any direct
information on the hydrocarbon potential of the Jan Mayen
area, a comparison with the results of hydrocarbon
prospecting on these conjugate margins is of great interest
(cf. chapter 2.1.5)

3.1 POTENTIAL SOURCE ROCKS

3.1.1 TERTIARY POST-RIFT SOURCE ROCKS

Results from organic geochemical studies of cores from leg 38 of the Deep Sea Drilling Project generally indicate that the Tertiary sediments of the Norwegian-Greenland Sea have little hydrocarbon potential (Kvenvolden, 1976). The only positive opinion is expressed by Erdman and Schorno (1976). Based on analysis of 5 samples from sites 346 and 349 they found total organic contents (TOC) in the range .18 % - 1.04%. They conclude that the sediments in general are relatively rich in organic carbon, including marine organic matter that could be favorable for oil generation. Oil genesis in the samples they studied was however at a very early stage. The source rock characteristics of partly the same cores were measured by Hood et al. (1976). They found slightly higher TOC-values, highest effective carbon contents not exceeding 0.22%, and the same low maturation level as the previous authors. Their conclusion is however that it is doubtful whether the sediments contain enough hydrocarbon-generating material to be considered potential source-rocks.

Dillon et al. (1986) have recently reviewed the resource potential of the western North-Atlantic basin, i.e. the deep sea basin east of North America. This environment is possibly comparable to the Norway Basin and the Jan Mayen Ridge area, and general conclusions could be applicable to both areas. No evidence is found of Tertiary beds so rich in organic material, that they could be considered as source beds.

A cautionary note is appropriate here, as the Tertiary sediments have not been fully sampled yet. According to a paleogeographical study of the Norwegian-Greenland Seas by Grønlie et al. (1979), the opening ocean basins were restricted to the south by the emergent Iceland-Faeroe

Ridge until in Middle Miocene time (about 13 Ma), and a full opening towards the north, the Arctic Sea, formed at anomaly 13 time (36 Ma). During the time of restricted water exchange the conditions in these relatively narrow and shallow ocean basins (Norway, Lofoten and Greenland Basins) could have led to stagnation (reducing conditions) and accumulation of organic matter in the sediments. The study indicates that the boreholes of the Deep Sea Drilling Project in the Norwegian-Greenland Sea did not penetrate these deep basinal sediments that accumulated in the first phase of the formation of the sea-floor (Eocene time). These early Tertiary sediments, that are e.g. found below the lowermost eastern slopes of the Jan Mayen Ridge, could therefore possibly be source rocks.

3.1.2   SOURCE ROCKS IN PRE-RIFT STRATA

The seismic detection of sedimentary layers of presumable Mesozoic and Paleozoic age below the early Tertiary basalts, generally improves the hydrocarbon potential of the Jan Mayen area. These strata are most clearly imaged in the south-eastern part of the North Ridge, under the eastern flank (Figs. 2.12, 2.16, 3.1, 3.3, Appendix 5). No direct information is available about the lithology of these pre-rift continental sediments, so we can only assume that the sediments of the Jan Mayen Ridge are similar to those found on the continental margins on both sides of the ocean (Figs. 2.8 and 2.9). On both margins sediments of all lithologies required for hydrocarbon accumulation are known, from Upper Permian to Lower Cretaceous age (Fig. 2.9). Upper Jurassic shales and Middle Jurassic sandstones are the most prolific combination of source and reservoir rock. Although the geophysical data indicate the existence of pre-rift sediments under the JMR, we see no way to assess which part of the Mesozoic or Paleozoic sequence is present. Drilling will be needed to get this information.

The Jan Mayen Ridge remained as part of the Greenland continental margin during the first phase of seafloor spreading in the Norwegian-Greenland Sea, and its geological history is probably closer to that of Greenland than of Norway. A commercial group has carried out some prospecting, including acquisition of seismic reflection data, on Jameson Land. So far no exact information is available about the results, but drilling is evaluated, so there are positive indications. In their evaluation of the hydrocarbon potential of this basin, Surlyk et al. (1984) point to a major sequence of black shales, which occur throughout the basin and are of Upper Permian age. These shales are rich in organic matter, and would be a good source rock for oil, given the appropriate maturity. The exposed sediments are generally on the immature side, but over-mature where locally affected by Tertiary volcanic intrusions. Listed as other possible source-beds (Surlyk et al. 1986) are the Graaklint beds of the Middle Triassic Gipsdalen Fm., the lowermost Jurassic Kap Stuart Fm. with some coals interbedded with shales and sands, and a laterally consistent shale unit of Middle Jurassic age, the Sortehat member of the Vardekløft Fm.. Upper Jurassic shales are the most promising source rocks, except for their lack of maturation as they are found at shallow depth. These Jurassic formations are the equivalent of the very productive Kimmeridgian formations of the North Sea, and would be very promising if they are also found offshore buried at greater depth.

It appears that the source rocks of Jameson Land are generally not mature for peak oil production, except possibly a part of the Permian shales. If a similar sedimentary sequence is present in the Jan Mayen Ridge, such problems would be less serious. The greater over-burden of Tertiary basalts and sediments should have led to a higher temperature regime and more advanced maturation of organic matter. In the following section on maturation modelling, an attempt is made to estimate these effects.

3.1.3   SAMPLING AND ANALYSIS OF HYDROCARBONS

The only optimistic reports of sampling and
analysis of gases in shallow cores in the Jan Mayen area
are from a cruise of the Soviet research ship Akademic
Kurchatov, that investigated the Jan Mayen area in 1971
and 1973.   These investigations included an analysis of
gases in a few bottom cores.   Traces of hydrocarbons were
found in samples from water depths of about 1200 to 1500 m
in the southern area, that included methane and heavier
hydrocarbons.   These results were interpreted by the Soviet
scientists as indications of deep hydrocarbon sources of
possible economic importance (Geodekyan et al., 1980).
In general, a correlation was observed between thickness of
sediments and amounts of hydrocarbons in shallow cores in
the seas north and northeast of Iceland.   The results of
the measurements were handed over to Orkustofnun, and
Oljedirektoratet was later asked to give their opinion (See
letter by Egil Bergsager, Oljedirektoratet, to Gudmundur
Palmason, Orkustofnun, E/b/IO, 16.2.,81, including appendix
by SSE).   This analysis indicated that the amount of gas
was not exceptionally high and could well have had its
source in shallow low-temperature chemical or biochemical
processes, and that the composition and distribution with
depth did not indicate migration of gas from deep sources.

3.1.4   HYDROCARBON MATURATION MODELLING

Methods have been developed to estimate the degree of
maturation of organic material in sediments. Many
parameters must be known to do these calculations with some
degree of accuracy. The dominant parameter is however the
temperature-history of the various layers - which is
dependent on subsidence and depth of burial on one hand,
and heat flow and temperature gradient on the other. Such

modelling has been attempted at relevant positions on the
JMR to get some idea about the level of maturation. Our
results are only approximate, as the constraints are not
known in any detail. The method used is based on kerogen
maturation as described by Tissot and Welte (1978), and
Waples (1980). The methods are calibrated to data from
wells on the Norwegian shelf. Also for sediment
conductivity and porosity-changes through
compaction/decompaction, Norwegian well-data have been used
for calibration of the computer-modelling.

The accuracy of our calculations is limited by the lack of
a reliable subsidence history, and the insufficient
knowledge of heat flow through time. The only available
measurements of heat flow in the area are reported by
Sundvor and Myhre (1987), who measured the temperature
gradient and conductivity in the upper few meters below
sea-bottom. They found the heat flow today to be about 85
mW/m^2 just west of the JMR, and about 65-70mW/m^2 on top of
the ridge and on the eastern flank. The early- and mid-
Tertiary rifting episodes were certainly associated with
higher heat flow, which have affected all possible source
levels. Post-rift intrusions (sills) are also observed.
Their effect is expected to have been to increase the
maturation locally , but regional effects can not be ruled
out, especially on the lower eastern flank of the ridge.
The level of maturation is strongly influenced by the
highest temperature experienced - so the heatpulses will
have had a large impact on maturation in the area. The fact
that the area previously has experienced higher heat-flow,
supposedly has a generally negative effect on the present
effective expulsion of hydrocarbons from mature source-
rock, since lowering of temperature tends to reduce the
expulsion effiency.

In order to account for the uncertainties in the heat flow
history two heat flow models have been used, a low heat
flow case assuming 70 mW/m^2 from the deposition, and a high

heat flow case assuming 100 mW/m^2. Both models assume
constant heat flow through time. A more realistic model
assuming heat flow decay during the last 25 Ma, would
result in maturation values between the two extreme cases.

Four sites along seismic line JM-12-85 have been modelled.
Their position is shown in Fig 3.1. Site 1 is located in
the downfaulted west flank of the North Ridge, site 2 in
blockfaulted terrain on the central part of the ridge, site
3 on the upthrust faultblock on the eastern flank, and site
4 further down the eastern flank. The pre-opening strata
observed at sites 3 and 4 are assumed to be present also at
sites 1 and 2, and to represent Mesozoic sediments.
Uncertainties are additionally introduced by the depth
conversion being based on seismic stacking velocities.

The estimated subsidence curves for the four sites are
shown in Fig 3.2. The questionmarks reflect uncertainty in
the existence of and depth to the levels modelled. For
points 2 and 3 an Oligocene erosion of 500 m was assumed in
the calculations.

Results of the modelling are:

Site 1: Assuming relatively high heat flow the early
Eocene possible source-rocks have reached the oil-window.

Site 2: The Tertiary source-rocks are immature. Assuming
the postulated Mesozoic source-rocks to be at a depth of about
three km below the seafloor, they have passed into the gas-
window in the high heat flow case. With a moderate heat-
flow history they are presently in the oil-window.

Site 3: The Tertiary source-rocks are not likely to be
mature, but may have reached a very early oil-mature stage.
The postulated Mesozoic source rocks are assumed to be at a
depth of some 4 km below the sea-floor. In the high heat-
flow case this results in over-cooking of the organic

material, in a more moderate case the source-rocks are
presently producing gas. The burial of the pre-Purple
reflector Brown is however decreasing north of the site, so
the assumed Mesozoic source-levels may still be in the late
oil-window.

Site 4: The hypothetical Tertiary source-level is
presently at a burial depth of about 2- 2.5 km below sea-
bottom. With a moderate heat flow history it is early
oil-mature.

Again stressing the uncertainties in these calculations, we
conclude that the hypothetical early Tertiary source-rocks
are likely to be early oil-mature west of the ridge, and on
the eastern flank, while they are certain to be immature
beneath its top. The postulated Mesozoic source-levels are
likely to be in a main/late oil-window beneath the top of
the ridge, while they would be in the late oil-window/early
gas-window beneath the eastern flank. The post-Oligocene
decrease of heat-flow in the area may hamper the effective
expulsion of hydrocarbons today.
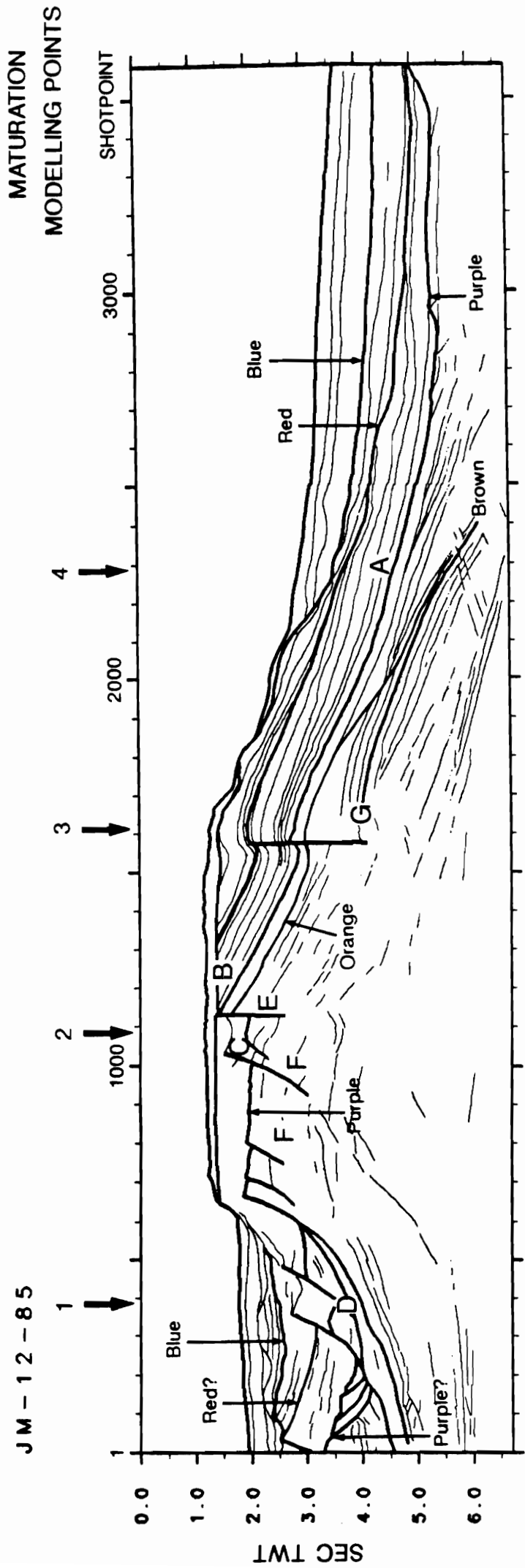
Fig 3.1 Interpretation of seismic line JM-12-85 across the Jan Mayen Ridge, showing sites where subsidence/maturation modelling has been carried out (cf. Fig.3.2). Letters show location of the principal hydrocarbon play types in the area, described in section 3.2.

