I.O.S.

GEOPHYSICAL INTERPRETATION OF THE STRUCTURE AND EVOLUTION OF THE JAN MAYEN RIDGE

BY

C. D. PELTON

REPORT NO. 205

1985

NATURAL ENVIRONMENT RESEARCH COUNCIL
INSTITUTE OF
OCEANOGRAPHIC
SCIENCES

INSTITUTE OF OCEANOGRAPHIC SCIENCES

Wormley, Godalming,
Surrey, GU8 5UB.
(0428 - 79 - 4141)

(Director: Dr. A.S. Laughton FRS)

Bidston Observatory,
Birkenhead,
Merseyside, L43 7RA.
(051 - 653 - 8633)

(Assistant Director: Dr D.E. Cartwright FRS)

Crossway,
Taunton,
Somerset, TA1 2DW.
(0823 - 86211)

(Assistant Director: M.J. Tucker)

When citing this document in a bibliography the reference should be given as follows:-

PELTON, C.D. 1985 Geophysical interpretation of the structure and evolution of the Jan Mayen Ridge. *Institute of Oceanographic Sciences, Report*, No. 205, 38pp.

INSTITUTE OF OCEANOGRAPHIC SCIENCES

WORMLEY

Geophysical interpretation of the structure and evolution of the Jan Mayen Ridge

by

C.D. Pelton

I.O.S. Report No. 205

1985

ABSTRACT

The Jan Mayen Ridge and its Southern Ridge Complex form part of a continental block which was rifted from the Greenland continental margin during the Mid-Eocene. Recently-processed multichannel seismic data interpreted with published geophysical data has enabled work to be carried out on (a) improved positions for the Southern Ridge Complex basement ridges; (b) isochron compilations for two important seismic events, namely, Horizon A, mapped for the first time in this work, and Horizon 0 which, in conjunction with depth-to-basement values, has been used to construct an improved total sediment thickness map; (c) a study of the change in spreading conditions along the eastern flank of the Jan Mayen Block; and (d) a revised ocean/continent boundary for the Jan Mayen Block.

CONTENTS

INTRODUCTION

Jan Mayen Island lies 480 km east of Greenland at a latitude of 71°N (Fig. 1). The Jan Mayen Ridge (JMR) is a broad, flat-topped feature trending SSE from the island. At 69°30'N it curves SSW and continues as a narrowing ridge to 68°20'N (Fig. 2). Here it is offset by about 15 km to the west, and continues a further 60 km with roughly the same trend. Further south there are more complex topographic features consisting of six subsidiary ridges trending approximately SSW from 68°30'N to 66°35'N. In the text, these ridges will be labelled R1 to R6 after Talwani and Eldholm (1977) and collectively referred to as the Southern Ridge Complex after Nunns (1980). The Southern Ridge Complex is separated from the JMR by a SW-NE trending topographic depression, the Jan Mayen Trough (Fig. 2). Immediately to the west of the JMR and Southern Ridge Complex lies the Jan Mayen Basin, a N-S elongated topographic low on the eastern edge of the Iceland Plateau. The JMR and Southern Ridge Complex will be considered as parts of the Jan Mayen Block, which originally formed part of the Greenland continent before being rifted from it during the Mid-Eocene (Nunns, 1983a).

The database represents the most comprehensive set of single and multichannel seismic reflection profiles assembled for this area (Fig. 3). The inclusion of 1500 km of recently-processed multichannel data recorded during Shackleton Cruise 9/77 in conjunction with bathymetry, gravity, magnetics and borehole data has enabled the following work to be carried out:

1. A complete revision of isochron compilations using key stratigraphic horizons in the Jan Mayen Ridge locality. These data have been interpreted with the help of new and existing theories on the structure and evolution of the Jan Mayen Block, and partially-correlated with borehole data obtained during DSDP Leg 38, Sites 346-350 (Talwani, Udintsev *et al.*, 1976).
2. A more precise identification of the location of the individual ridges comprising the Southern Ridge Complex than that made by previous workers.
3. A revision of the ocean-continent boundary position.
4. An examination of the ocean-continent transition with reference to changes in spreading conditions along the boundary and the study of dipping reflectors comparable to those on the conjugate Norwegian margin (Mutter *et al.*, 1984).

THE DATABASE

Published seismic reflection data on the Jan Mayen Ridge are available from the following sources: Single Channel: *Vema*, cruises 23, 27 and 28 (Talwani, 1974); Glomar Challenger, DSDP Leg 38 (Talwani, Udintsev et al., 1976); Meteor cruise 28 (Garde, 1978); Multichannel: CEPAN 1, 1975 (Gairaud et al., 1978); BGR (Bundesanstalt für Geowissenschaften und Rohstoffe) cruises in 1975 and 1976 (Garde, 1978); the main source of seismic data was from RRS Shackleton cruise 9/77 which comprised 1500 km of multichannel data obtained by the University of Durham. These data were reprocessed, redisplayed, and selected sections migrated as part of research into North Atlantic passive margins commissioned by the Department of Energy. Despite this processing, however, the deep sections still show extensive diffractions and acoustic cross-talk, while the resulting 9-fold stack of 12-channel data further degraded the final processing quality. A summary track chart is illustrated in Fig. 3.

The bathymetry used in this work was taken from data compiled on to 1:1 million plotting sheets at IOS (Fig. 2). The free-air gravity map (Fig. 4) was taken from Gronlie et al. (1979) and the magnetic anomalies up to 69°N were taken from the magnetic anomaly map of Iceland and surrounding seas (Nunns et al., 1983). North of 69°N the magnetic anomalies were taken from Nunns (1980) (Fig. 5).

INTERPRETATION OF SEISMIC REFLECTION PROFILES

Two seismic events, previously described as Horizon A and Horizon O by Gairaud et al. (1978) have been studied in this work. Both seismic horizons appear to mark angular unconformities, with A being the younger of the two. The post-Horizon A sequence will be referred to as Sequence 1 (sub-units a, b, c), the post-Horizon O sequence will be referred to as Sequence 2 and the pre-Horizon O sequence will be referred to as Sequence 3 (Fig. 6a, Table 1).

HORIZON A, SEQUENCES 1 (sub-units a-c) AND 2

Horizon A appears on seismic records as a smooth, well-defined sub-horizontal reflector beneath the crests of the JMR and Southern Ridge Complex (Fig. 6a). Here it lies at a depth of between 1.0-1.5 secs two-way time (twt) but dips steeply on the eastern flank of the ridge to 5.0 secs twt (Fig. 7). Southeast of the JMR it is present at a depth of 1.5-2.0 secs twt on ridges R5 and R4, where it dips steeply eastwards below the overlying sediments to a depth of 3.5 secs twt (Figs. 6a & 7) and eventually onlaps oceanic basement (Fig. 6b). The southern data limit is at 67°N where, on Shackleton 9/77, Line L, the horizon can be traced to its easternmost occurrence, at 6°10'W (Fig. 3).

Horizon A was penetrated by DSDP Holes 346, 347 and 349. Sequence 2 consists of massive terrigenous sandy mudstones with conglomerates and breccia, suggested to have been laid down adjacent to the former Greenland continental margin (Talwani, Udintsev et al., 1976). Above the horizon (sub-units 1b and 1c) lie sandy muds and siliceous oozes with some clastic debris. Volcanic ash is present as both scattered particles and thin layers. Covering this (sub-unit 1a) lies 40-60 metres of 'glacial' sediments consisting of terrigenous sandy muds, mud and clay. Two prominent volcanic ash units were present and the lower sequence had a significant volcanic ash component. The change in acoustic character apparent on seismic records (Fig. 6a & Table 1) between 1b and 1c may be due to the upper sequence having been deposited by turbidity currents or slump processes, while 1c may be more massive and derived from rapid erosion of homogeneous material (Nunns, 1980). The junction between sequences 1 and 2 is clearly marked lithologically by a basal conglomerate at site 349, and the horizon represents an erosional unconformity of late Eocene to upper mid-Oligocene age (Talwani, Udintsev et al., 1976). Talwani, Udintsev et al. (1976) suggest that the unconformity may have been the result of erosion caused by the thermal uplift associated with the separation of the JMR from the Greenland continent. However, Nunns (1980) suggests that by transferring the biostratigraphic dates of Schrader & Fenner (1976) to the later biostratigraphy of Hailwood et al. (1979), a maximum age for the unconformity as indicated by the youngest fossil assemblage from Sequence 2 is 39 Ma, i.e. magnetic anomaly 17. He suggests that, as separation began at anomaly 20 time, the unconformity is unrelated and a more likely cause could be the major mid-Oligocene drop in sea level at around 30 Ma (Vail et al., 1977). A recent biostratigraphy (Berggren et al., in press) correlates the unconformity as indicated by nannofossil zonation at the top of Sequence 2 with anomaly 15 (oldest age). This result would support the Oligocene sea-level fall as a more likely cause for the unconformity.

Figure 7 shows an isochron map of Horizon A, in seconds two-way time.

HORIZON O, SEQUENCE 3

Horizon O is a smooth basement reflector, locally interrupted by faulting and is most clearly seen on the eastern flanks of the JMR and Southern Ridge Complex where the underlying Sequence 3 exhibits a suite of eastward dipping reflectors in its upper section (Figs. 6b & 6c). The horizon can be traced below the top of oceanic basement and may continue eastwards for 10-15 km beneath it (Gairaud et al., 1978; their Fig. 7, line CP112; and Fig. 6b, this paper).

Unfortunately, Horizon 0 was not reached at DSDP site 350. However, the overlying basalts were sampled and dated at 40-44 Ma (Mid-Eocene) (Talwani, Udintsev et al., 1976). Gairaud et al. (1978) consider that the horizon represents the unconformity on which the post-rift series was deposited. They also suggest that the absence of Horizon 0 over parts of the Jan Mayen Block may be due to it being obscured by flood basalts. Alternatively, Hinz and Schlüter (1980) suggest that the Sequence 3 is composed of crystalline basement overlain by a thin Mesozoic sequence, which may explain the occurrence of internal dipping reflectors. Nunns (1980) considers that Horizon 0 represents either the top of basaltic, early rifting phase crust extruded sub-aerially in the same way that the earliest dipping reflector sequences are probably formed (Hinz, 1981), or plateau basalts overlying continental crust (see section on Jan Mayen Block). Both Gairaud et al. and Nunns agree that Sequence 3 pre-dates anomaly 24 and is, therefore, a pre-rifting sequence.