RN-0218/2
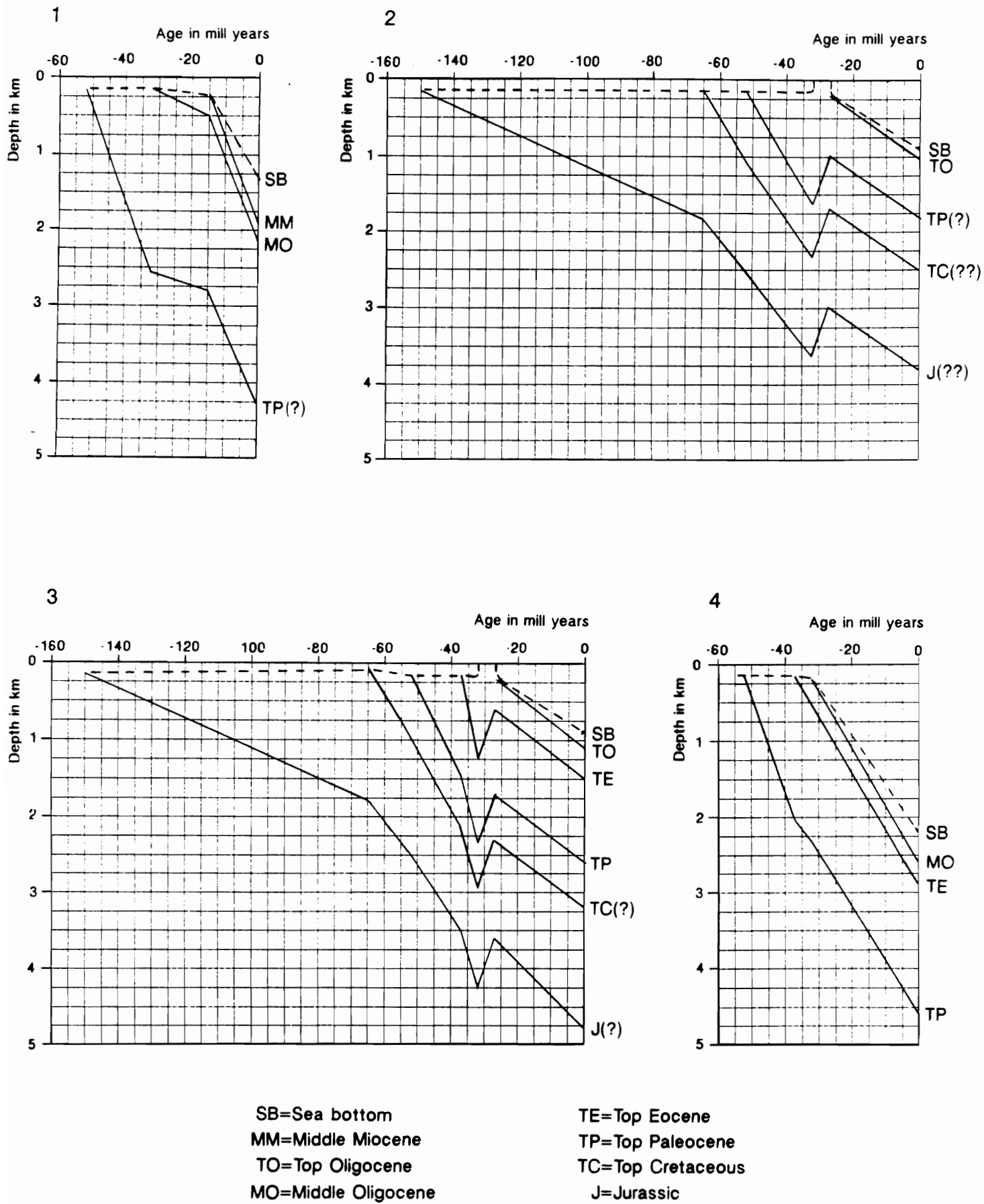
Fig 3.2   Subsidence curves for 4 sites on a transect across the Jan Mayen Ridge
           Location of the sites is shown in Fig 3.1.

SB=Sea bottom   TE=Top Eocene
MM=Middle Miocene   TP=Top Paleocene
TO=Top Oligocene   TC=Top Cretaceous
MO=Middle Oligocene   J=Jurassic

3.2 POTENTIAL HYDROCARBON TRAPS AND ASSOCIATED PLAYS

3.2.1 TERTIARY POST-RIFT PLAYS

The sequence of interest spans the time interval from the early Eocene deposition of reflector Purple to the formation of the mid-Oligocene unconformity (Reflector Blue). Data from the boreholes give no evidence of good reservoir or source rocks. The general lithology is mudstone with variable contents of silts and sands. The sampling of the relevant sequence is however far from complete, and thus some possibilities still exist. Sand contents up to 50% were measured in hole 349. Turbiditic processes and contour currents may result in the formation of sedimentary bodies with even higher sand contents the eastern flank of the ridge (A). (Block letters in parantheses denote different hydrocarbon play types . See also Fig. 3.1.) A well developed channel sequence lies buried within the continental rise of the southern U.S.A. (Dillon and Paul 1978). Similar channel-fill deposits have also been described for the continental slopes off New Jersey (Poag 1985) and Georges Bank (Schlee et al. 1985). Such stratigraphic traps might include coarse turbidites and debris-flows forming channel filling wedges. Alternatively, coarse strata in channel ridges could be sealed by fine-grained channel infill.

The deep sea fans associated with the formation of the channel system are also possible stratigraphic traps. They are seen deep in the section on the east flank of the Jan Mayen Ridge, and seem to form well defined wedges that pinch out updip (A) (Cf. chapter 2.5.5). Their location is just above the lowermost basinal post-rift sediments, which are the most likely source rocks in post-rift times.

Oil accumulation in structural traps must also be considered possible within the Tertiary sequence. Of interest would be the subcropping against the flat main

unconformity under the top of the ridge (B). This is however dependent on the ability of the thin overlying pelagic sediments to form an effective seal, which must be considered unlikely. Block faulting, most of which was terminated by the mid-Oligocene, has caused a number of structures on the crest of the ridge that could form traps given the right combination of porous sandstone beds and tight seals (C). Local source rocks are not likely to be mature, so hydrocarbons would either have to migrate laterally a long way from possible post-rift source rocks, or originate from pre-rift sediments below the basalts. Similar fault-blocks west of the ridge (D) have experienced deeper subsidence, possibly resulting in locally mature Tertiary source-rocks.

3.2.2 PRE-RIFT HYDROCARBON PLAYS

Again no direct information exists on the reservoir quality of the pre-rift sediments of the Jan Mayen Ridge. Potential reservoirs in the Jameson Land sedimentary basin on East Greenland include thick (100 m) Upper Permian limestone units. Their porosity and permeability is however presently unknown. The basal Triassic sequence contains coarse-grained bodies of fan delta origin, but their properties have not been properly investigated. Jurassic sandstones have excellent reservoir potentials, but form the surface of Jameson Land and are therefore useless there. If a good seal was formed on top of similar sandstones on the ·JMR, these rocks would be of great interest for oil prospecting.

By seeking an analogy in the geology of Greenland, it is possible that a layer of continental sandstone of Paleocene age exists just below the plateau basalts associated with horizon Purple. A layer of volcanic breccia could have formed at the base of the basaltic pile by the action of water. This raises the possibility of a reservoir at the base of the Tertiary basalts, capped by the lavas or the post-rift Tertiary sediments above.

Hydrocarbon traps below the basalts should be possible in the numerous fault-blocks that have resulted from the Oligocene tectonism that affected the crest and western slopes of the North Ridge. The faultblock just east of site 2 (E) is likely to be a trap - although its geometry is not known with certainty. Hydrocarbons may have migrated from deeper buried areas in the east, or from deeper locally mature source-rocks. A number of complex rotated fault blocks further west (F) could have received migrated hydrocarbons from the Jan Mayen Basin, if the pronounced listric faults act as migration routes, or from deeper buried local sources. More seismic information is however necessary to map these structures satisfactorily. No convincing pre-Purple reflectors have been observed in these locations - so the depth to, and even existence, of Mesozoic source/reservoir rocks is hypothetical.

The observed reflectors below the basalts under the south-eastern flank of the North Ridge are terminated to the west by an apparently reverse fault that has formed a high on the eastern side (G). This high is so far the most likely candidate for a hydrocarbon trap below horizon Purple. The strata of this basin have a general eastward dip and undulating topography that could create closures and traps against the western fault, or against unconformities truncating the dipping strata. Fig. 3.3.a shows an interpretation of a segment of the north-trending line JM-25 through the high just east of the fault. It shows southeast-dipping truncated strata, overlain with thin sediments of possible late Cretaceous to earliest Tertiary age, the plateau basalt and post-rift sediments. A map of reflector Brown is shown in fig 3.3.b. The unconformity associated with the reflector could be the top of a closed structure. Indications of flat-spots under the unconformity are interesting, but vague.

The Southern Ridge Complex is formed by large scale brittle

extension in the second rift phase which also block faulted the western flank of the North Ridge. The listric faulting has formed large rotated fault blocks (the "ridges") and local sedimentary basins, half grabens, in between. The fault blocks could trap hydrocarbons, and in the basins an increased temperature could accelerate oil formation. Perhaps the large scale faulting was detrimental in the sense that deep sections were exposed and the possibility of leaking increased.
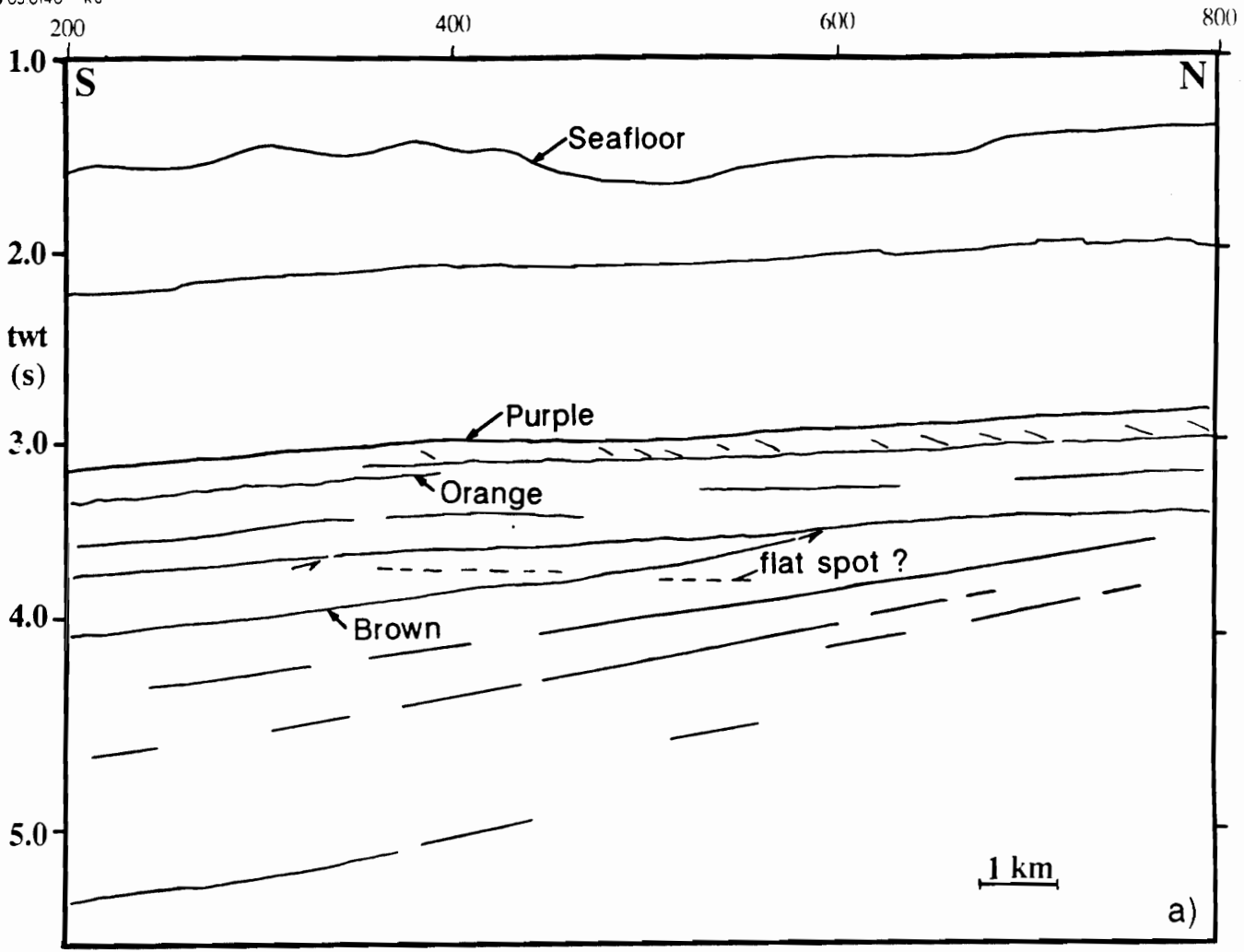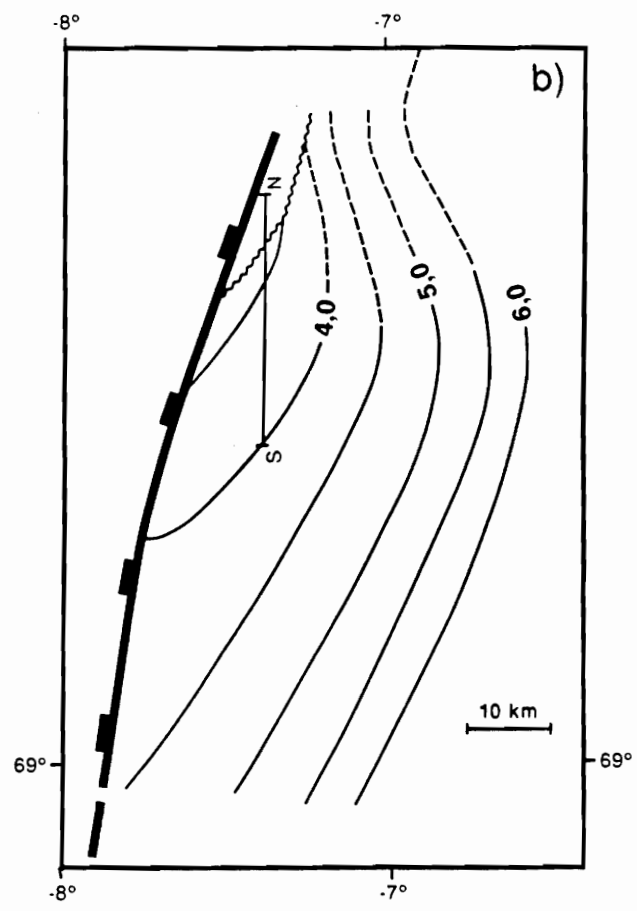
Figure 3.3

a) An interpretation of a segment of line JM-25-85
(sp 200-800). The seafloor and horizons Purple.
Orange and Brown are indicated.

b) Two way reflection time to horizon Brown. Bar shows
position of the line segment interpreted in Fig 3.3a).
The horizon is partly truncated by the fault and
partly by an unconformity. The horizon bends down
towards the south-east and disappears under the
wedge of seawards dipping basalts.

3.3 POCKMARK INDICATIONS

On the high flat plateau that forms the top of the North
Ridge, the migrated seismic data show a multitude of
crater-like depressions in the sea bottom between about 69°
00'N and $70^{\circ}20$'N, at water depths in the range 500-1000 m.
No similar depressions are detected outside this area. They
are variable in size, from being just detectable up to
measuring some 40 m in depth and 300 m in diameter. Some
have steep sides and flat bottoms, others are V-shaped,
besides other more irregular shapes. Occasionally the
edges are slightly raised. About 70 holes have been noted
on a roughly 150 km long and 20 km wide strip along the
ridge top, and their location is shown in Fig. 3.4.
Possibly we observe only some 3% of all the depressions, as
this is the approximate seismic coverage of the sea bottom.
This is based on the estimate that the effective swath of
the seismic search is 200 m wide on the sea-bottom, and the
average distance between lines in the area being about
6 km.

One cannot exclude the possibility that the holes are in
reality only cross sections of channels in the sea bottom.
Channels due to scouring of icebergs are known features in
northern latitudes, but hardly a likely explanation in this
case as no iceberg reaches a depth of 1000 m, even if the
marks were thought to be a remnant of the last glaciation.
We think it also unlikely that narrow erosion channels wind
their way accross the high plateau. These questions could
be answered by detailed 3-D bathymetric mapping survey,
including a side scan sonar survey.

It is tempting to compare the "craters" to the so-called
pockmarks, that are for example found in the bottom of the
North Sea (McQuillin & Fannin, 1979; Hovland 1981). These
craters are indeed common in fine grained sediments of many
continental shelfs and vary from 10 to some hundred meters
in diameter, on average well below hundred meters. Their

depth is proportional to the diameter, up to 15 m but usually around 5 m. Thus the observed craters on the Jan Mayen Ridge are in the upper range in size. Pockmarks are also not normally observable on conventional multichannel seismic lines because of the relatively low areal resolution of such data - so the parallel is inconclusive. Crater-like features are also observed in the Barents Sea (Solheim et al. 1985,1987,1988). Their origin is debated, one possibility being "eruptions" when gashydrates (cf. below) have become unstable and "gased out". Where observed, pockmarks are thought to be formed by seepage of gas through the sea-bottom. As this gas could be methane formed in situ at shallow depth, or other gases, the features are not thought to be a clear indicator of economic hydrocarbon accumulations, although indications of clustering of these holes around major hydrocarbon fields have been observed.

The distribution of the craters is not related to any bathymetric features or waterdepth, except that they are found on the flat top of the ridge. A comparison with the geological structures, as interpreted from seismic data, indicates that they cluster in areas of structural basement highs, and are furthermore associated with either faulting of horizon Purple or erosive truncation of sub-Purple strata. If the pockmark hypothesis is correct, these observations could indicate that the gas originates in deep geological formations, i.e. the sub-Purple sediments, rather than from shallow gas formations. The latter possibility must, however, be kept in mind, as gas hydrates (see below) could seal off shallow gases and channel these to high bathymetric positions.

Fig 3.4 Distribution of observed "craters" (circles) on
the Jan Mayen Ridge. Waterdepth in meters.

3.4 GAS HYDRATES

Gas hydrates are ice-like crystalline solids that form as a cage-like structure of water molecules surrounding a gas molecule. In nature the gas is most commonly methane (CH_4). Gas hydrates are stable below a temperature curve that increases with depth. A comparison of the phase boundary of methane hydrate and a typical temperature-depth curve for the sea and sediments of the Jan Mayen area shows that gas hydrates could occur at and below the sea bottom at water depths exceeding 300 m (see Fig. 3.6 a). The deep-sea temperature in the area is close to $0^{o}C$. The top of the gas hydrate layer will coincide with the sea bottom,and the hydrates will persist down to the depth where the phase boundary curve is intersected by the geothermal temperature curve. Below that depth, gas hydrate would be unstable and any gas would be dissolved in pore water or be present as free gas. The thickness of the gas hydrate layer increases therefore with increasing depth to the bottom, and decreases with increased geothermal gradient. As an example, we predict the thickness of the hydrate zone as about 420 m where water depth is at 2 km, 470m at 3 km and 340m at 1 km depth, assuming a gradient of $50^{o}C/km$. Because the geothermal gradient tends to vary little over sizeable areas, the base of the hydrates-region is often observed to be at approximately constant depth below the sea bottom and follow its undulations. This boundary is often recognized in seismic reflection surveys, and referred to as a bottom simulating reflector (BSR). These are widely found, e.g. on the continental margin of the eastern USA as summarized by Dillon et al. (1986), and off the northern coast of Canada. A recent review of the possible economic importance of gas hydrates (Dillon et al., 1986), seems to indicate that the possibility of producing gas bound in the hydrates is presently rather remote, although it might ultimately be possible. A more important aspect could be that sediments saturated with gas hydrate may act as seals trapping hydrocarbons.

In various locations of the Jan Mayen Ridge area clear
reflectors are seen in the seismic data that could be
interpreted as BSR's. These have not been previously
identified in the area (Eggen 1984). It is not easy to
confirm that these reflectors are really due to gas
hydrates, as they tend to appear below the flat bottom of
the deep ocean basin where the original stratification of
the sediments is also nearly parallel to the sea-bottom.
They do not show up on structural highs. This could either
be due to different physical properties of the sediments on
these highs, or lack of gas.