Figure 8 shows the extent of Horizon 0 and the total sediment thickness over Horizon 0 and oceanic-basalt, contoured in seconds two-way time. Where Horizon 0 dips eastwards to the ocean/continent boundary, a linear basin can be seen lying parallel to the eastern flank of the JMR and to the east of R4. Maximum sediment thicknesses here coincide locally with the Horizon 0/oceanic basement boundary (2.8 secs twt). Elsewhere, local faulting of Horizon 0 has produced high sedimentary thicknesses and Figure 8 shows the position and downthrow of faults mapped during this work. Due to the complex nature of the faulting of Horizon 0, the trends shown are purely speculative and have been taken as parallel to the ridge trends.

BASEMENT REFLECTORS

Three basement reflector types can be seen on seismic data from the Jan Mayen Ridge and surrounding region. These reflector types are each characteristic of one of the following areas, namely, the Iceland Plateau, the Jan Mayen Block and the Norwegian Basin.

The Iceland Plateau is characterised by an acoustic basement defined by a continuous, readily-recognised reflector (Fig. 6a). Horizon 0, which underlies parts of the Jan Mayen Block, occurs as a smooth, locally-faulted basement reflector, best seen beneath the northern part of the JMR (Gairaud et al., 1978); their Fig. 6, lines CP129 & CP 122).

On the west flank of the Jan Mayen Ridge there is evidence of a reflector lying beneath Horizon 0, seen on CEPAN Lines 112 and 129 as a diffuse event which

Gairaud et al. (1978) considered to be a Caledonian granite basement. This event is not detectable on the Shackleton 1977 lines. To the east of the Ridge, the top of Sequence 3 exhibits inclined reflectors, visible for up to 0.5 secs beneath Horizon 0 (Fig. 6c). Gairaud et al. (1978) consider these to be an underlying sedimentary formation, possibly limestones, shale and dolomite, and support this theory with velocity analyses of up to 4 km/sec. Velocities taken from Shackleton Line M1 were around 4.5 km/sec. Nunns (1980) disputes this sedimentary origin and quotes the similarity between the sub-0 reflectors and those within the crust of the Rockall and Voring Plateaux (Roberts et al., 1979; Hinz & Schlüter, 1979). Nunns (1980) also states that the velocity analyses of Gairaud et al. (1978) could also indicate plateau basalts or igneous intrusions.

To the east of the Jan Mayen Block and throughout the Norwegian Basin, typically hummocky oceanic basement is seen (Fig. 6e) which, along the eastern edge of the Jan Mayen Block, exhibits eastward-dipping intra-basement reflectors (Fig. 6d). Dipping reflectors have been described by Hinz (1981) and Mutter et al. (1982, 1984) who studied the extensive wedges of oceanward-dipping sub-acoustic basement reflectors that are found on many passive continental margins. These, they postulated, were formed by massive volcanic eruptions associated with the syn-rifting phase of sea-floor spreading. The relatively short-lived initial volcanic activity at the opening of an ocean basin led to the formation of extensive lava wedges which subsided into the active rift to form oceanward-dipping reflectors.

The boundary between oceanic basement and Horizon 0 is a variable one with marked differences between the north and south edges of the Block (see section on the transition zone).

All three of these basement types have been used to construct an isochron map of total sediment thickness in seconds, two-way time, over the Jan Mayen Block and surrounding area (Fig. 8). This has been compiled using CEPAN 1 and the 1977 Shackleton multichannel seismic data, with the addition of total sediment thickness data from Garde (1978).

THE RIDGES

Accurate positioning of the ridge crests R1-R6 was possible due to the abundance of seismic profiles in the area, a large number of which were orientated normal to their general trend. These were interpreted with the help of recompiled bathymetric and gravity data (Figs. 2 & 4) and the ridge profiles have been plotted from selected orthogonal seismic lines to illustrate their morphology (Fig. 9). It can be seen from Figure 4 that there is a strong correlation between the basement ridge crests and gravity highs. The apparent convergence of R4 and R5 to the north and south is not reported by previous workers, although Nunns (1980) shows a labelled cross-section of CEPAN 103 with R5 and R4 adjacent. However, he does not show this on his ridge crest orientations (his Fig. 1.8) in which R5 and R4 are sub-parallel features. Further north and to the west of the Jan Mayen Ridge at 69°N, there are two subordinate ridges running parallel to the main ridge (X and Y, Fig. 9). Ridge Y lies on the western flank of the JMR and follows the trend of the gravity anomalies (Fig. 4). Ridge X is best seen on profile P (Fig. 9) and has been positioned to pass through a poorly-defined basement high of possible Horizon O (Gairaud et al., 1978; their Fig. 5b, Line CP112). However, there is no evidence for this trend in the gravity anomalies (Fig. 4). Neither ridge appears on profile Q (Fig. 9). Although Horizon A cannot be discerned, the seismic sections across X and Y show evidence of a sequence similar to the post-Horizon A sequence seen on the JMR. A similar origin to the JMR must be presumed from both this evidence and their geographical proximity. At 70°N, 11°W, a scarp bounds the Jan Mayen Basin which, in turn, has a small central ridge trending N-S (Figs. 2 & 9).

THE BASEMENT RIDGES - COMPOSITION AND ORIGIN

The Jan Mayen Ridge and the Southern Ridge Complex can be divided physiographically into three areas (Fig. 10). The JMR and its southwest extension are separated by the Jan Mayen Trough from ridges R4-R6 which trend approximately SSW. To the south-east, ridges R1 and R3 have less relief and trend in a SW direction. These morphological and geographical differences have led previous workers to describe these zones separately and this paper adopts the zone nomenclature suggested by Talwani, Udintsev et al. (1976). Talwani & Eldholm (1977) consider that the Jan Mayen Ridge (Zone 1) and R4-R6 (Zone 2) are continental in origin and form 'windows' in the seismically-opaque basement layer, while ridges R1-R3 (Zone 3) are underlain by oceanic crust created contemporaneously with the Norwegian Basin. These 'windows' generally occur where the 'O' horizon is visible in multichannel records (Nunns, 1980) and were first described by Eldholm & Windisch (1974). Gronlie et al. (1979) agree that geophysical and bathymetric data strongly support the theory that the Jan Mayen Ridge and ridges R4-R6 (Zones 1 and 2) are continental in origin. The magnetic anomalies over the Jan Mayen Ridge are very weak and are characteristic of the quiet zones found on the Norwegian Continental Margin (Vogt et al., 1980) (Fig. 5).

The origin of ridges R1-R3 is more uncertain. Talwani & Eldholm (1977), using DSDP dating for the basalts overlying Horizon O, have suggested that they are oceanic in origin and were created by sea-floor spreading contemporaneously with the opening of the Norwegian Basin. This suggestion was prompted by the fact that anomalies in the Norwegian Basin younger than anomaly 20 tend to form a fan-shaped pattern towards the south (Nunns et al., 1983). Geometrically, therefore, there must have been another area of oceanic crust created between anomaly 20 time and anomaly 7 time so that the present-day Norwegian Basin does not decrease in width from north to south; a consideration that is required by the relative motion of rigid plates. If Zone 3 (ridges R1-R3) is included in the Norwegian Basin, then this requirement is met. The dating of deepest recovered basalts from DSDP site 350 of 41.2 ± 10 Ma (Kharin et al, 1976) broadly agrees with Talwani & Eldholm's (1977) 50-26 Ma age of the basement in Zone 3, calculated from anomalies 20-7. Gairaud et al. (1978), however, believe that Zone 3 (R1-R3) forms part of the Greenland continental margin. They consider that the Jan Mayen Trough, which separates the JMR from R5 (Fig. 10) is a graben floored with extrusive basalts, and that this rifting was associated with the separation of the Jan Mayen Block from the Greenland Continental Margin. Due to Gairaud et al.'s (1978) proposed existence of the JAG fault (described below), they concur that ridge R1 forms the eastern side of this right-laterally- displaced graben and it is likely, therefore, that Zone 3 (R1-R3) has the same deep structure as Zone 2 (R4-R6). The basalts overlying R1 would, therefore, have been extruded with the plateau basalts of the Greenland margin. Nunns (1980) disputes this correlation by stating that the preferred dates of the sampled basalts from DSDP site 350 of 41.2 ± 10 Ma (Kharin et al., 1976) would make them younger than the East Greenland basalts which were erupted prior to anomaly 24 time (52 Ma). Nunn's alternative suggestion for the origin of R1 basalts, and hence of Zone 3, is that Horizon O in this region may consist of plateau basalts from the East Greenland margin while the overlying basalts sampled at Site 350 represent flood basalts originating from the subsequently- active Aegir axis which may have covered the southern part of the Jan Mayen Block. Whether Horizon O also represents plateau basalts under the main Jan Mayen Ridge is uncertain.

'JAG' FAULT

Gairaud et al. (1978) propose the existence of a right-hand transcurrent displacement, which they refer to as the 'JAG' fault which crosses line CP105 at 67°40'N and runs parallel to, and between, Lines CP103 and CP108 (Fig. 3). The evidence comes from these parallel profiles which appear to show a displacement of a rifted trough by approximately 60 km to the east from CP1089 in the north to CP103 in the south. This rift is identified in Gairaud et al. (1978; their Fig. 5b) as occurring between the Jan Mayen Ridge and R5 on CP108. The fault then appears to displace the Jan Mayen Ridge 60 km to the east, with the rift occurring on CP103 (Gairaud et al., 1978; their Fig. 5b) between ridges identified in this work as R5/R4 and R1 (Fig. 9). Gairaud et al. (1978) had poor seismic coverage in this area and based this observation on the similarity in faulting and tilting direction of the two ridges (JMR and R5) on separate profiles. There is also evidence of a tilted block and a basaltic dome on line CP105 at the crossing point of the fault. They cite the apparent offset of the Aegir axis by a similar amount as further proof and, in the structural sketch map of the area, Gairaud et al. (1978; their Fig. 10) extend the JAG fault through the extinct axis.