Fig. 3.5 shows the distribution of observed BSR's
interpreted to be related to gas hydrates. These
reflectors are most prominent in the southern part of the
area and are difficult to define in the north. The BSR's
are mostly detectable in the range of 1500 to 2200 m sea
depth, and range from 350 to 500 m in thickness. Some
discrete measurements are plotted in Fig. 3.6 b. The data
points show a considerable scatter, and they do not show a
definite increase of thickness with depth, contrary to
expectations. The thickness tends to be slightly less on
the western side of the ridge, perhaps reflecting a higher
thermal gradient of the younger margin. The geothermal
gradient can be estimated by referring to the phase
boundary curve in Fig. 3.6 a. According to this the
gradients range from 36 to 58^0 C/km, with about 50^0 C/km as
the median value, but it remains to be tested if these
values are realistic.
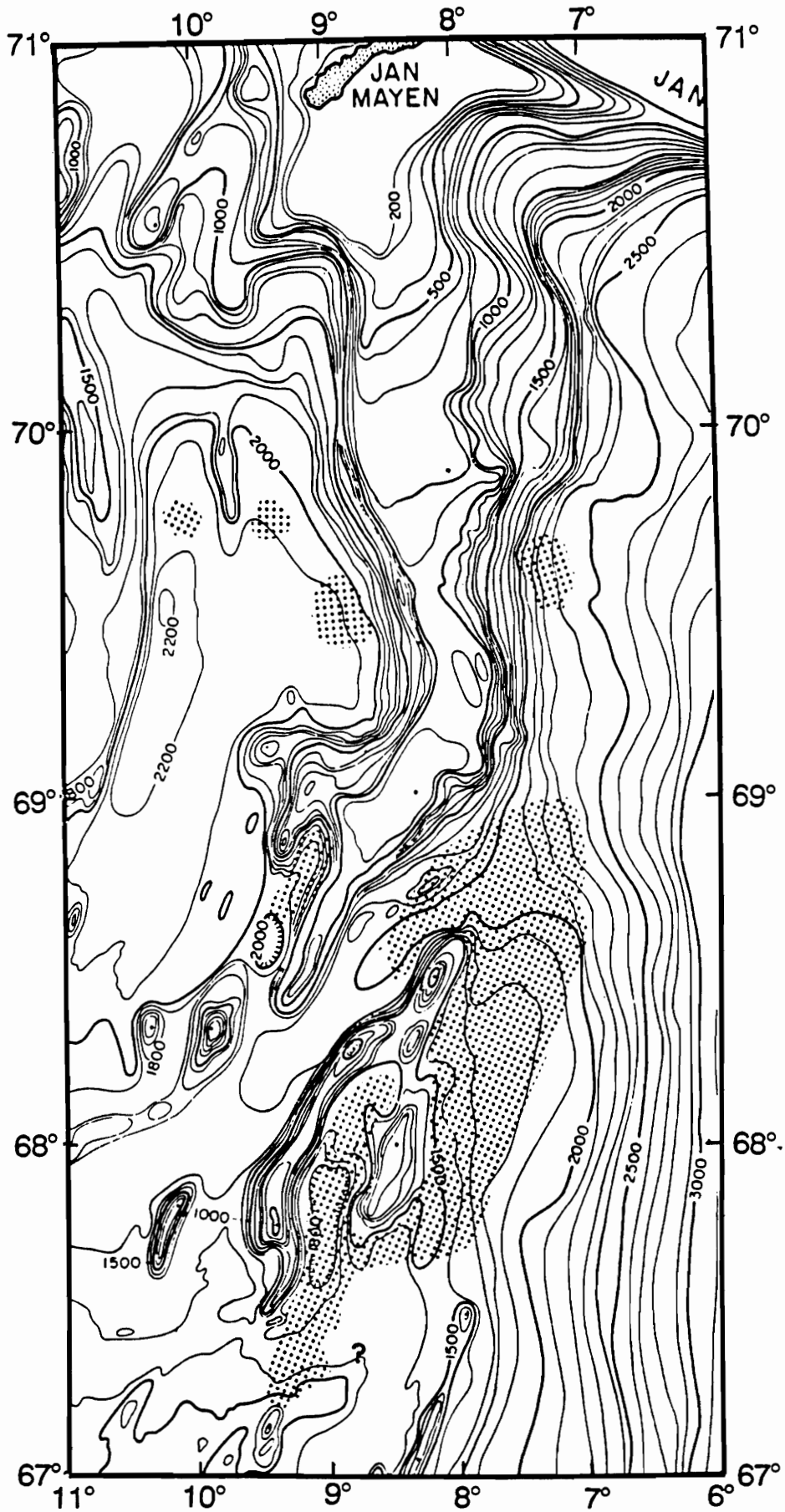
Fig 3.5   Areas of possible "bottom simulating reflectors"
(BSR's) (shaded) that could indicate gas
hydrates in the sediments. Waterdepth
in meters.
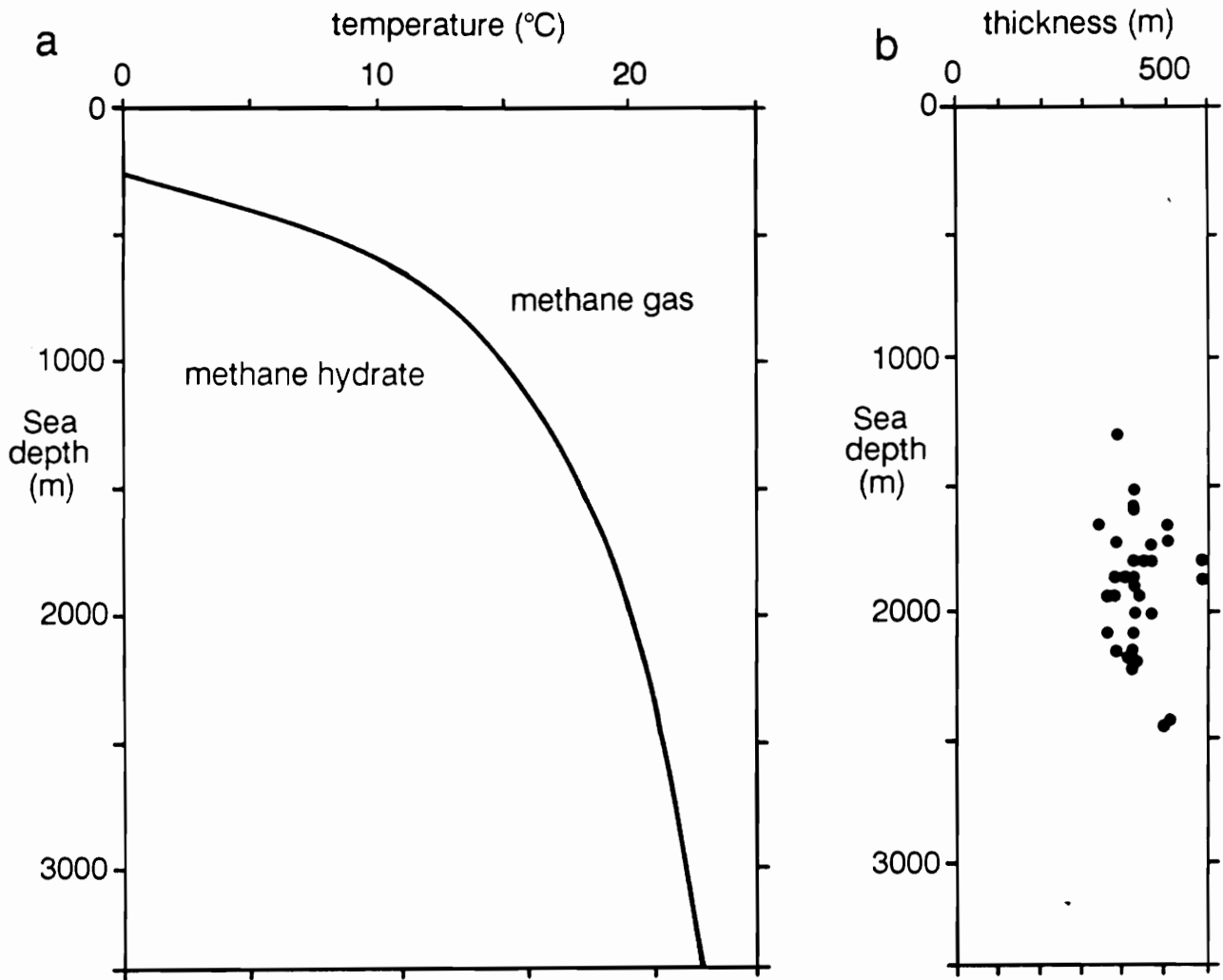
Fig 3.6 a) Phase boundary curve for methane and methane hydrate.

b) The observed thickness of the hydrate lager in various
places in the Jan Mayen area, as a function of sea depth.

3.5 CONCLUSIONS

No direct evidence has been presented proving the existence of hydrocarbon resources in the JMR area. Geophysical data indicate however that two different types of plays are possible, one in the post-rift Tertiary sediments and the other in pre-rift sediments that are seen in places below the syn-rift plateau basalts (horizon Purple). The latter play-type is more promising as the deep sediments are probably of Mesozoic and Paleozoic age and comparable to the prospective sediments found on the continental shelf of Norway, and in East-Greenland. These sediments are best observed on the south-eastern part of the North Ridge, but their areal distribution is not well known, mainly because of limited penetration of seismic waves through the basalts.

No indication of Tertiary source rocks have been found in boreholes, but these are few and have not sampled the optimal sequences. If existent such strata are not likely to be mature for oil expulsion, except where they are thickest on the lower flanks of the ridge. Also reservoir levels in the Tertiary section remain hypothetical.

Crater-like features on the flat top of the main ridge and possible gas hydrates in deep areas are observed, indicating the possibility of some gas in the sediments, be it of deep or shallow origin.

A final test of the hydrocarbon potential can only be obtained by drilling. The seismic data indicate possible sites for exploratory wells, but a denser seismic grid would be preferable in chosen areas before drill-sites are determined.

4. RECOMMENDATIONS

The geological mapping carried out indicates that the JMR
may have some hydrocarbon-potential, but it can not be
considered very great. The existing database is not
sufficient to give a conclusive answer to the question.

Considering today's technology and market situation, the
large water depth, remoteness and exposed location of the
area, exploitation of potential hydrocarbon resources is
very unlikely in the near future. Technology and economics
can however change rapidly, and it is advisable to have a
long-term plan to advance the status of the JMR-area. For
this purpose there is need for further exploration. In the
following we present some research projects that are in
progress, and can be regarded as the final phase of the
present regional study. Then we discuss possible long-term
exploration strategy for the area.

4.1 RESEARCH IN PROGRESS

Some projects are presently active and involve both
processing of new seismic data, and interpretation of the
existing data, mainly those of the 1985 cruise. Processing
and interpretation of the geophysical data from the JMR
will continue in 1989 in cooperation between the two
countries.

a) A project was organized in 1988 regarding the
interpretation of the sonobuoy data acquired in the 1985
cruise. This involves about 40 sonobuoys, that are expected
to give new information on the velocity structure of the
JMR crust, and thereby indication of the possible lithology
of the upper crustal layers. The project was finished in
august 1989 with a report: The Jan Mayen Ridge - Velocity
structure from sonobuoy data (OS-89030/JHD-04, Reykjavik,
August 1989). The work was carried out at NEA mainly by Dr

Ingi Olafsson. NPD provided his salary for half a year, while NEA provided facilities and support. The main purpose of this study was to obtain new information on the velocity structure of the pre-Tertiary rocks, i.e. the strata below the post-rift sediments of uncertain composition. Of special interest was the possibility of detecting Mesozoic or Paleozoic sediments, and determining their distribution.

b) The seismic reflection data set is studied at the Department of Geology, University of Oslo, under the supervision of Steinar T. Gudlaugsson. The work focuses on two aspects, the stratigraphy of the Tertiary sequence in order to evaluate sedimentation and vertical movements at the ridge, and studies of velocity distribution, especially in the Tertiary sediments, as a basis for geophysical modelling of crustal structure.

c) Additional seismic data were collected in the JMR area in September 1988, when some 1000 kms were shot in a 12 day cruise by the research vessel Håkon Mosby, hired from the University of Bergen (Fig 4.1). Gravity and magnetics were also recorded, and a few sonobuoys deployed. The cruise was planned and carried out in cooperation between NPD and NEA, with participation of the University of Oslo and assistance of the Seismological Observatory, University of Bergen. The main purpose was to make a detailed survey of a small area on the JMR for a more accurate mapping of one of the most interesting locations for sedimentary studies. This area is within the Norwegian part of the shelf. The second priority task was to acquire some seismic lines in the southern part of the Jan Mayen microcontinent, in order to broaden our view of the tectonic history of the region.
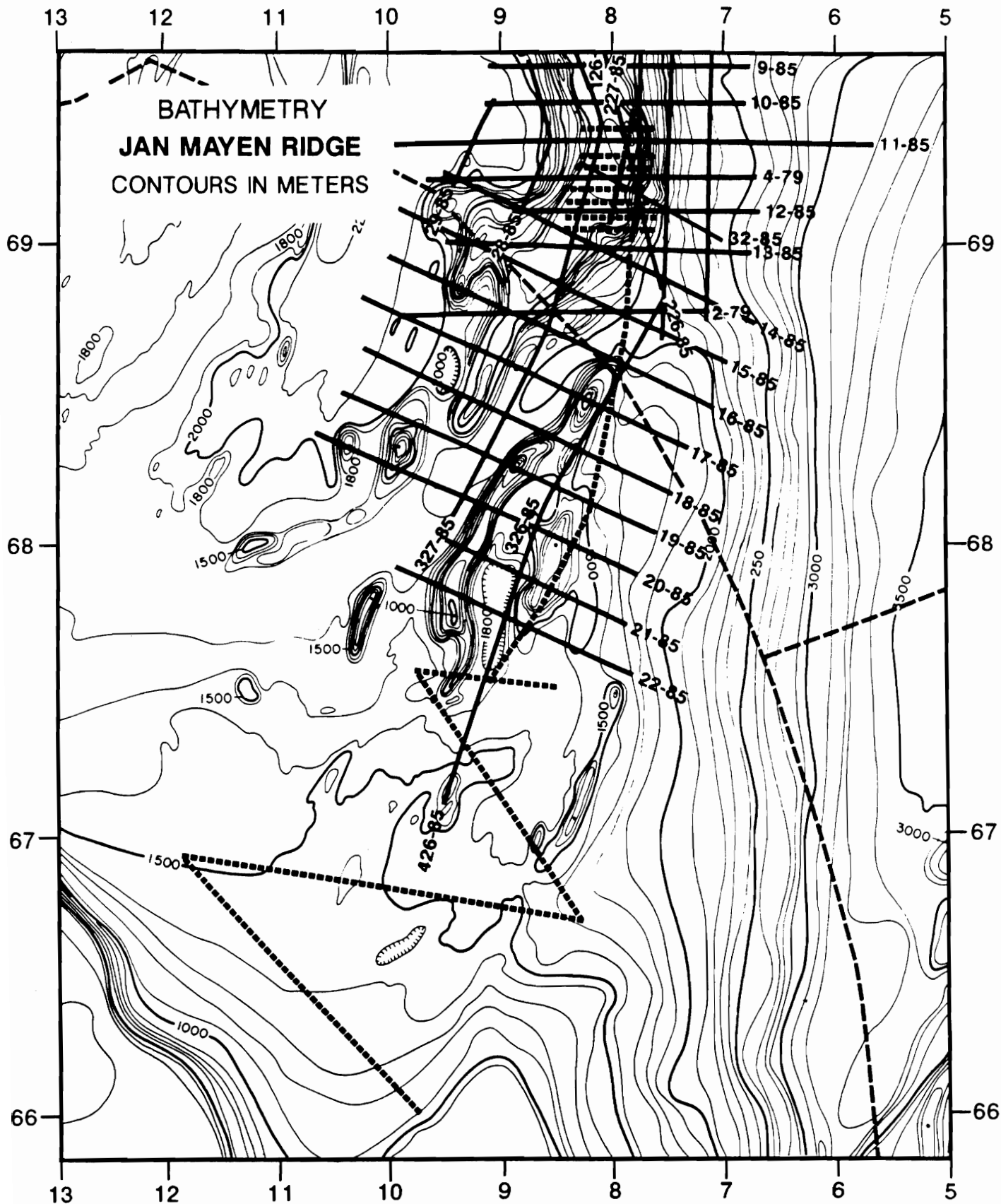
Fig 4.1 Seismic data aquired by NEA/NPD in 1988 in the Jan Mayen Ridge area.

RN-0178

NPD covered the cost of the survey in 1988. NEA has obtained Icelandic funds for the processing of the data in 1989. The processing is done by the seismic processing group at NEA, in consultation with the cooperative partners. This work will be finished late 1989. The data will be treated as common property of the two governments, in the same way as the 1985-data. Interpretation of these data will take place during the first half of 1990.

4.2 SUGGESTIONS FOR FUTURE EXPLORATION PROJECTS

As previously stated, our present state of knowledge is not sufficient to draw safe conclusions about whether interesting hydrocarbon accumulations exist or not on the JMR. The geological database is too small and insufficient in variety.

One of the main gaps in our knowledge of the area is lack of stratigraphic information, i.e. we do not know the type of rock and the age of the reflectors on the seismic sections. We are already attempting by indirect means to limit the range of possibilities, but final conclusions can only be reached by drilling - quite an expensive operation.

We introduce below some logical options for the continued investigation of the area in order of increasing . intensity and cost.

4.2.1 INTERPRETATION AND EVALUATION OF EXISTING DATA

A considerable amount of geophysical data from the JMR exists in various stages of processing and interpretation. Work on these data would give valuable information at minimum cost. Among tasks to be done is to compile a detailed map of water depths, more detailed sedimentary

seismic stratigraphy, regional tectonic and stratigraphic studies, and modelling of crustal structure using all types of geophysical data. These studies will narrow the range of questions concerning the hydrocarbon potential of the area, but are not likely to give a final answer.

The outer continental margins of the northern Atlantic Ocean are presently being examined, and new models of their structure and formation are being presented. The Jan Mayen area is geologically speaking a part of these areas. It is important to be updated on the development in this field, in order to reevaluate our model of the JMR.

4.2.2 ADDITIONAL GEOPHYSICAL SURVEYS

Additional seismic data to increase the density of seismic lines in interesting areas is needed for more detailed mapping. It is also likely, as investigations proceed, that other types of seismic data would be needed for new purposes, for example with deeper penetration or higher resolution.

Heat-flow measurements could give information on the thermal state of the ridge, and indirectly the level of maturation of potential hydrocarbons.

In view of the discovery of fields of numerous pockmarks or craters in the seafloor on the top of the ridge,. possibly related to escape of gas from below, a detailed mapping of chosen areas of the sea-bottom would be of interest. This should include side scan sonar surveying.

4.2.3 DRILLING

Drilling in the Jan Mayen area would be of great importance, as borehole calibration is limited at the time being. We expect the most suitable location to be on the main ridge just north of 69^{0}N, in the area covered by the

more detailed survey in 1988 (Fig 4.1) with water depth of
about 800-1000m. This applies to sampling the Tertiary
sedimentary sequence, as well as penetrating the underlying
rocks that could include older prospective sediments under
cover of plateau basalts. We have defined two different
drilling projects.

The larger project centers on a deep borehole that
would be drilled through the Tertiary sediments and the
early Tertiary lavas into probable pre-Tertiary sediments.
This would require an advanced expensive rig like a semi-
submersible platform or a drillship. The weather conditions
and remoteness of the area can be compared to the Barents
Sea, and drilling to a depth of some 4-5 km would
accordingly entail costs in the order of 150 million NOK.

A much cheaper and less demanding project would be to
drill a few shallow boreholes, no more than 200 m deep.
This depth limitation is for safety reasons, and consistent
with Norwegian rules. The drilling sites would have to be
investigated with high-resolution seismics in order to
avoid shallow gas and other potential geotechnical
problems. The sites will be located so that each borehole
samples different parts of the stratigraphic section. In
this way the Tertiary sedimentary section could be sampled
reasonably well, although continuous deep drilling would be
preferable. It is more uncertain if deeper levels can be
sampled, and this would most likely be restricted to the
underlying early Tertiary lavas. Hopefully the seismic data
acquired in 1988 will indicate more accurately how deep in
the section it is possible to reach in this way. It can
however already be stated that it is unlikely that deeper
pre-Tertiary sequences can be sampled. The cost for this
project would be in the order of a few tens of millions
NOK.

A realistic time schedule for a shallow drilling project
could be as follows:
- 1989: Processing of the seismic data from the 1988 survey
- 1990: Interpretation of the new seismic data, and
        evaluation of the value of the shallow borehole
        project based on geological interpretation, and the
        willingness of the Icelandic and Norwegian
        governments and the oil companies to invest in the
        area. Possible acquisition of more seismic data if
        drilling sites are not satisfactorily defined, and
        acquisition of high-resolution seismic data at the
        chosen sites. Seismic processing
- 1991: Reevaluation of the drilling project based on new
        data. Planning and drilling the holes.

It can finally be mentioned here that drilling for
scientific purposes in the general JMR area is still a
possibility within the program of the Ocean Drilling
Project, where the Nordic countries have a membership. The
drilling sites would however be chosen from general
scientific points of view, rather than for the purpose of
hydrocarbon evaluation. Such boreholes would therefore give
incomplete information in this context, but would still
be a project worth encouraging.

4.3 ORGANIZATION AND SCOPE OF FUTURE EXPLORATION

Progress should be made in preparing the area for possible
future opening for exploration or licencing. In this
context it must be decided if the seismic coverage is
sufficient, presently about 12 x 20 km, or if a more dense
grid of about 4 x 4 km is appropriate. This latter density
is common procedure in the seismic acquisititon program NPD
carries out on the Norwegian shelf. The cost of filling in
the 1985 survey to these specifications would require about
three times the amount of data we already have, or some 12
000 km of seismic lines. The cost of this is estimated to

some 50 millions NOK. These numbers would naturally be reduced by a more narrow definition of the interesting areas.

An alternative to government funding is to open the area for seismic acquisition by private companies. Seismic data acquisition could also be included if production-licences with limited work-obligation are granted.

The drilling of a deep exploration hole is a major and very expensive undertaking. Such a borehole may be paid for by the governments, or be part of work-obligations connected to a granted production licence. Such a production licence could be awarded through opening of the whole area for applications, or through choosing and offering one or more key blocks. We feel that it is not realistic at present to contemplate such drilling without the involvement and backing of the oil industry, based on better hydrocarbon indications and changed technical and economical conditions.

The smaller drilling project, consisting of a few shallow holes as described above, is in comparison relatively cheap. It could be financed totally by the governments, or it could be organized as a scientific investigation funded at least partly by the oil companies. The latter arrangement has been used successfully in the Barents Sea, but depends on high level of interest by the companies.

Summing up, we like to express the opinion that it will be natural for the two responsible governmental institutions to carry on their cooperation and maintain close contact in order to further the cause of exploration and possible exploitation of the JMR-area. For this purpose some lesser cooperative research projects could be organized to answer specific questions as they arise, and academic research projects could be encouraged and supported. Here we are talking about smaller projects to a total cost of a few

millons NOK or less.

A higher level of activity would include large scale seismic mapping or shallow drilling. In view of lack of lithological information in the area, we tend to favour the drilling as a priority project.

A large scale project centered on the drilling of one or more deep exploration boreholes would be necessary to finally decide if the area offers possibilities in hydrocarbon production.

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APPENDICES

Appendix 1   Agreement between the governments of
              Norway and Iceland on the continental
              shelf in the area between Iceland and
              Jan Mayen

Appendix 2   The Jan Mayen Ridge 1979 and 1985 seismic
              surveys: Data acquisition and processing

Appendix 3   The Jan Mayen Ridge 1975 and 1985 seismic
              surveys: Sale of data

Appendix 4 a Geophysical survey grid on the Jan
              Mayen Ridge acquired by NEA and NPD in
              1985 and NPD in 1979. Scale 1 : 500 000
              (Reduced versions in Fig 1.2 and 1.3)

         b   Main structural and volcanic features
              of the Jan Mayen Ridge.
              Scale 1 : 500 000.
              (Reduced version in Fig 2.13)

         c   Isochrone map of reflector Purple.
              Scale 1 : 500 000.
              (Reduced version in Fig 2.14)

         d   Isochrone map of reflector Red..
              Scale 1 : 500 000.
              (Reduced version in Fig 2.20)

         e   Isochrone map of reflector Blue.
              Scale 1 : 500 000.
              (Reduced version in Fig 2.22)

f   Isopach map of total sediment
     thichness (in TWT) above reflector
     Purple. Scale 1 : 500 000.
     (Reduced version in Fig 2.15)

g   Isopach map of the Purple-Red
     megasequence. Scale 1 : 500 000.
     (Reduced version in Fig 2.21)

h   Isopach map of Red-Blue megasequence.
     Scale 1 : 500 000.
     (Reduced version in Fig 2.23)

i   Isopach map of the sequence above
     reflector Blue. Scale 1 : 500 000.
     (Reduced version in Fig 2.24)

Appendix 5 a   Line drawings of four seismic dip lines
               (JM-85-4,10,12 and 17) across the Jan
               Mayen Ridge. (Reduced version in Fig 2.16)

           b   Line drawing of a composite seismic
               strike line (composed of lines JM-85-
               1226 and 326) along the eastern flank
               of the Jan Mayen Ridge. (Reduced
               version in Fig 2.17)

           c   Evolution of the Jan Mayen Ridge.
               (Reduced version in Fig 2.19)

Overenskomst mellom Norge og Island om kontinental-sokkelen i området mellom Island og Jan Mayen

Regjeringene i Norge og Island

som ønsker å fastsette delelinjen på kontinentalsokkelen i området mellom Island og Jan Mayen,

som ved å inngå Overenskomsten av 28. mai 1980 vedrørende fiskeri- og kontinentalsokkelspørsmål var enige om at Islands økonomiske sone skal utstrekkes til 200 nautiske mil også i de områder mellom Island og Jan Mayen hvor avstanden mellom grunnlinjene er mindre enn 400 nautiske mil,

som i artikkel 9 i ovennevnte overenskomst ble enige om at partene i fellesskap skulle oppnevne en forlikskommisjon som skulle fremsette anbefalinger vedrørende delelinjen for sokkelområdet mellom Island og Jan Mayen, og som i fellesskap oppnevnte en slik Kommisjon,

som i mai 1981 mottok Forlikskommisjonens enstemmige anbefalinger, som går ut på at delelinjen mellom de to parters deler av kontinentalsokkelen i området mellom Island og Jan Mayen skal falle sammen med delelinjen for de økonomiske soner, samt at det etableres et samarbeid mellom de to parter ved utforskning og utnyttelse av petroleumsforekomster i et nærmere angitt område mellom Island og Jan Mayen på begge sider av delelinjen, og

som finner a kunne bygge på Kommisjonens anbefalinger

er blitt enige om følgende:

Artikkel 1

Delelinjen mellom partenes deler av kontinentalsokkelen i området mellom Island og Jan Mayen skal falle sammen med delelinjen for partenes økonomiske soner.

Artikkel 2

Bestemmelsene i artiklene 3 –9 kommer til anvendelse i et område begrenset ved følgende koordinater:

70'' 35' N
68'' 00' N
10'' 30' V
6'' 30' V

Artikkel 3

I den første undersøkelsesfase, hvis formål er en systematisk geologisk kartlegging av det området som er nevnt i artikkel 2, skal partene i fellesskap drive seismiske og om nødvendig magnetiske undersøkelser. Den praktiske gjennomføring av disse undersøkelser foretas av det norske Oljedirektorat på grunnlag av planer utarbeidet i fellesskap av de to parters eksperter. Omkostningene ved undersøkelsene skal bæres av Oljedirektoratet/Den Norske Stat, medmindre partene blir enige om noe annet. Norske og islandske eksperter skal ha samme adgang til a delta i undersøkelsene og i evalueringen av de fremkomne data. Dataene og evalueringen av dem skal tilstilles de to parters myndigheter. De skal behandles konfidensielt, medmindre partene blir enige om noe annet.

Dersom det oppnås fortjeneste ved salg av seismiske eller magnetiske data til selskaper eller organisasjoner, skal nettoutbyttet deles mellom de to parter etter avtale dem imellom.

Artikkel 4

Dersom de undersøkelser som er nevnt i artikkel 3, viser at det er ønskelig å foreta mer detaljerte undersøkelser av særlige felter i området, herunder mer detaljert seismikk og igangsettelse av boringer, skal eventuelle eksklusive undersøkelses- og utvinningstillatelser for slike spesielle felter baseres på kontrakter om fellesforetak (joint venture), medmindre partene blir enige om en annen kontraktsform. Partene kan bli enige om å la statlige eller ikke-statlige oljeselskaper delta i slike kontrakter.