Nunns (1980) discounts this evidence and feels that the axis of rifting has been mis-identified. The improved seismic coverage available for this work confirms Nunns' ideas showing that R5 continues through the 'JAG' fault. It appears that the Jan Mayen Ridge identified on CP103 by Gairaud et al. (1978) is, in fact, R5/R4 and the change in direction of tilting and faulting can be explained by an eastward transposition of the axis of down-faulting southwards from CP108. The rift between R5/R4 and R1 in CP103 is, therefore, an en echelon equivalent of the Jan Mayen Trough (Nunns, 1980). A similar change in fault and tilt direction can be seen between CP129 and CP108 (Gairaud et al., 1978; their Figs. 6 & 7). Note that Shackleton, Line M1 (Fig. 3) crosses the supposed fault and exhibits a dome structure overlain by Horizon O at the theoretical fault crossing; however, the significance of this structure or whether it forms a continuous feature through the area is unknown. There is no evidence from either bathymetry or gravity to support the existence of a major fault.

DELINEATION OF THE JAN MAYEN BLOCK

The Jan Mayen Block is here defined as being delineated by the extent of Horizon O (Fig. 8). From the seismic section illustrated in Figure 6a it can be seen that this smooth, dipping basement reflector differs markedly from the hummocky oceanic basement of the Norwegian Basin and from the basalts of the Jan Mayen Basin, which occur as a strong horizontal reflector. It appears from seismic data (e.g. Fig. 6b) that the oceanic basement of the Norwegian Basin onlaps Horizon O and, therefore, proves that the Jan Mayen Block existed prior to the spreading axis shift from the Aegir axis to the Kolbeinsey axis.

The transition from Horizon O to oceanic basement is characterised by increasingly discontinuous basement reflectors from _Shackleton_ Lines R in the north to M in the south (see following section). The transition zone narrows from 24 km at 68°40'N to 11 km at 67°30'N and is schematically illustrated in Figure 10. The increasing roughness of the basement reflectors to the south suggests an initially slower spreading rate than in the north; uneven subsidence caused by differential cooling giving a more chaotic appearance to the basement reflectors. Other factors involved may be alterations in the relative plate motions prior to the jump in the spreading axis (Sundvik _et al._, 1984) or sill intrusions (see section on the transition zone).

The western boundary of the Jan Mayen Block is delineated along the western edges of the basement ridges. It should be noted that this line diverges southwards from a line running parallel to anomaly 6B (as identified by Talwani & Eldholm (1977) and Gairaud _et al_. (1978) but the gravity and seismic data show no evidence that the Jan Mayen Block extends into this area. In this respect the western boundary proposed by this work is in agreement with that of Nunns (1980). Note that the ridge within the Jan Mayen Basin at 70°N, 10°W (Fig. 10) is underlain by Horizon O (Gairaud _et al_, 1978) and is, therefore, included within the Jan Mayen Block. Further south the boundary runs across the basin to the west side of R6.

Talwani & Eldholm (1977) consider Zone 3 to be oceanic but Gairaud _et al._ (1978) and Nunns (1980, 1983b) agree in their positioning of the eastern boundary of the block immediately to the west of anomaly 24B (Fig. 10), the oldest anomaly in the Norwegian Basin. Using the transition from Horizon O to oceanic basement as the eastern boundary, this work agrees closely with Nunns (1980, 1983b) with the addition of the transition zone, indicating a possible change in spreading conditions in the Norwegian Basin. On the conjugate margin, Smythe (1983) has located the continent-ocean boundary of the Faeroe Plateau at the lower end of the oldest (closest to the margin) of the oceanward-dipping reflector series. Only one line in the present work (_Shackleton_ M3; Figs. 3 & 6d) exhibits unequivocal examples of dipping reflectors, but this may be due to difficulties in the deep-section processing described earlier, and the Jan Mayen Block boundary has been positioned where these occur using Smythe's (1983) criteria (Fig. 10). Lack of seismic data to the south of the Jan Mayen Block precludes any identification of a southerly boundary.

THE TRANSITION ZONE FROM THE EASTERN JAN MAYEN BLOCK TO OCEANIC BASEMENT

This zone has been studied using seismic data from the *Shackleton* 1977, Lines M, O, P and R. Lines M and O provide near-orthogonal sections across the southern half of the zone while Lines P and R run progressively more obliquely across it to the north (Figs. 3 & 10).

Line M (parts 1 and 3) (Figs. 6c, 6d)

The transition from the easternmost expression of Horizon O to an unequivocal oceanic basement reflector is characterised in the west (Line M1) by an 11 km zone of incoherent basement reflectors which is confused by point-source diffraction hyperbolae. Horizon O dips steeply eastward into this region and some parallel dipping reflectors are evident in the underlying sequence. Further east (Line M3), the basement forms a continuous hummocky reflector characteristic of oceanic crust. From the western end of line M3, eastwards for 16 km, eastward-dipping reflectors are visible beneath the hummocky basement. The true dip of these reflectors has been measured as 14°, a figure which compares favourably with measurements taken from similar dipping reflectors on the western Rockall Plateau (IOS unpublished data). Seismic site surveys for IPOD Legs 48 and 81 indicated dip values of up to 18° in this area. Mutter *et al.* (1982) published seismic data from the Voring Plateau which exhibited dipping reflectors with angles of up to 10°. The similarity in character of the Jan Mayen dipping reflectors and those from the Norwegian Margin south of the Voring Plateau can be seen by comparing Figures 6d and 6f.

Line O (Fig. 6a)

The transition zone at this point is characterised by a region of discontinuous reflectors between Horizon O to the west and oceanic basement 11 km to the east. The upper section of the seismic record shows well-stratified sequences above the transition zone.

Line P (Fig. 6b)

The transition here exhibits a less chaotic seismic character than Line O with discontinuous reflectors extending for 11 km between Horizon O and well-defined oceanic basement.

The discontinuous nature of the reflectors described above can be attributed either to faulting initiated by the cooling and subsequence subsidence of the ocean crust or they may be the expression of isolated lava flows perhaps associated with the formation of the oldest oceanic crust. However, the occurrence of truncated reflectors higher in the sequence, e.g. at 4.2 secs twt on Line P (Figs. 3 & 6b), could also represent a late sill complex.

Line R (Fig. 6e)

This line runs more obliquely across the transition than the other lines but its appearance on the seismic records is similar to that of Line P. However, the discontinuity of the reflectors here is not so marked and they exhibit a general westward dip from unequivocal oceanic basement in the SE to Horizon O which appears 24 km to the NW.

CONCLUSIONS

The improved data set interpreted here has enabled (1) an isochron compilation for Horizon A to be produced, and (2) a total sediment thickness map to be compiled over both Horizon O on the Jan Mayen Block, and basement from the Norwegian and Jan Mayen Basins.

Examination of the ocean/continent boundary along the eastern edge of the Jan Mayen Block has revealed a transition zone with increasing discontinuity of basement reflectors to the south which may indicate either (1) slower-spreading rates in the south, (2) differential plate motions prior to the jump in spreading axis from the Aegir to Kolbeinsey Ridges or, (3) localised sill intrusions.

An example of oceanward-dipping reflectors has been studied and appears comparable to those from the conjugate Norwegian Margin. An unpublished multichannel seismic line south of the Voring Plateau illustrates the dipping reflectors from the conjugate margin (Fig. 6f).

The age and composition of Horizon O, and hence the origin of the Jan Mayen Block, can only be truly ascertained from direct sampling. The drilling of a complete sequence from Horizon A through to Horizon O would provide samples that should substantiate what are, at the present time, only speculative theories on its continental or oceanic origin. A seismic refraction survey would also be valuable in yielding data on the velocity structure of the sub-Horizon Sequence 3 and could also provide a conclusive ocean/continent boundary if unequivocal oceanic basalt/continental granite velocity boundaries were established.

ACKNOWLEDGEMENTS

I should like to acknowledge the Department of Energy for funding the processing of the _Shackleton_ 1977 seismic data. Lindsay Parson is thanked for much helpful comment during the preparation of this work, while Doug Masson and Guy Rothwell provided valuable criticism as reviewers. The manuscript was capably typed by Thelma Ellis and Gabrielle Mabley.

REFERENCES

BERGGREN, W.A., KENT, D.V. & FLYNN, J.J., 1984. Palaeogene geochronology and chronostratigraphy. In: Snelling, N.J. (Ed.), Geochronology and the Geologic Time Scale. Geol. Soc. of London Spec. Pub. (in press).

ELDHOLM, O & WINDISCH, C.C., 1974. The sediment distribution in the Norwegian-Greenland Sea. Bull. Geol. Soc. Am.,85, pp. 1661-1676.

GAIRAUD, H., JACQUART, G., AUBERTIN, F. & BEUZART, P., 1978. The Jan Mayen Ridge: synthesis of geological knowledge and new data. Oceanol. Acta., Vol. 1, No. 3, pp. 335-358.

GARDE, S.S., 1978. Zur geologischen entwicklung des Jan Mayen Rückens nach geophysikalischen daten. Dissertation, Technischen Universität Clausthal, December 1978. (Unpublished manuscript).

GRONLIE, G., CHAPMAN, M. & TALWANI, M., 1979. Jan Mayen Ridge and Iceland Plateau: origin and evolution. In: Geophysical studies in the Norwegian-Greenland Sea. Norsk Polarinstitutt, No. 170, pp. 25-47.

HAILWOOD, E.A., BOCK, W., COSTA, L., DUPEUBLE, P.A., MULLER, C. & SCHNITKER, D., 1979. Chronology and biostratigraphy of Northeast Atlantic sediments: DSDP Leg 48. In: Montadert, L. & Roberts, D.G., Initial Reports of the Deep-Sea Drilling Project, Vol. 48, U.S. Government Printing Office, Washington, pp. 1119-1141.

HINZ, K., 1981. A hypothesis on terrestrial catastrophes. Wedges of very thick oceanward-dipping layers beneath passive continental margins: their origin and palaeoenvironmental significance. Geologische Jahrbuch, Reihe E, Heft 22, 28 pp.

HINZ, K. & SCHLUTER, H.U., 1979. The North Atlantic - results of geophysical investigations by the Federal Institute for Geosciences and Natural Resources on North Atlantic Continental Margins. OILGAS - European Magazine, 3, 31-38.

HINZ, K. & SCHLUTER, H.U., 1980. Continental margin off East Greenland. In: Proceedings of the 10th World Petroleum Congress, Bucharest 1979. Special Paper 7, Exploration Supply and Demand, Vol. 2, pp. 405-421.

KHARIN, G.N., UDINTSEV, G.B., BOGATIKOV, O.A., DMITRIEV, J.I., RASCHKA, H., KREUZER, H., MOHR, M., HARRE, W. & ECKHARDT, F.J., 1976. K/Ar age of the basalts of the Norwegian-Greenland Sea, DSDP Leg 38. In: Talwani, M., Udintsev, G. et al., 1976. Initial Reports of the Deep-Sea Drilling Project, Vol. 38, U.S. Government Printing Office, Washington, pp. 755-760.

MUTTER, J.C., TALWANI, M. & STOFFA, P.L., 1982. Origin of seaward-dipping reflectors in oceanic crust off the Norwegian margin by "sub-aerial sea-floor spreading". Geology, 10, 353-357.

MUTTER, J.C., TALWANI, M. & STOFFA, P.L., 1984. Evidence for a thick oceanic crust adjacent to the Norwegian Margin. Jour. Geophys. Res., Vol. 89(B1), pp. 483-502.

NUNNS, A.G., 1980. Marine geophysical investigations in the Norwegian-Greenland Sea between the latitudes of 62°N and 74°N. Ph.D. Thesis, University of Durham, 1980. (Unpublished manuscript).

NUNNS, A.G., 1983a. Plate-tectonic evolution of the Greenland-Scotland Ridge and surrounding regions. In: M.H.P. Bott et al. (Eds.) Structure and development of the Greenland-Scotland Ridge: new methods and concepts, NATO Conference Series, Vol. IV, No. 8, pp. 11-30.

NUNNS, A.G., 1983b. The structure and evolution of the Jan Mayen Ridge and surrounding regions. In: Studies in continental margin geology, Watkins, J.S. & Drake, C.L. (Eds.), A.A.P.G. Mem. No. 34, 801 pp.

NUNNS, A.G., TALWANI, M., LORENTZEN, G.R., VOGT, P.R., SIGURGEIRSSON, T., KRISTJANSSON, L., LARSEN, H.C. & VOPPEL, D., 1983. In: Bott, M.H.P., et al. (Eds.), Structure and development of the Greenland-Scotland Ridge: new methods and concepts. NATO Conference Series, Vol. IV, No. 8, 685 pp. & 1 chart.

ROBERTS, D.G., MONTADERT, L. & SEARLE, R.C., 1979. The Western Rockall Plateau: stratigraphy and structural evolution. In: Montadert, L & Roberts, D.G., 1979. Initial Reports of the Deep-Sea Drilling Project, Vol. 48, U.S. Government Printing Office, Washington, 1061-1088.

SCHRADER, H-J. & FENNER, J., 1976. Norwegian Sea Cenozoic diatom biostratigraphy and taxonomy, Part I. In: Talwani, M., Udintsev, G. et al., 1976.Initial Reports of the Deep-Sea Drilling Project, Vol. 38, U.S. Government Printing Office, Washington, pp. 921-962.

SMYTHE, D.K., 1983. Faeroe-Shetland escarpment and continental margin north of the Faeroes. In: M.H.P. Bott et al. (Eds.), Structure and development of the Greenland-Scotland Ridge: new methods and concepts, NATO Conference Series, Vol. IV, No. 8, pp. 109-119.

SUNDVIK, M., LARSON, R.L. & DETRICK, R.S., 1984. Rough-smooth basement boundary in the western North Atlantic basin: Evidence for a seafloor-spreading origin. Geology, 12(1), pp. 31-34.

TALWANI, M., 1974. In: Talwani, M. (Ed.), Lamont-Doherty Survey of the World

Ocean. Underway marine geophysical data in the North Atlantic, June 1961-January 1971. Parts A-F. Palisades, New York. Lamont-Doherty Geological Observatory of Columbia University.

TALWANI, M. & ELDHOLM, O., 1977. Evolution of the Norwegian-Greenland Sea. Bull. Geol. Soc. Am., 88, pp. 969-999.

TALWANI, M., UDINTSEV, G. _et al_., 1976. Initial Reports of the Deep-Sea Drilling Project, Vol. 38, U.S. Government Printing Office, Washington.

VAIL, P.R., MITCHUM, R.M., TODD, R.G., WIDMIER, J.M., THOMPSON, S., SANGEE, J.B., BUBB, J.N. & HATLELID, W.G., 1977. Seismic stratigraphy and global changes of sea-level. Part I: Overview. _In_: C.E. Payton (Ed.) Seismic stratigraphy applications to hydrocarbon exploration. American Association of Petroleum Geologists Memoir 26, Tulsa, Okla., pp. 49-52.

VOGT, P.R., JOHNSON, G.L. & KRISTJANSSON, L., 1980. Morphology and magnetic anomalies north of Iceland. Journal of Geophysics, Vol. 47, pp. 67-80.

FIGURE CAPTIONS

Figure 1 Location map.

Figure 2 Bathymetry of the Jan Mayen Ridge and Southern Ridge Complex. Contour interval, 100 metres (corrected). See Figure 1 for location.

Figure 3 Seismic lines and DSDP drilling sites on the Jan Mayen Ridge and surrounding area. CP = CEPAN; V = Vema; BGR = Bundesanstalt für Geowissenschaften und Rohstoffe. Seismic sections illustrated in Figures 6a-6e are shown as bold lines.

Figure 4 Free-air gravity map of the Jan Mayen Ridge and Southern Ridge Complex. Contour interval, 10 mgals. Basement ridges plotted from bathymetric profiles are shown as dashed lines (see Fig. 9).

Figure 5 Magnetic anomaly map of the Jan Mayen Ridge and surrounding area. Stippled areas represent positive anomalies. Bold lines indicate the basement ridges as shown in Figure 9.

Figure 6a to 6e Interpreted multichannel seismic sections from Shackleton Cruise 9/77 (See Fig. 3 for location). Vertical scale in seconds two-way time.

6a = Line 0, showing Horizon A, Horizon 0, Sequences 1-3, oceanic basement from the Norwegian Basin, and basalts from the Jan Mayen Basin and Trough (B).

6b, 6c and 6e = Lines P, M1 and R showing the ocean/continent transition zone, Horizon A, Horizon 0 and oceanic basement.

6d = Line M3, showing dipping reflectors from the eastern flank of the Jan Mayen Block.

Figure 6f Multichannel seismic section from Line B, Shackleton Cruise 1976 (Durham University), exhibiting dipping reflectors from the Norwegian Margin. Vertical scale in seconds two-way time.

(1) Basement, showing off-lapping lava flows,

(2) Seaward-dipping reflectors.

Figure 7 Isochron map to Horizon A, contoured in seconds two-way time, at 0.5 sec intervals.

Figure 8 Isochron map of total sediment thickness, contoured in seconds two-way time at 0.2 sec intervals. Shading indicates extent of Horizon 0 from current data.

<u>Figure 9</u> Selected bathymetric profiles of the Jan Mayen Ridge and Southern Ridge Complex. Dashed lines indicate the crests of the basement ridges. See Figure 3 for line identification.

<u>Figure 10</u> Delineation of the east and west boundaries of the Jan Mayen Block and the ocean-continent transition zone. Numbers 1-3 represent the zones of Talwani & Udintsev (1976).

TABLE 1 - Summary of the seismic stratigraphy

SEISMIC SEQUENCE	AGE	ACOUSTIC CHARACTER from CEPAN 1 multichannel records (Gairaud et al., 1978)	ACOUSTIC CHARACTER from SHACKLETON 9/77 multichannel records	LITHOLOGY
1 sub-units a	Upper Mid-Oligocene to Recent	Thin, horizontal layers	Horizontally stratified	Terrigenous sandy muds and clay, 40-60 m thick with 2 volcanic ash units, overlying sandy muds and siliceous oozes with some clastic debris and volcanic ash.
b		Chaotic with hummocky upper surface	Poorly stratified	
c		Reflection free	Some stratification on the upper basement ridge slope flanks, but becoming poor downslope	
HORIZON A				
2	Middle-Late Eocene	Strong, parallel reflectors	Strong parallel reflectors on the upper basement ridge slopes becoming more discontinuous downslope	Massive, terrigenous mudstones and sandy mudstones with conglomerates and breccias, both graded and un-graded.
HORIZON O				
3	Pre-Early Eocene	Diffuse reflectors with some eastward-dipping reflectors on the JMR in the upper section.	Acoustically transparent with refraction hyperbolae.	Possibly a sedimentary sequence of limestones, dolomites and shales or alternatively plateau basalts or igneous intrusions.