Artikkel 5

I den del av det område som er nevnt i artikkel 2, som ligger nord for delelinjen mellom de to parters økonomiske soner (ca. 32 750 km²), skal Island ha adgang til å delta med en andel på 25 % i slik petroleumsvirksomhet som er nevnt i artikkel 4. I forhandlinger med utenforstående statlige eller ikke-statlige oljeselskaper skal Norge søke å oppnå at både den norske og den islandske andel av omkostningene ved slik petroleumsvirksomhet blir båret (carried) av vedkommende selskap (eller selskaper) opp til det stadium hvor kommersielle funn er blitt erklært.

Samkomulag milli Noregs og Islands um landgrunnid a svæðinu milli Islands og Jan Mayen

Ríkisstjórn Noregs og ríkisstjórn Íslands

sem óska eftir að ákvarða markalínuna á landgrunninu á svæðinu milli Íslands og Jan Mayen,

sem með gerð samkomulagsins frá 28. maí 1980 um fiskveiði- og landgrunnsmál urðu ásáttar um að efnahagslögsaga Íslands skuli ná út í 200 sjómílur, einnig á þeim svæðum milli Íslands og Jan Mayen þar sem fjarlægðin milli grunnlínanna er minni en 400 sjómílur,

sem í 9. gr. fyrrnefnds samkomulags urðu ásáttar um að aðilar skyldu í sameiningu skipa sáttanefnd sem gera skyldi tillögur um skiptingu landgrunnssvæðisins milli Íslands og Jan Mayen, og sem sameiginlega skipuðu slíka nefnd,

sem í maí 1981 fengu samhljóða tillögur sáttanefndarinnar, er fela í sér að mörk landgrunns hvors aðila á svæðinu milli Íslands og Jan Mayen skuli vera hin sömu og mörk efnahagslögsögu hvors aðila, svo og að komið verði á samvinnu milli aðilanna um rannsóknir og nýtingu á olíuefnum («hydrocarbons») á nánar tilgreindu svæði milli Íslands og Jan Mayen, beggja vegna markalínunnar, og

sem telja sig geta farið að tillögum nefndarinnar,

hafa orðið ásáttar um eftirfarandi:

1. gr.

Mörk landgrunns hvors aðila á landgrunninu á svæðinu milli Íslands og Jan Mayen skulu vera hin sömu og mörk efnahagslögsögu þeirra.

2. gr.

Ákvæði 3.—9. gr. taka til svæðis, sem afmarkast af eftirfarandi hnitum:

70° 35' n.br.
68° 0' n.br.
10° 30' v.lg.
6° 30' v.lg.

3. gr.

Á fyrsta stigi rannsókna sem ætlað er til kerfisbundinnar jarðfræðikönnunar á svæði því, sem tilgreint er í 2. gr., skulu aðilar sameiginlega annast jarðsveiflumælingar («seismic» mælingar) svo og segulrannsóknir, ef með þarf. Norska olíustofnunin sér um framkvæmdahlið þessara rannsókna á grundvelli áætlana, sem samdar verða sameiginlega af sérfræðingum aðilanna. Kostnaður við þessar rannsóknir verður greiddur af norsku olíustofnuninni/norska ríkinu, nema aðilar komi sér saman um annað. Norskir og íslenskir sérfræðingar skulu hafa jafna möguleika á þátttöku í rannsóknunum og í mati á upplýsingum sem fram koma. Upplýsingar og matsgerðir skal leggja fyrir stjórnvöld landanna. Fara skal með þær sem trúnaðarmál nema aðilar komi sér saman um annað.

Verði ágóði af sölu jarðsveiflu- eða segulupplýsinga til fyrirtækja eða samtaka skal skipta hreinum hagnaði milli beggja aðila samkvæmt samningi þeirra á milli.

4. gr.

Sýni þær rannsóknir, sem um er fjallað í 3. gr., að æskilegt sé að framkvæma nákvæmari athuganir á vissum hlutum þessa svæðis, þ.á.m. að gera nákvæmari jarðsveiflumælingar og að hefja boranir, skulu hugsanleg einkaleyfi til rannsókna og vinnslu á slíkum sérsvæðum veitt á grundvelli samnings um sameiginlegt verkefni («joint venture»), nema aðilar komi sér saman um annað samningsform. Aðilar geta komið sér saman um að láta olíufélög, ríkisrekin eða ekki, eiga aðild að slíkum samningum.

5. gr.

Á þeim hluta þess svæðis sem tilgreint er í 2. gr. og sem liggur norðan markalínu efnahagslögsögu landanna (u.þ.b. 32.750 km²) skal Ísland eiga rétt á 25 % þátttöku í olíustarfsemi sem þeirri, sem um er fjallað í 4. gr. Í samningaumleitunum við utanaðkomandi olíufélög, ríkisrekin eða ekki, ber Noregi að reyna að fá því framgengt, að bæði norskur og íslenskur hluti kostnaðar við slíka olíustarfsemi sé borinn («carried») af hlutaðeigandi félagi (eða félögum) allt fram að því að lýst er yfir að fundist hafi arðbært vinnslusvæði.

Dersom det ikke er mulig å oppnå at de to parters omkostninger blir båret av vedkommende selskap (eller selskaper), skal partene oppta forhandlinger om muligheten for å drive virksomhet som et fellesforetak hvor hver av dem bærer sine omkostninger, eller hvor de deler omkostningene. Dersom Island ikke ønsker å delta på dette grunnlag, kan Norge fortsette på egenhånd. Dersom kommersielle funn blir erklært, skal Island ha adgang til på dette stadium å tre inn med sin andel mot a godtgjøre Norge den del av de påløpne omkostninger opp til dette tidspunkt som ville svare til Islands andel dersom Island hadde deltatt fra begynnelsen av.

Norsk lovgivning, norsk oljepolitikk og norske bestemmelser om kontroll med virksomheten, om sikkerhetstiltak og om miljøvern kommer til anvendelse for virksomhet i det område som er nevnt i første ledd. Også håndhevelsen og forvaltningen i det nevnte område tilligger norske myndigheter.

Artikkel 6

I den del av det område som er nevnt i artikkel 2, som ligger sør for delelinjen mellom de to parters økonomiske soner (ca. 12 720 km²), skal Norge ha adgang til a delta med en andel på 25 % i slik petroleumsvirksomhet som er nevnt i artikkel 4. I forhandlinger med utenforstående statlige eller ikke-statlige oljeselskaper skal Island ikke være forpliktet til å søke å oppnå at den norske andel av omkostningene ved slik petroleumsvirksomhet blir båret av vedkommende selskap (eller selskaper).

Islandsk lovgivning, islandsk oljepolitikk og islandske bestemmelser om kontroll med virksomheten, om sikkerhetstiltak og om miljøvern kommer til anvendelse for virksomhet i det område som er nevnt i første ledd. Også håndhevelsen og forvaltningen i det nevnte område tilligger islandske myndigheter.

Artikkel 7

Etter at et funn er erklært kommersielt, skal hver av partene bære sine omkostninger ved den videre utvikling av feltet i forhold til sin andel i henhold til vedkommende kontrakt.

Artikkel 8

Dersom et petroleumsfunn dekker et felt som ligger på begge sider av delelinjen mellom de to parters økonomiske soner, eller i sin helhet ligger sør for delelinjen, men strekker seg utover de koordinater som er gitt i artikkel 2, skal vanlige unitiseringsprinsipper for fordeling og utnyttelse av funnet komme til anvendelse. De nærmere regler som skal gjelde i slike tilfelle, avtales mellom partene.

Dersom et petroleumsfunn dekker et felt som i sin helhet ligger nord for delelinjen, men strekker seg utover de koordinater som er gitt i artikkel 2, skal funnet i sin helhet anses liggende innenfor koordinatene, jfr. artiklene 5, 6 og 7.

Artikkel 9

Dersom en av partene mener at de bestemmelser om sikkerhetstiltak og miljøvern som det er vist til i artiklene 5 og 6, ikke gir tilstrekkelig vern ved utforskning eller utvinningsvirksomhet i det område som er nevnt i artikkel 2, skal partene konsultere hverandre, jfr. artikkel 10 i overenskomsten av 28. mai 1980 vedrørende fiskeri- og kontinentalsokkelspørsmål. Dersom partene under slike konsultasjoner ikke blir enige, skal spørsmålet henvises til en forlikskommisjon bestående av tre medlemmer. Partene skal ikke påbegynne eller fortsette virksomhet som nevnt før forlikskommisjonens anbefaling foreligger, medmindre tungtveiende grunner tilsier det.

Hver av partene skal oppnevne ett medlem av kommisjonen. Kommisjonens formann oppnevnes av partene i fellesskap.

Kommisjonens anbefalinger skal forelegges for de to regjeringer snarest mulig. Anbefalingene er ikke bindende for partene, men partene skal under sine videre drøftelser ta rimelig hensyn til dem.

Artikkel 10

. Denne overenskomst skal tre i kraft når partene ved noteveksling har meddelt hverandre at den nødvendige konstitusjonelle behandling er avsluttet.

Til bekreftelse på dette har de befullmektigede undertegnet denne overenskomst.

Utferdiget i Oslo, 22. oktober 1981 i to eksemplarer på norsk og islandsk, med samme gyldighet for de to tekster.

Verði ekki unnt að fá því framgengt, að kostnaður beggja aðila verði borinn af hlutaðeigandi félagi (eða félögum) skulu aðilar taka upp samningaumleitanir um möguleika á að reka starfsemina sem sameiginlegt verkefni, þar sem hvor þeirra beri sinn kostnað eða þeir skipti með sér kostnaði. Óski Ísland ekki eftir þátttöku á þessum grundvelli er Noregi heimilt að halda áfram á eigin áhættu. Verði því lýst yfir að fundist hafi arðbært vinnslusvæði skal Ísland á því stigi eiga þess kost að ganga inn í starfsemina með sinn hlut gegn því að greiða Noregi þann hluta útlagðs kostnaðar fram að þessum tíma sem hefði svarað hlut Íslands ef það hefði verið þátttakandi frá upphafi.

Norsk löggjöf, norsk stefna í oliumálum og norsk ákvæði um eftirlit með starfseminni, öryggisráðstafanir og umhverfisvernd skulu gilda um starfsemi á því svæði sem tiltekið er í fyrstu málsgrein. Norsk stjórnvöld skulu einnig fara með framkvæmdavald og stjórnun á þessu svæði.

6. gr.

Á þeim hluta þess svæðis sem tilgreint er í 2. gr. og sem liggur sunnan markalínu efnahagslögsögu landanna (u.þ.b. 12.720 km²) skal Noregur eiga rétt á 25 % þátttöku í oliustarfsemi sem þeirri, sem um er fjallað í 4. gr. Í samningaumleitunum við utanaðkomandi oliufélög, ríkisrekin eða ekki, skal Íslandi ekki vera skylt að reyna að fá því framgengt, að hinn norski hluti kostnaðar við slíka oliustarfsemi sé borinn af hlutaðeigandi félagi (eða félögum).

Íslensk löggjöf, íslensk stefna í oliumálum og íslensk ákvæði um eftirlit með starfseminni, öryggisráðstafanir og umhverfisvernd skulu gilda um starfsemi á því svæði sem tiltekið er í fyrstu málsgrein. Íslensk stjórnvöld skulu einnig fara með framkvæmdavald og stjórnun á þessu svæði.

7. gr.

Eftir að lýst hefur verið yfir að fundist hafi arðbært vinnslusvæði skal hvor aðili bera sinn kostnað við áframhaldandi framkvæmdir á svæðinu í hlutfalli við sinn hlut i viðkomandi samningi.

8. gr.

Finnist oliuefni á svæði sem liggur báðum megin markalínu efnahagslögsögu landanna eða sé það allt sunnan markalínunnar en teygist út yfir þau hnit sem nefnd eru í 2. gr. skulu venjulegar meginreglur um einingarnýtingu auðlinda («unitisering») gilda um skiptingu og nýtingu fundarins. Aðilar skulu semja um nánari reglur sem gilda eiga í slíkum tilvikum.

Finnist oliuefni á svæði sem allt liggur norðan markalínu, en teygist út yfir þau hnit sem nefnd eru í 2. gr., skal það allt teljast liggja innan hnitanna, sbr. 5., 6. og 7. gr.

9. gr.

Ef annar aðilinn telur að ákvæðin um öryggisráðstafanir og umhverfisvernd, sem um er fjallað í 5. og 6. gr., veiti ekki nægilega vernd þegar fram fara rannsóknir eða vinnsla á því svæði, sem tilgreint er í 2. gr., skulu aðilar hafa samráð, sbr. 10. gr. samkomulagsins frá 28. mai 1980 um fiskveiði- og landgrunnsmál. Verði aðilar ekki sammála í slíkum samráðum skal málinu vísað til sáttanefndar þriggja manna. Aðilar skulu eigi hefja slíkar aðgerðir eða halda þeim áfram fyrr en tillögur sáttanefndarinnar liggja fyrir, nema þrýn þörf krefji.