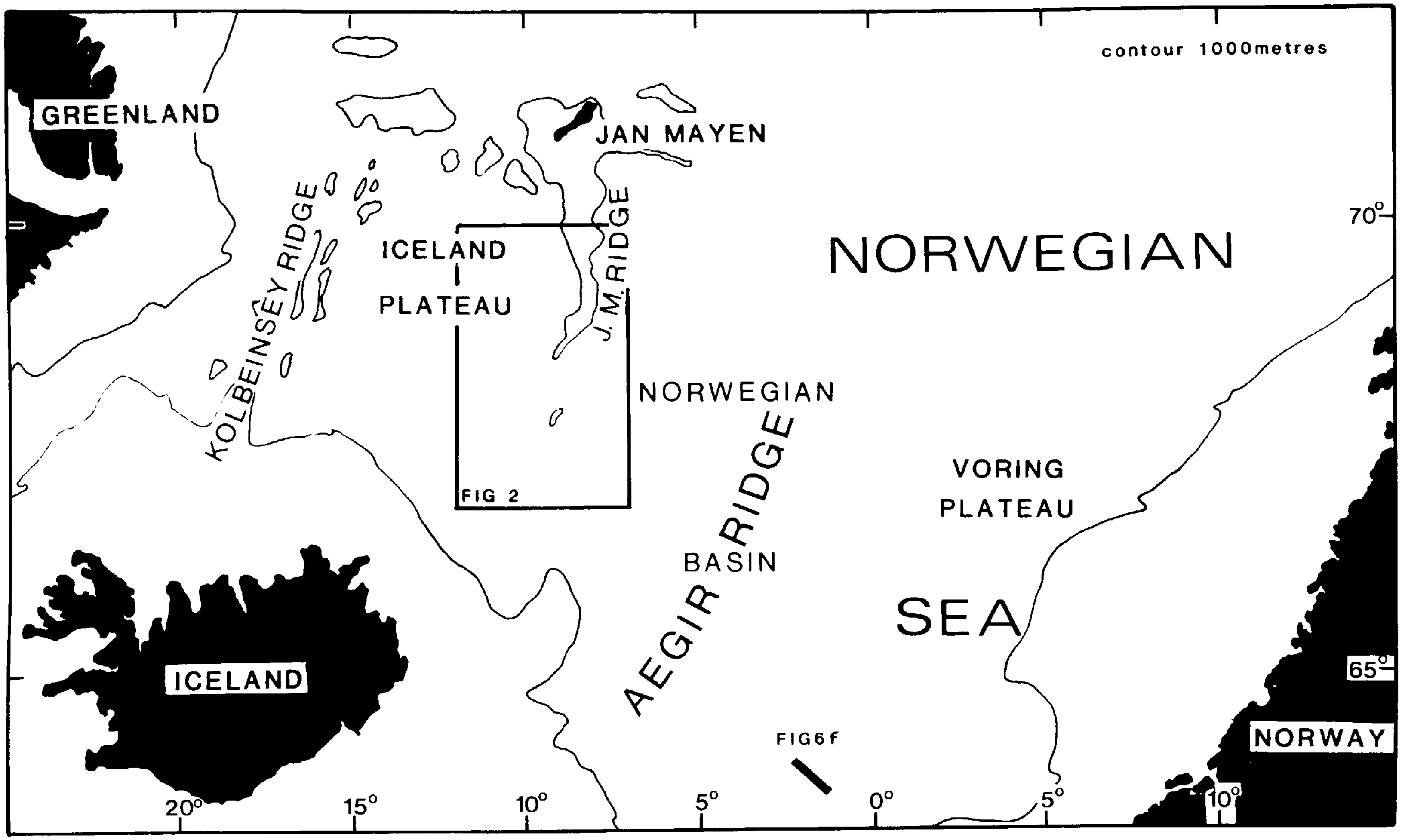

Figure 1 Location map.

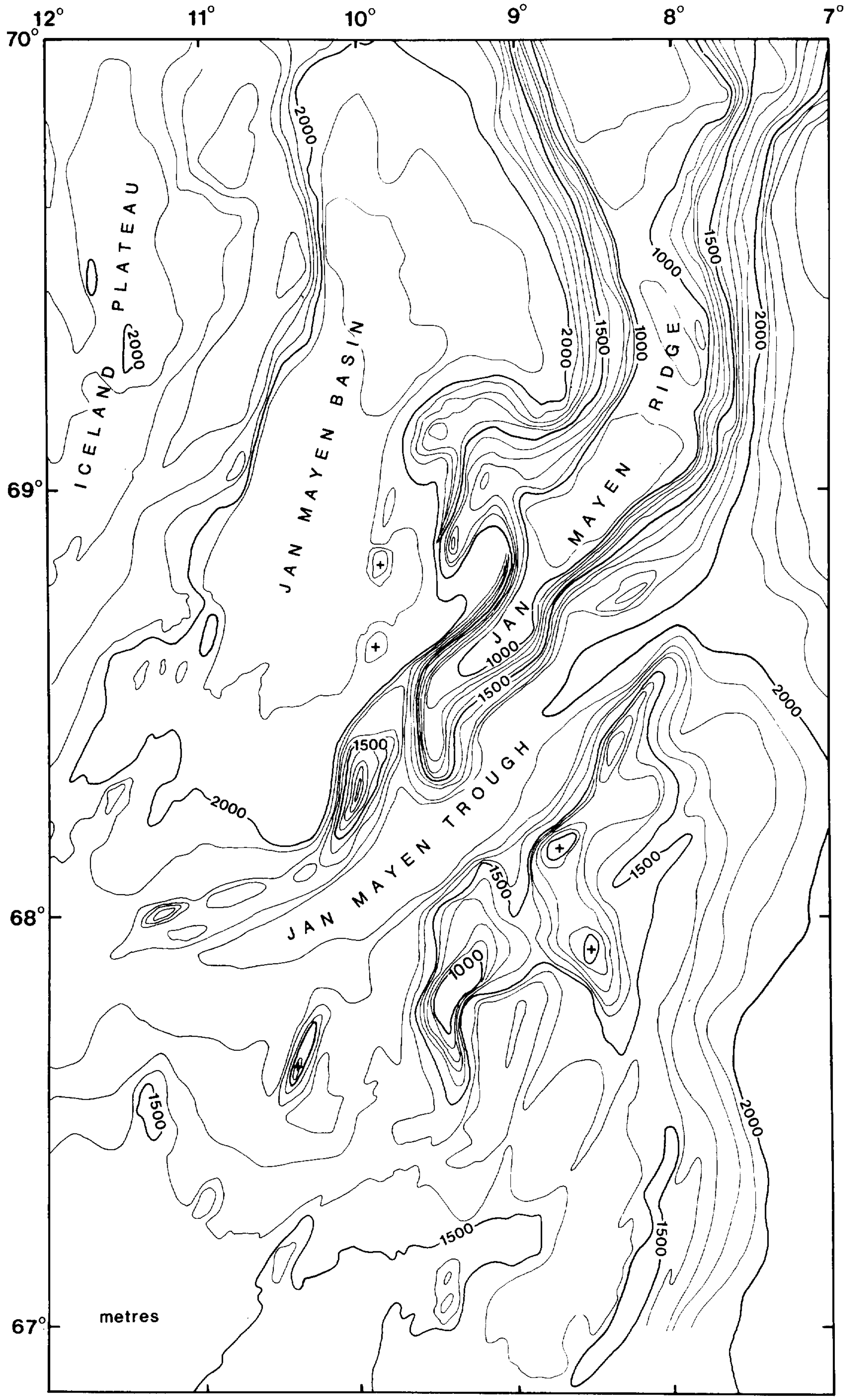

Figure 2 Bathymetry of the Jan Mayen Ridge and Southern Ridge Complex. Contour interval, 100 metres (corrected). See Figure 1 for location.

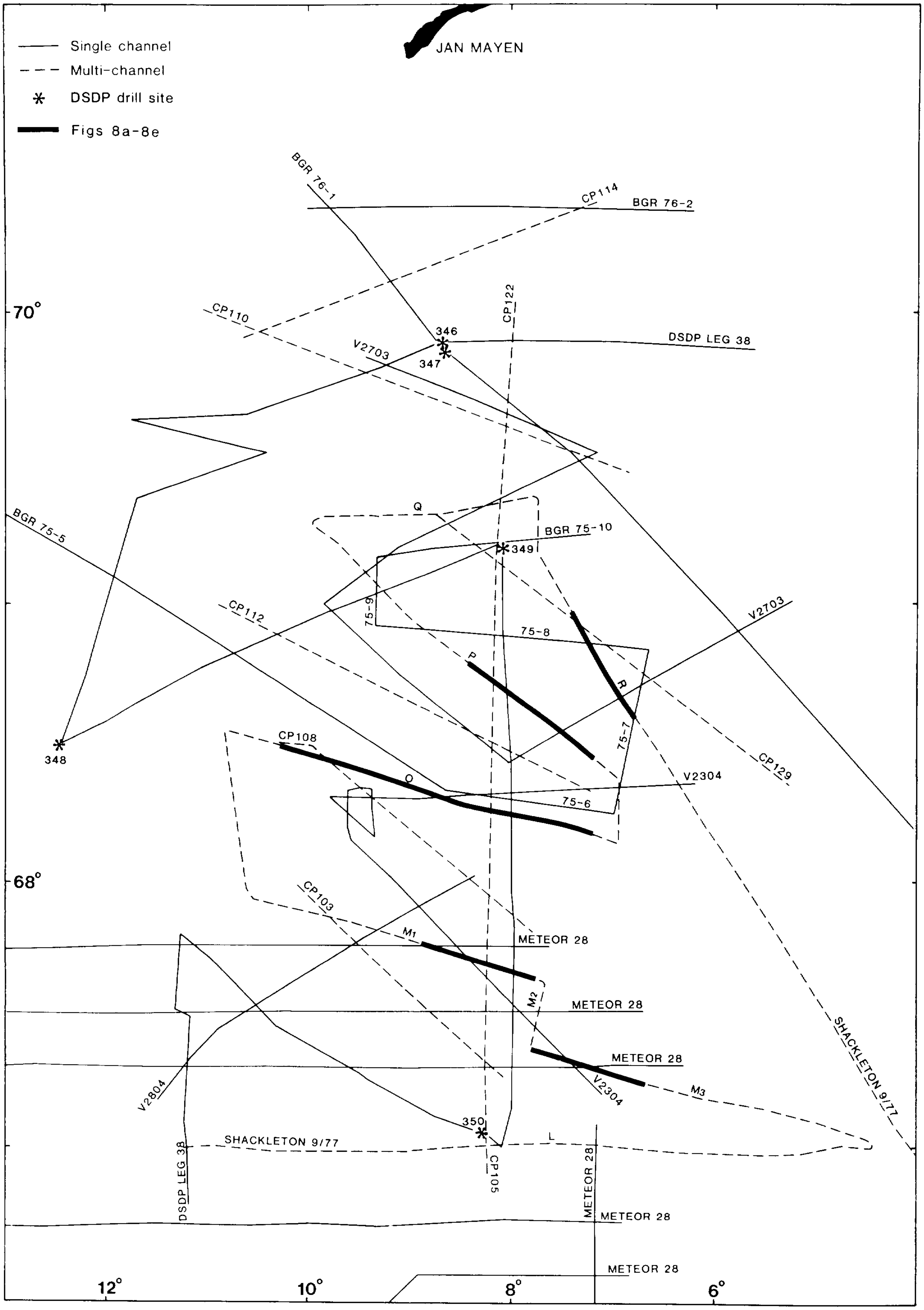

Figure 3 Seismic lines and DSDP drilling sites on the Jan Mayen Ridge and surrounding area. CP = CEPAN; V = Vema; BGR = Bundesanstalt für Geowissenschaften und Rohstoffe. Seismic sections illustrated in Figures 6a-6e are shown as bold lines.

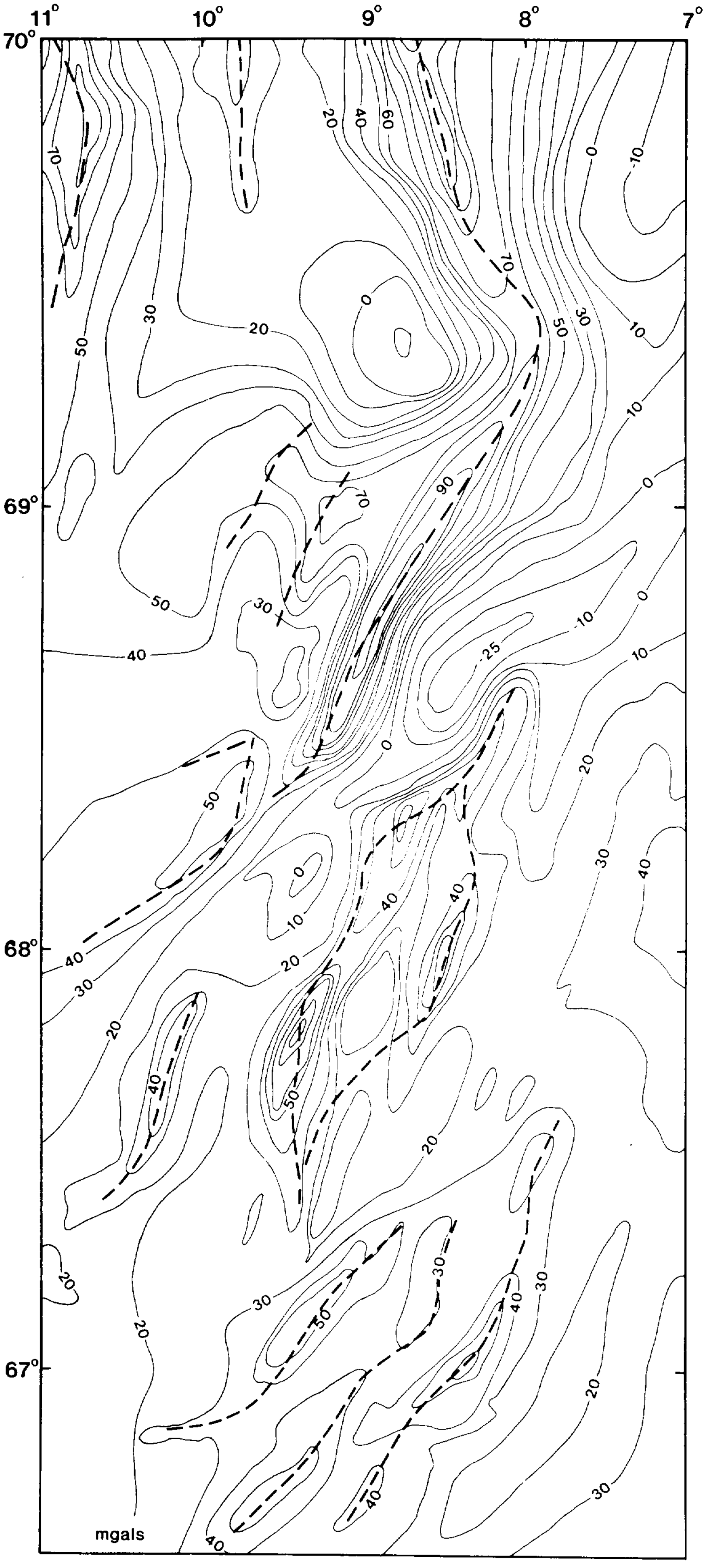

Figure 4 Free-air gravity map of the Jan Mayen Ridge and Southern Ridge Complex. Contour interval, 10 mgals. Basement ridges plotted from bathymetric profiles are shown as dashed lines (see Fig. 9).

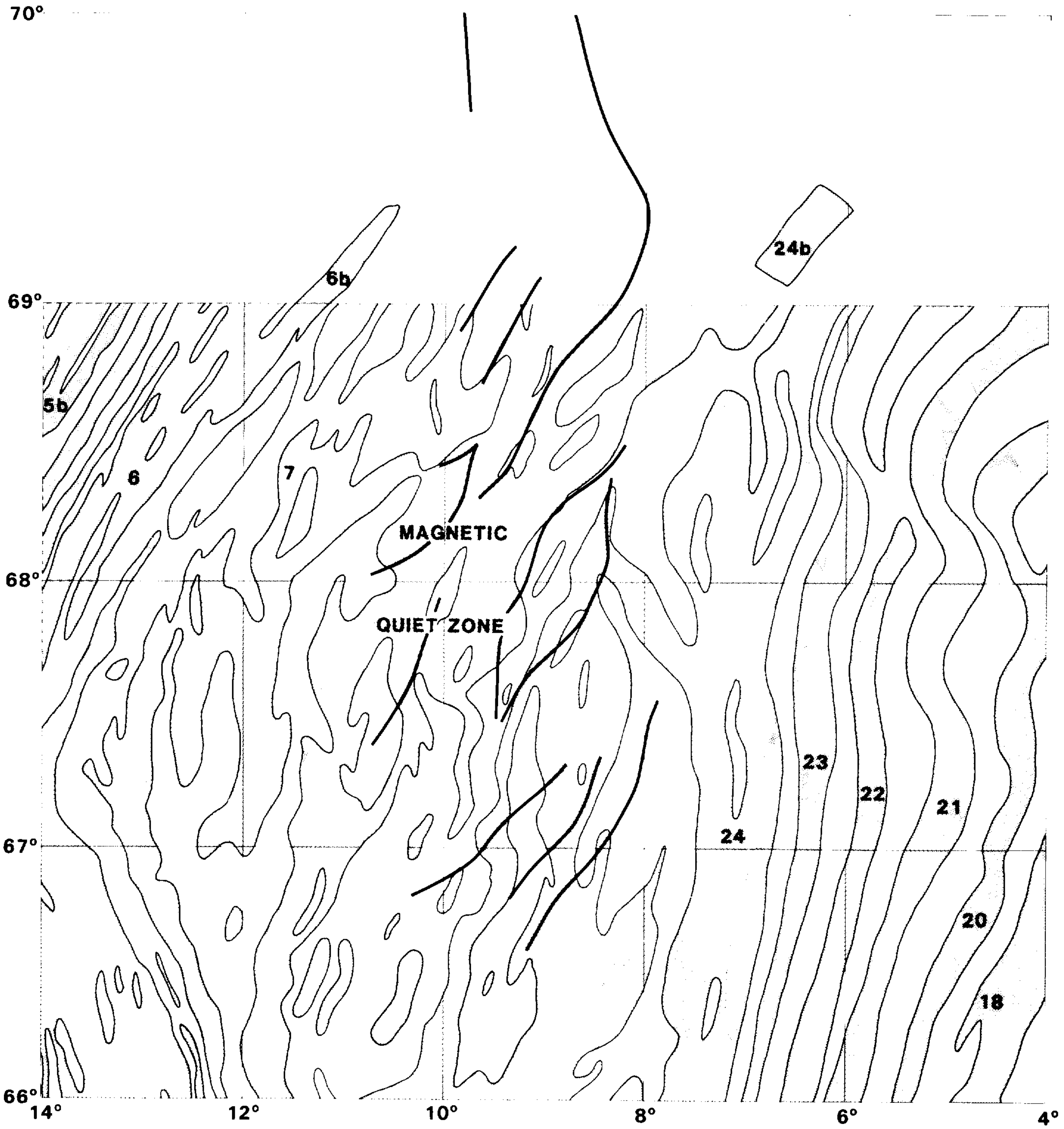

Figure 5 Magnetic anomaly map of the Jan Mayen Ridge and surrounding area. Stippled areas represent positive anomalies. Bold lines indicate the basement ridges as shown in Figure 9.

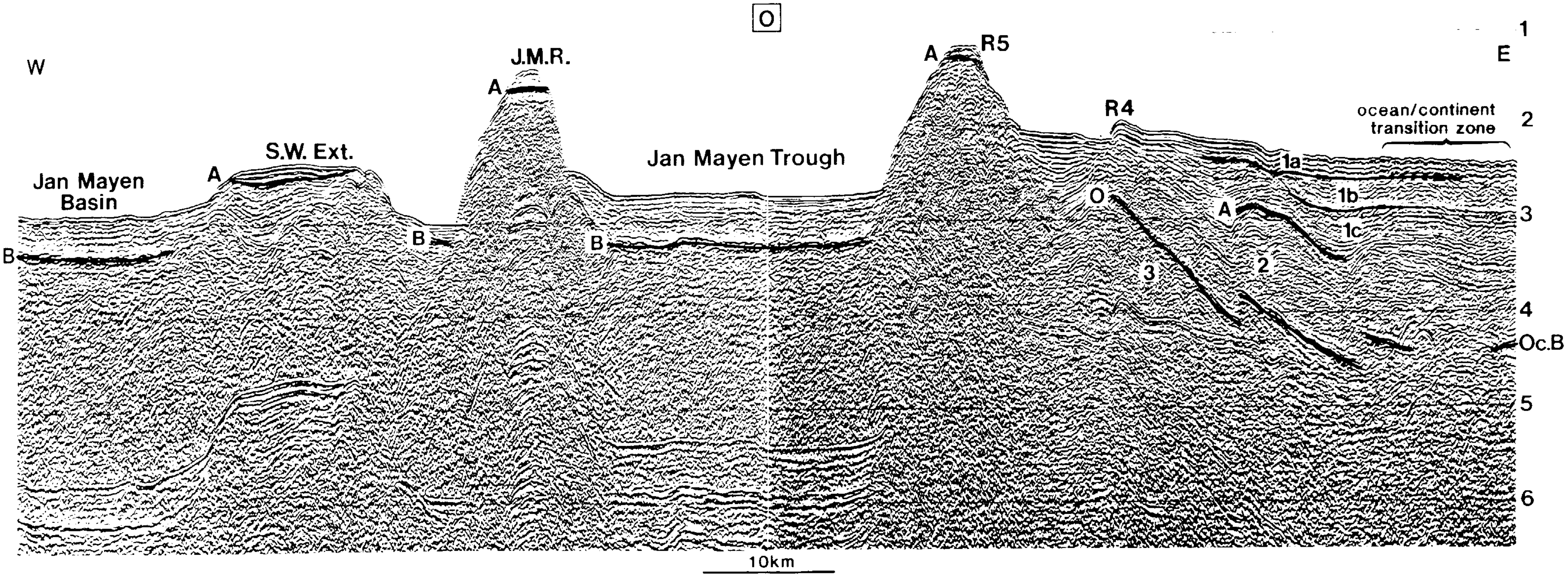

Figure 6a Line O, showing Horizon A, Horizon O, Sequences 1-3, oceanic basement from the Norwegian Basin, and basalts from the Jan Mayen Basin and Trough (B).