Hvor aðili skal tilnefna einn mann í sáttanefndina. Formaður nefndarinnar er tilnefndur með samkomulagi aðilanna.

Tillögur nefndarinnar skulu lagðar fyrir ríkisstjórnirnar svo fljótt sem verða má. Tillögurnar eru án skuldbindingar fyrir aðilana, en þeir skulu taka sanngjarnt tillit til þeirra í frekari málsmeðferð.

10. gr.

Samkomulag þetta öðlast gildi þegar aðilar hafa skipst á orðsendingum um að nauðsynlegri stjórnskipunarmeðferð sé lokið.

Þessu til staðfestu hafa fulltrúar með umboði undirritað samkomulag þetta.

Gjört í Osló, hinn 22. október 1981 í tveimur eintökum á norsku og íslensku og eru báðir textarnir jafngildir.

<u>A C Q U I S I T I O N</u> <u>P A R A M E T E R S</u>
<u>1 9 8 5 S U R V E Y</u>

The Survey was shot during July and August 85 by GECO A/S using the vessel M/S Malene Østervold.

The following acquisition parameters were used the 85-lines:

<u>ENERGY SOURCE</u>

Type	Airgun Array (6 Subarrays)
Pop interval	50.0 m and 25.0 m
Shot point interval	50.0 m and 25.0 m
Source depth	7.5 m
Source power	3564 cu in
Pressure	2000 psi

<u>RECEIVER PARAMETERS</u>

Fold of recording	on lines with 50m sp. interval 3000%		
	on lines with 25m sp. interval 6000%		
Number of groups	60	Interval	50 m
Hydrophones per groups	40	Length	50 m
Cable length	3000 m	Depth	10 - 12m
Near trace	1	Offset	188 m

<u>INSTRUMENTATION</u>

Recording system	DFS V, DSS V.		
Gain constant	24 dB		
Filters: Low cut	3.5 Hz	Slope	18 dB/oct
High cut	64.0 Hz	Slope	72 dB/oct
Tape format	SEG D 8015	6250 BPI	
Sample rate	4 ms		

<u>NAVIGATION SYSTEM</u>

Primary	LORAN C
Secondary	SAT NAV

145M — 188M — 2975M

1 2 3   118 119 120

ARRAY WIDTH 60M
ARRAY LENGTH 42M
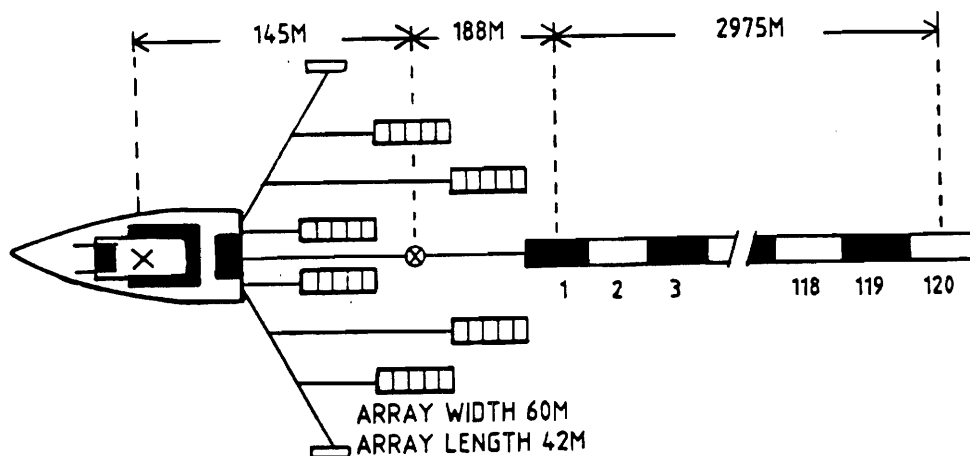
ACQUISITION PARAMETERS

1979 SURVEY

The Survey was shot during July 79 by GECO A/S using the
vessel M/S GECO Alpha.

The following acquisition parameters were used the 79-lines:

ENERGY SOURCE

Type	Airgun Array
Pop interval	50.0 m
Shot point interval	50.0 m
Source depth	7.5 m
Source power	2970 cu in

RECEIVER PARAMETERS

Fold of recording	2400%		
Number of groups	48	Interval	50 m
Cable length	2400 m	Depth	13.5m
Near trace	1	Offset	194 m

INSTRUMENTATION

Recording system	DFS V		
Gain constant	24 dB		
Filters: Low cut	5.3 Hz	Slope	18 dB/oct
High cut	64.0 Hz	Slope	72 dB/oct
Tape format	SEG C	1600 BPI	
Sample rate	4 ms		

NAVIGATION SYSTEM   SAT NAV
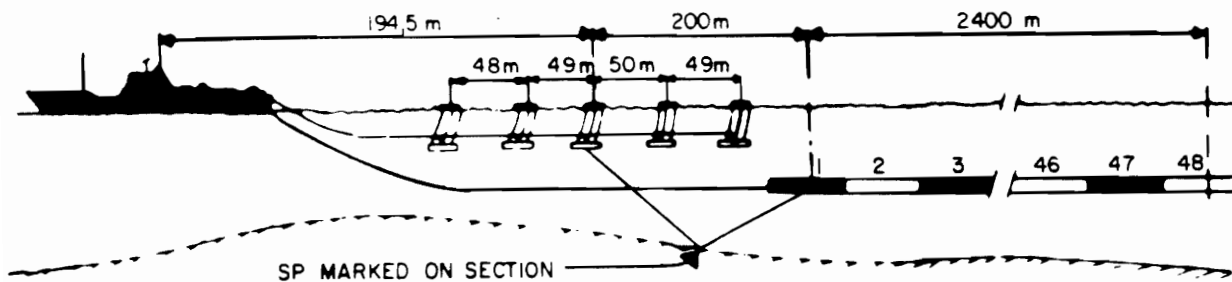
PROCESSING SEQUENCE

PROCESSED BY: GECO. SANDVIKA   DATE: JAN 1987

REFORMAT SEGD TO SEGY/TRACE EDIT
ADJACENT TRACE SUMMATION   WITH NMO CORRECTION
GEOMETRY INFORMATION/DATUM STATICS
SPHERICAL DIVERGENCE CORRECTION
CDP GATHER

MUTE   FIRST BREAK SUPRESSION

DECONVOLUTION BEFORE STACK
                                  OPERATOR LENGTH 232 MS
                                  PREDICTIVE GAP 32 MS
                                  DESIGN GATES AT NEAR TRC.:
                                  W.B.+ 200MS - W.B.+ 3700MS

VELOCITY ANALYSIS
                                  EVERY THIRD KILOMETER

FK MULTIPLE ATTENUATION
NORMAL MOVEOUT CORRECTION

                                  USING VELS DERIVED FROM
                                  GECO S CONTOURED VELOCITY
                                  SPECTRA

PRE-STACK MUTE   OFFSET DEPENDENT

TRACE EQUALIZATION WITH   WEIGHT X/X+XL X:OFFSET XL:FAR OFFSET
OFFSET WEIGHTING   AND CCSINE TAPER ON THE 15 FAR TRACES

CDPSTACK   30 FOLD

DECONVOLUTION AFTER STACK
                                  OPERATOR LENGTH 332 MS
                                  PREDICTIVE GAP 32 MS
                                  DESIGN GATES:
                                  W.B.+ 200MS - W.B.+ 3700MS

FK DIP FILTER
                                  MAXIMUM DIPS -12.12 MS PER TRACE

SPACE AND TIME VARIANT FILTER
                                  BANDPASS   TIMES BELOW W.B.
                                  12 HZ - 55 HZ   0.0 - 1.2 SEC
                                   8 HZ - 45 HZ   1.2 - 2.2 SEC
                                   6 HZ - 25 HZ   2.2 - 4.5 SEC
                                   4 HZ - 20 HZ   4.5 - 8.0 SEC

EXPONENT SCALING   . SCALER 0.8
AMPLITUDE BALANCE
                                  WINDOW 1000 MS

DISPLAY DATA

	FULL SCALE	HALF SCALE
TRACES PER CM	10	20
CMS PER SECOND	10.0	5.0
SHOTPOINTS ANNOTATED	CDP	CDP
HORIZONTAL SCALE	1:25000	1:50000
ONE KILOMETER ON SECTION EQUALS	4 CM	2 CM

PROCESSING SEQUENCE

REPROCESSED BY: GECO. SANDVIKA   **DATE: JAN 1987**

DEMULTIPLEX/TRACE EDIT	
TRACE MIX	5 TRACES WEIGTHS 1-2-2-2-1
PRE PROCESSING CDP GATHER	CORRECTIONS FOR SPHERICAL DIVERGENCE
DECONVOLUTION BEFORE STACK	TYPE MINIMUM PHASE INVERSE FILTER
	MINIMUM PREDICTION DISTANCE: 200MS
	MAXIMUM PREDICTION DISTANCE: 500MS
	LENGTH OF OPERATOR 300MS
	NO OF AUTOCORRELATION WINDOWS: 1
	STOP OF AUTOCORRELATION: 6000MS - 7000MS
	STOP OF DECONVOLUTION: 8000MS - 9000MS
NMO/STACK	NORMAL STACK. 2400%
MIX	RUNNINGMIX OF TWO ADJACENT TRACES
DECONVOLUTION AFTER STACK	OPERATOR LENGTH 332 MS
	PREDICTIVE GAP 32 MS
	DESIGN GATES:
	W.B.+ 200MS - W.B.+ 3700MS
WAVE EQUATION MIGRATION	FINITE DIFFERENCE SOLUTION DEPTH STEP: 24MS
FK DIP FILTER	MAXIMUM DIPS -12.12 MS PER TRACE
SPACE AND TIME VARIANT FILTER	BANDPASS TIMES BELOW W.B.
	12 HZ - 55 HZ 0.0 - 1.2 SEC
	8 HZ - 45 HZ 1.2 - 2.2 SEC
	6 HZ - 25 HZ 2.2 - 4.5 SEC
EXPONENT SCALING	SCALER 0.8
AMPLITUDE BALANCE	WINDOW 1000 MS

DISPLAY DATA

	FULL SCALE	HALF SCALE
TRACES PER CM	10	20
CMS PER SECOND	10.0	5.0
SHOTPOINTS ANNOTATED	CDP	CDP
HORIZONTAL SCALE	1:25000	1:500000
ONE KILOMETER ON SECTION EQUALS	4 CM	2 CM

NORWEGIAN PETROLEUM DIRECTORATE

PROF. OLAV HANSSENSVEI 10, P.O. BOX 600, N-4001 STAVANGER, NORWAY - TEL. 47-4-87 60 00 TELEFAX 47-4-55 15 71 TELEX 42863 NOPED

Likelydende brev sendt til: Offentlig

(se vedlagte liste)

Your ref.	Our ref (please quote) OD 87/ /JAE/SHe	Stavanger,

SEISMIC DATA IN THE JAN-MAYEN AREA

In cooperation with Orkustofnun (Icelands national energy
authority), the Norwegian Petroleum Directorate has
acquired geophysical data over the Jan Mayen ridge between
Iceland and the Jan Mayen island.

The ridge is believed to be a continental fragment split
off from Norway and Greenland respectively in Paleocene and
Oligocene. For exploration purposes the main implications
of this are:

- Mesozoic sediments have most likely been deposited in
  the area
- The area contains important information for regional
  understanding of the Norwegian and Greenland continental
  shelves
- The area has been exposed to some volcanic activity
  during rifting
- Subsidence after the rifting episodes have brougth most
  of the area to waterdepth of 1000 m and more

The dataset acquired has been parted in two. Package 026
(85-data) gives a very rough regional coverage, while
package 027 (79-data + rest 85-data) contains infill down
to about 15 x 15 km.

Jan-Mayen-85   (026) (fig 1)
consists of 1 802 kms of seismic data shot by Geco in 1985
and processed by Geco in 1986/87.

865 kms of the lines are recorded to 15 seconds. Full
record length of these lines is only shown on 5cm/sec and
3cm/sec filtered sections.

```
Contents:           1/1 scale filtered sections
                    1/2 scale filtered sections
                    1/1 scale migrated sections
                    1/2 scale migrated sections
                    3 cm/sec 1:200000 filtered
                    UKOOA-format navigation tape
                    Grav/Mag profiles
                    Maps 1:500´ as listed:
                    Water depth contoured
                    -----"----- posted
                    Free Air    contoured
                    ---"----    posted
                    Bouguer     contoured
                    ---"---     posted
                    Magnetic    contoured
                    ---"----    posted
```

Cost breakdown: Seismic data   971 998.- NOK
                Copying   22 100.- NOK
                Nav tape   450.- NOK

Data are available from 15 nov 1987

Jan-Mayen-79/85   (027) (fig 2)
consists of 2.837 kms of seismic data shot by Geco in 1979
(611 kms) and 1985 (2 226 kms). All the data is processed
by Geco in 1986/87.