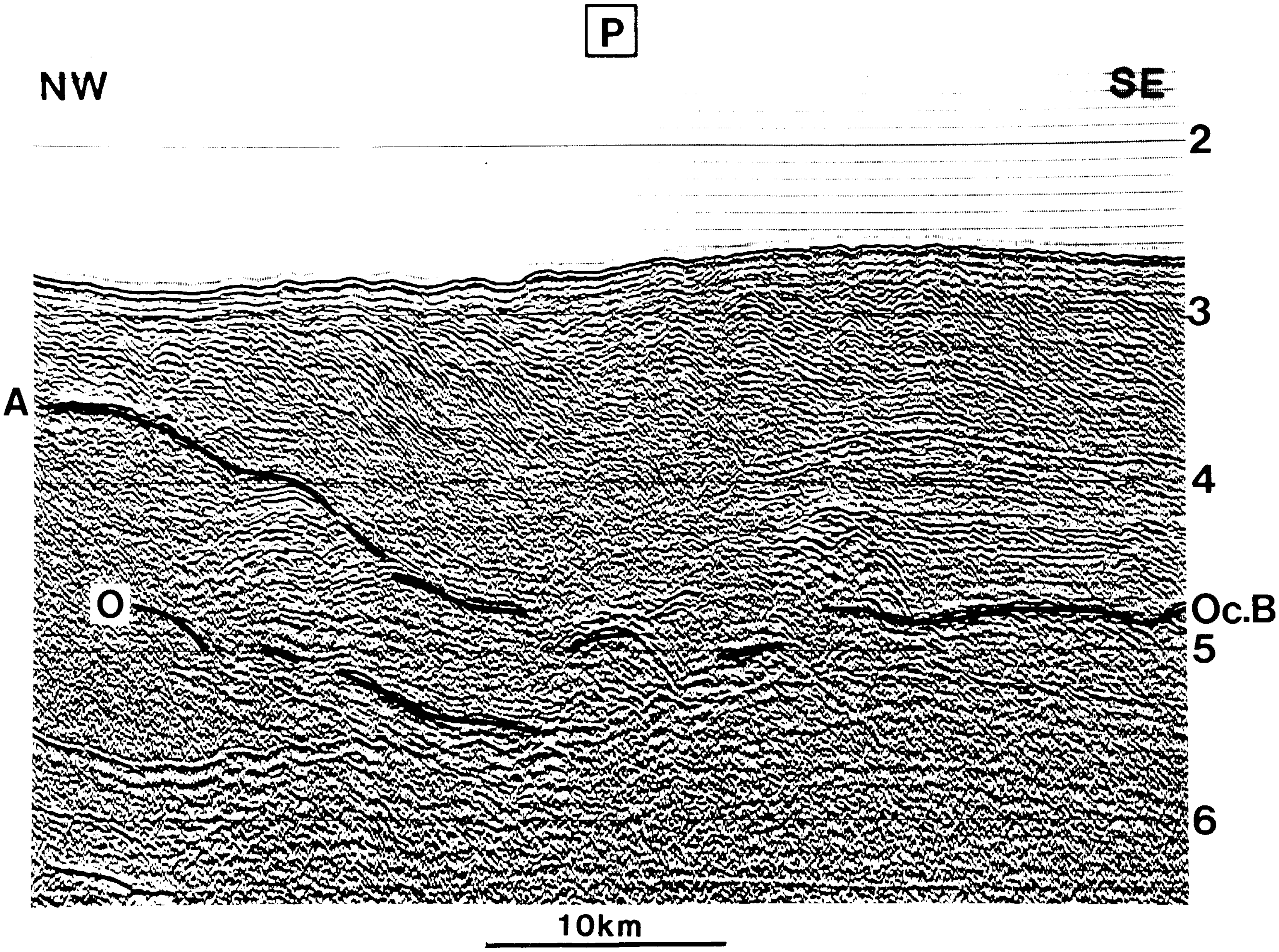

Figure 6b Line P, showing the ocean/continent transition zone, Horizon A, Horizon O and oceanic basement.

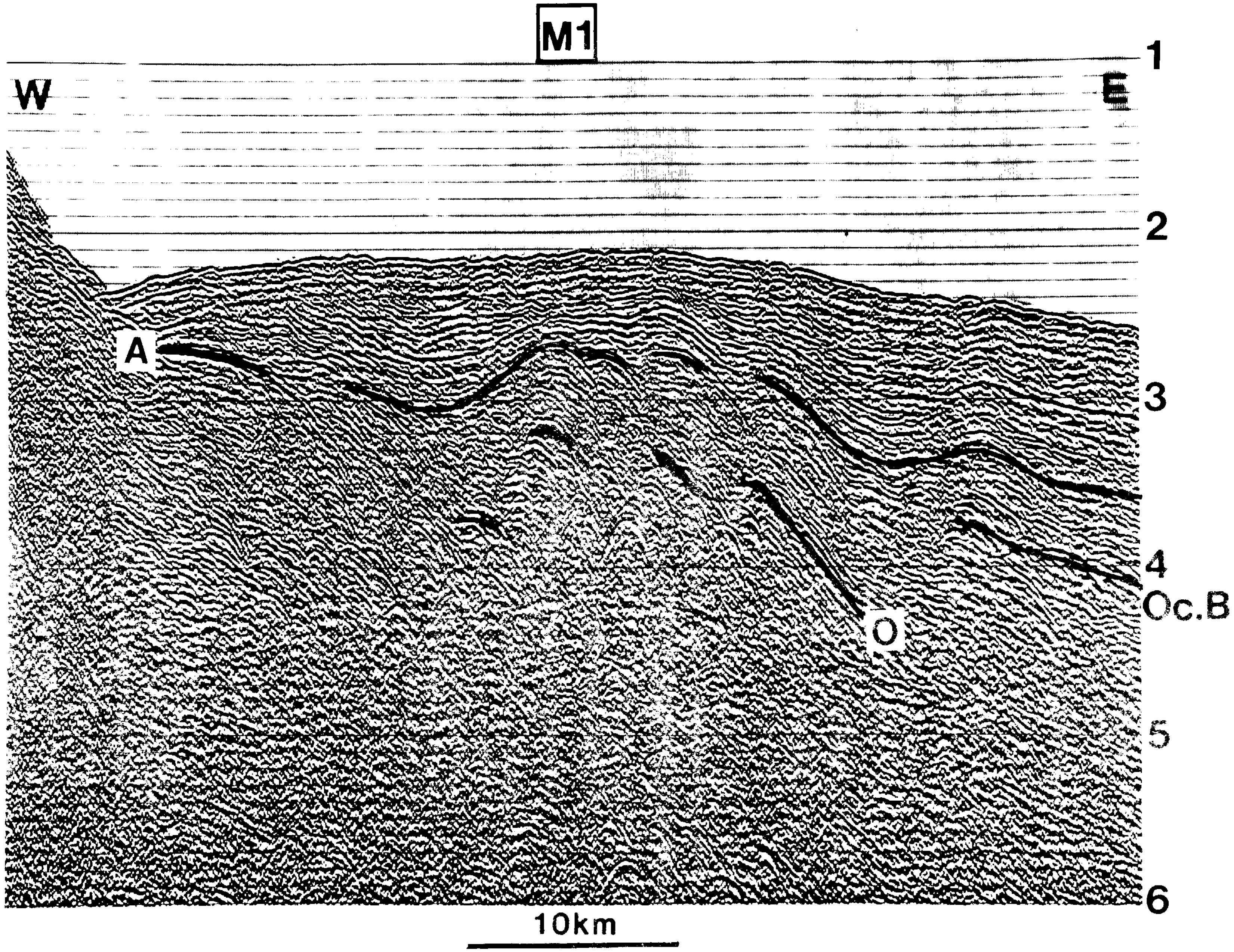

Figure 6c Line M1 showing the ocean/continent transition zone, Horizon A, Horizon O and oceanic basement.