438 kms of the 1985 lines are recorded to 15 seconds. Full
record length of these lines is only shown on 5cm/sec and
3cm/sec filtered sections.

```
Contents:           1/1 scale filtered sections
                    1/2 scale filtered sections
                    1/1 scale migrated sections
                    1/2 scale migrated sections
                    3 cm/sec 1:200000  filtered
                    UKOOA-format navigation tape
                    Grav/Mag profiles
                    Maps 1:250´ as listed:
                    Water depth contoured
                    -----"----- posted
                    Free Air    contoured
                    ---"----    posted
                    Bouguer     contoured
                    ---"---     posted
                    Magnetic    contoured
                    ---"----    posted
```

```
Cost breakdown: Seismic data 1 415 165.- NOK
                Copying          35 400.- NOK
                Nav tape            450.- NOK
```
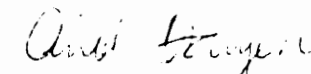
Data are available from 15 nov 1987.

Yours faithfully

Finn R. Aamodt (e.f.)
Head of Exploration Branch

Kari Ofstad
Acting Head of
Prospect Mapping
Section

Enclosures: 2 orderforms and 2 maps

ORDER FOR GEOPHYSICAL DATAPACKAGE 027

From:	To: Norwegian Petr. Directorate
	c/o **Teknisk Kopiservice**
	Jacob Askelandsvei 13
	4300 Sandnes, Norway
	Attn: Einar Johannessen
	Tlf : 04 - 67 76 44

Our ref:	Your ref:

THIS ORDERFORM MUST BE USED WHEN ORDERING DATAPACKAGE:
027 JAN-MAYEN-79/85

Terms of purchase are as stated on page 5 in the NPD´s publication:
"Geophysical datapackages available from The Norwegian Petroleum
Directorate" April-1986 edition or later.

Please note that the following prices may be subject to alteration.
PRICES ARE: Seismic data   1 415 165,-NOK
              Copying   35 400,-NOK
              Nav tape   450,-NOK

CONTENTS OF PACKAGE

1/2 scale filtered stack	O	3 cm/sec, 1:200000 filtered	O
1/1 scale filtered stack	O	UKOOA format nav tape	O
1/2 scale migrated stack	O	Grav/Mag profiles	O
1/1 scale migrated stack	O	1:250000 Grav/Mag/Bat maps	O

REMARKS/ADDITIONAL ORDERING INFORMATION:

BILLING ADDRESS:	DELIVERY ADDRESS:

Ordered ..../.................../Date...........
          (place)   (signature)

LETTER OF TRANSMITTAL

Please acknowledge receipt of the above data by returning this form to:
The Norwegian Petroleum Directorate, P O Box 600, 4001 Stvg, Norway.

Received ..../.................../Date..........
          (name)   (signature)

FOR USE BY THE NORWEGIAN PETROLEUM DIRECTORATE

Date/Sign:	Mottatt	Nav bestilt	Postlagt	Fakturert
	....	....	....	....

01.09.1987-4802020027-027

ORDER FOR GEOPHYSICAL DATAPACKAGE 026

From:	To: Norwegian Petr. Directorate c/o Teknisk Kopiservice Jacob Askelandsvei 13 4300 Sandnes, Norway Attn: Einar Johannessen Tlf : 04 - 67 76 44
Our ref:	Your ref:

THIS ORDERFORM MUST BE USED WHEN ORDERING DATAPACKAGE:
026 JAN-MAYEN-85

Terms of purchase are as stated on page 5 in the NPD´s publication:
"Geophysical datapackages available from The Norwegian Petroleum
Directorate" April-1986 edition or later.

Please note that the following prices may be subject to alteration.

PRICES ARE:	Seismic data	971 998,-NOK
	Copying	22 100,-NOK
	Nav tape	450,-NOK

CONTENTS OF PACKAGE

1/2 scale filtered stack	O	3 cm/sec, 1:200000 filtered	O
1/1 scale filtered stack	O	UKOOA format nav tape	O
1/2 scale migrated stack	O	Grav/Mag profiles	O
1/1 scale migrated stack	O	1:500000 Grav/Mag/Bat maps	O

REMARKS/ADDITIONAL ORDERING INFORMATION:

BILLING ADDRESS:	DELIVERY ADDRESS:

Ordered ..../..................../Date..........
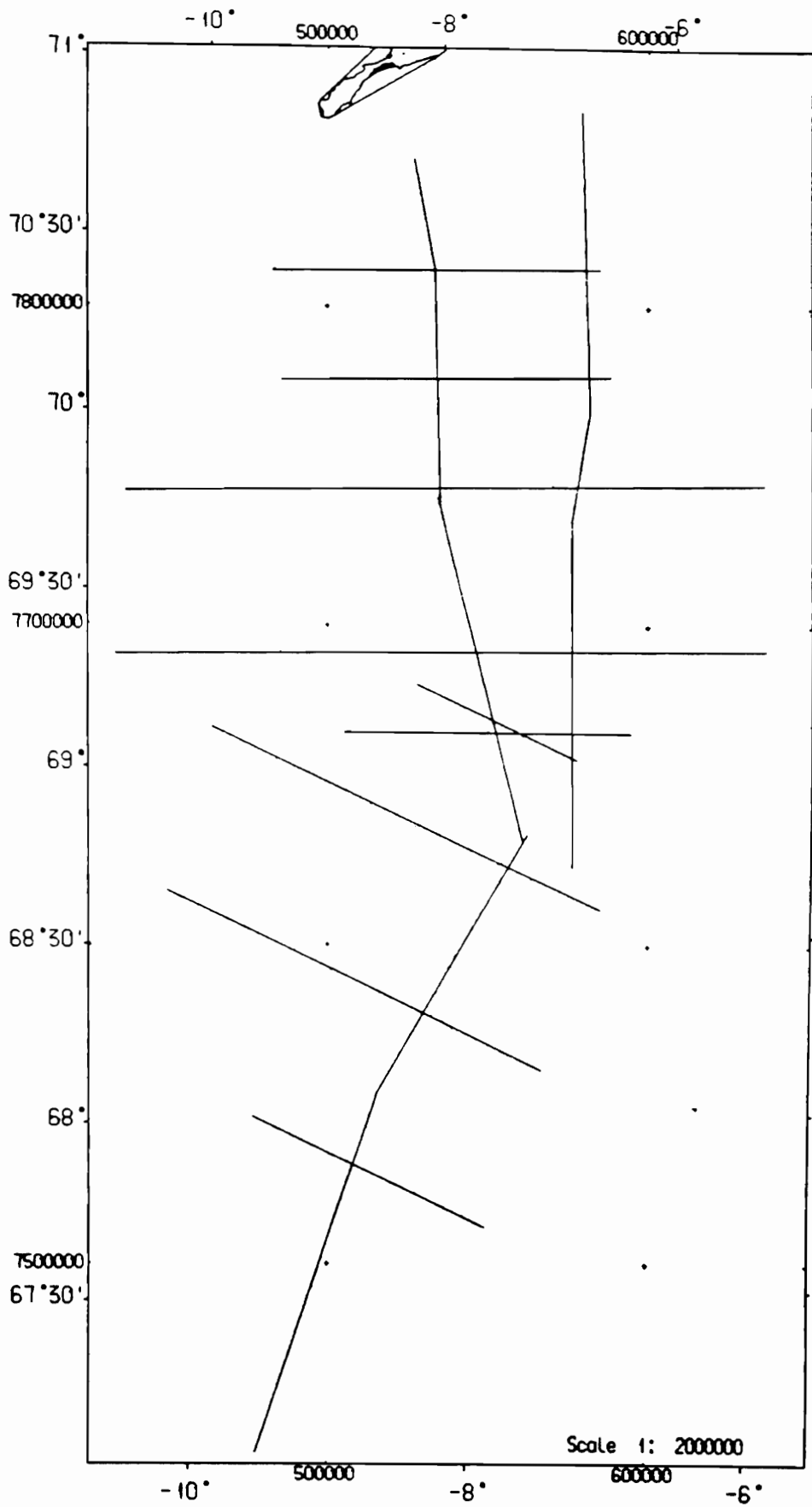   (place)   (signature)

LETTER OF TRANSMITTAL

Please acknowledge receipt of the above data by returning this form to:
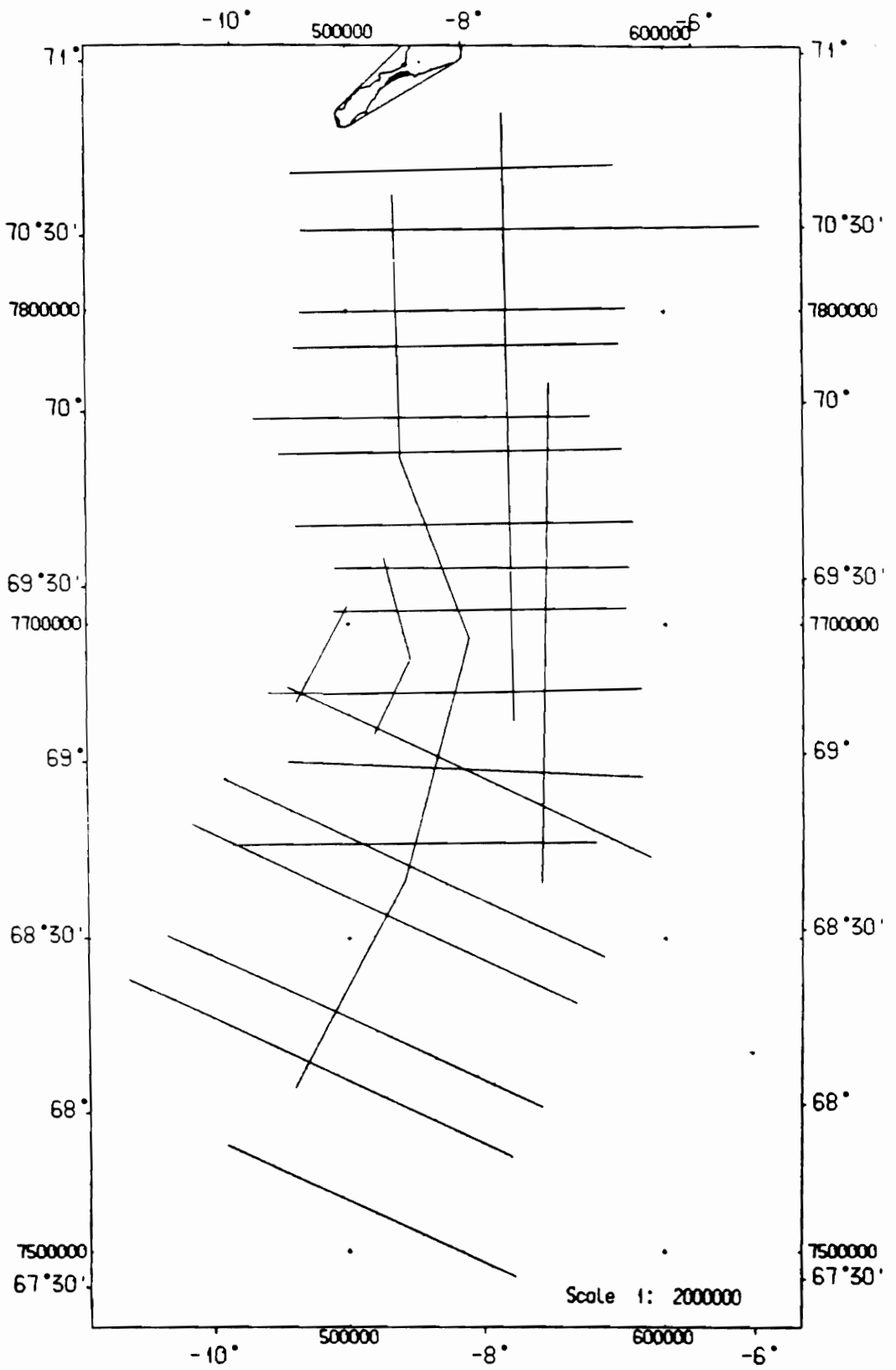The Norwegian Petroleum Directorate, P O Box 600, 4001 Stvg, Norway.

Received ..../..................../Date..........
        (name)   (signature)

FOR USE BY THE NORWEGIAN PETROLEUM DIRECTORATE

Date/Sign:	Mottatt	Nav bestilt	Postlagt	Fakturert
	....	....	....	....

Scale 1: 2000000

026 JAN-MAYEN-85

027   JAN-MAYEN-79/85