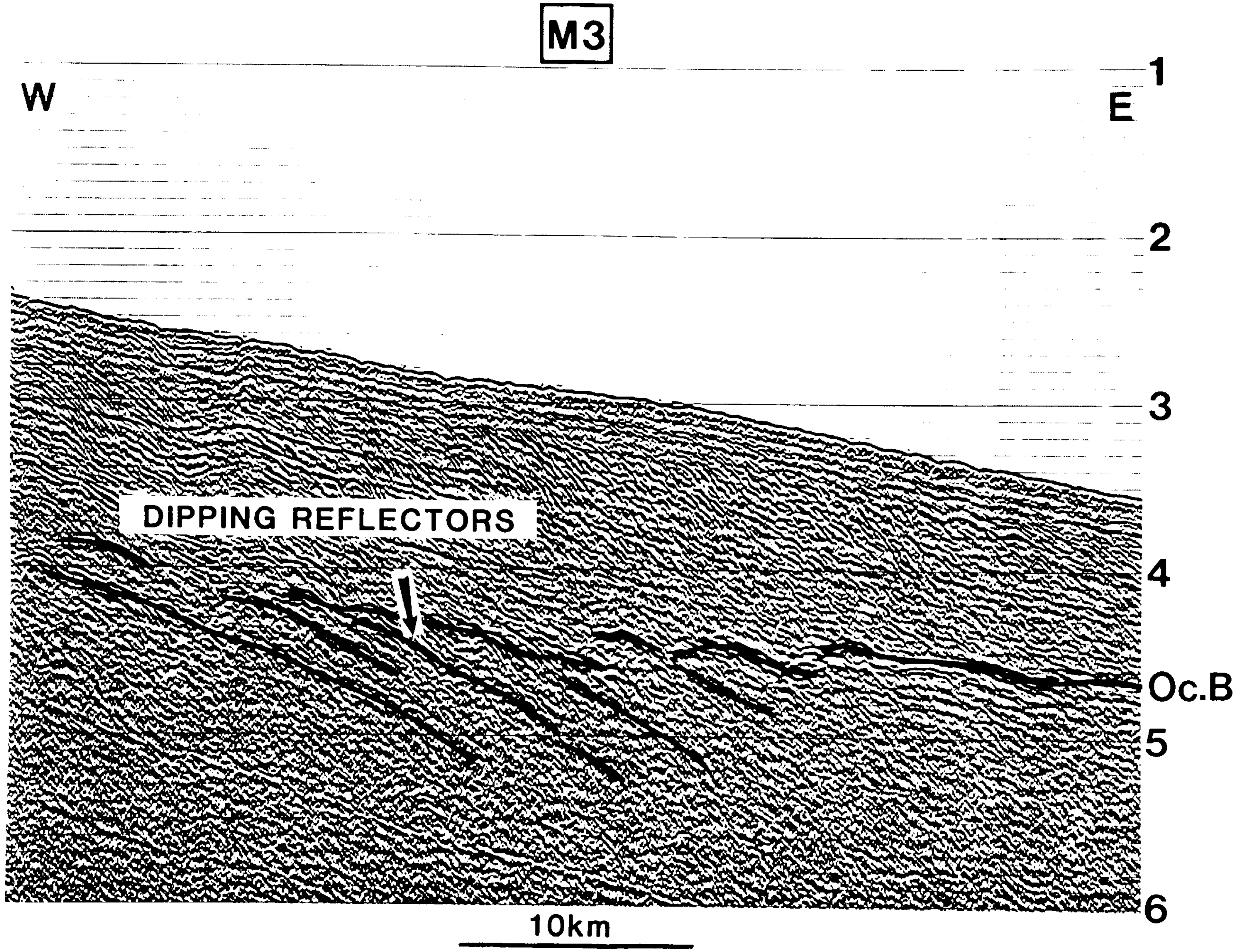

Figure 6d Line M3, showing dipping reflectors from the eastern flank of the Jan Mayen Block.

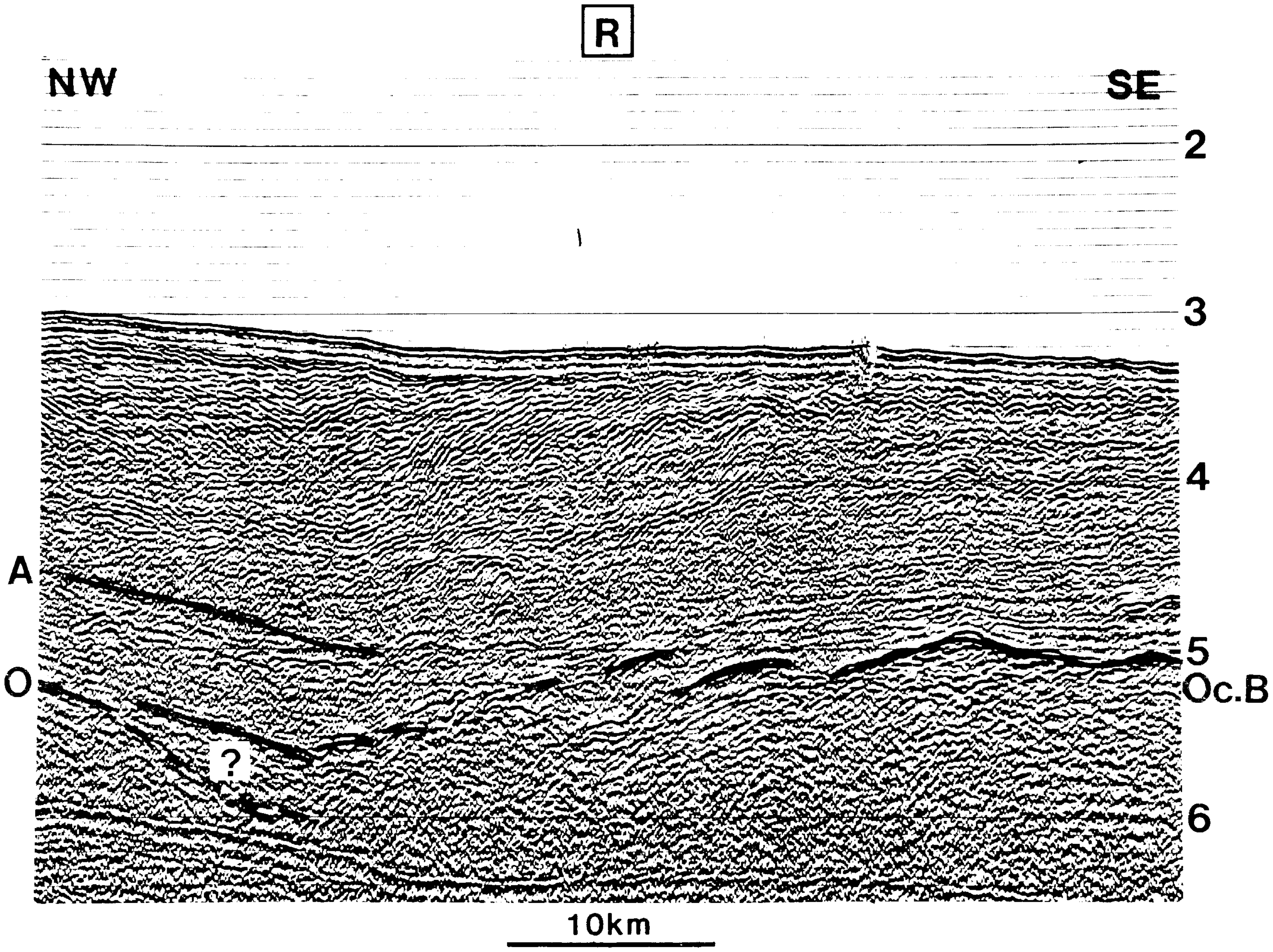

Figure 6e Line R showing the ocean/continent transition zone, Horizon A, Horizon O and oceanic basement.

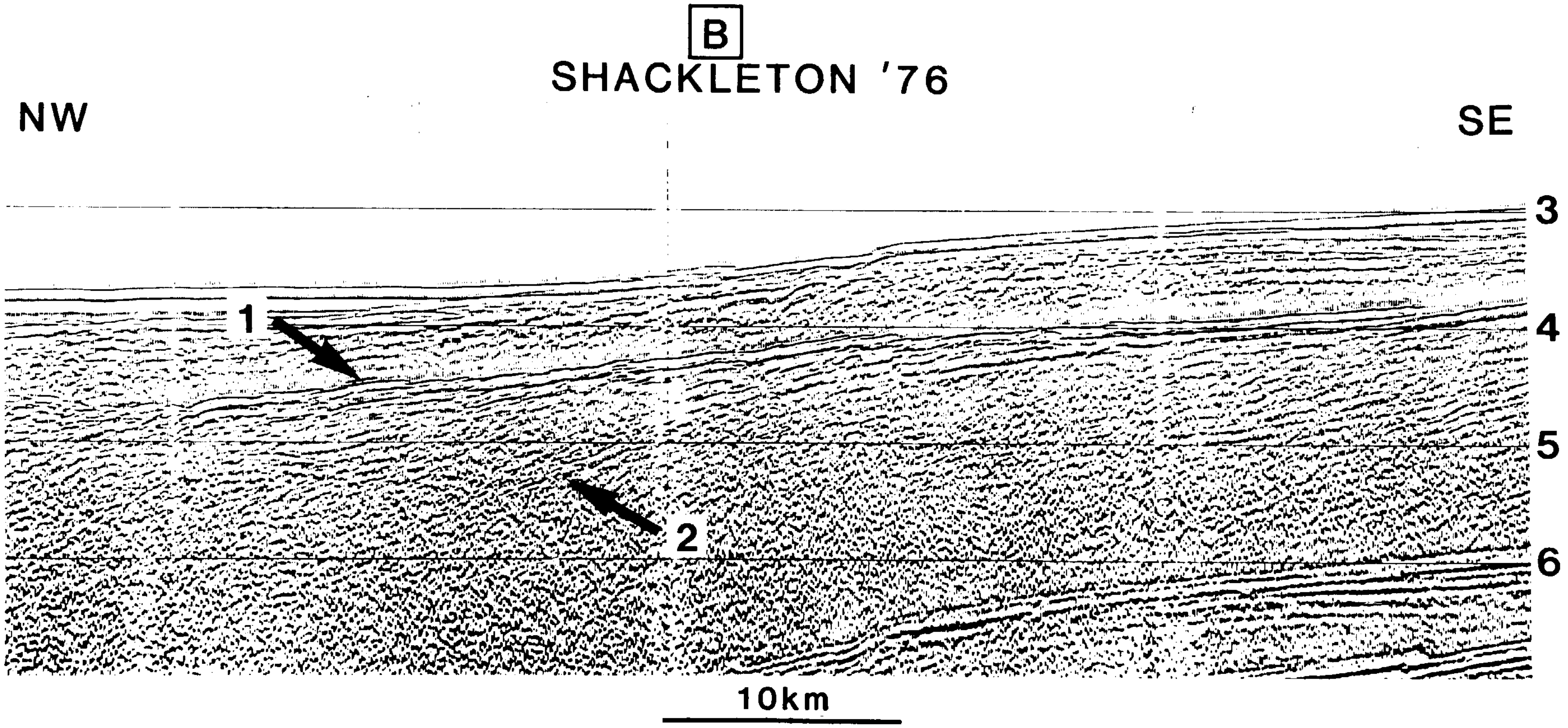

Figure 6f Multichannel seismic section from Line B, Shackleton Cruise 1976 (Durham University), exhibiting dipping reflectors from the Norwegian Margin. Vertical scale in seconds two-way time. (1) Basement, showing off-lapping lava flows, (2) Seaward-dipping reflectors.

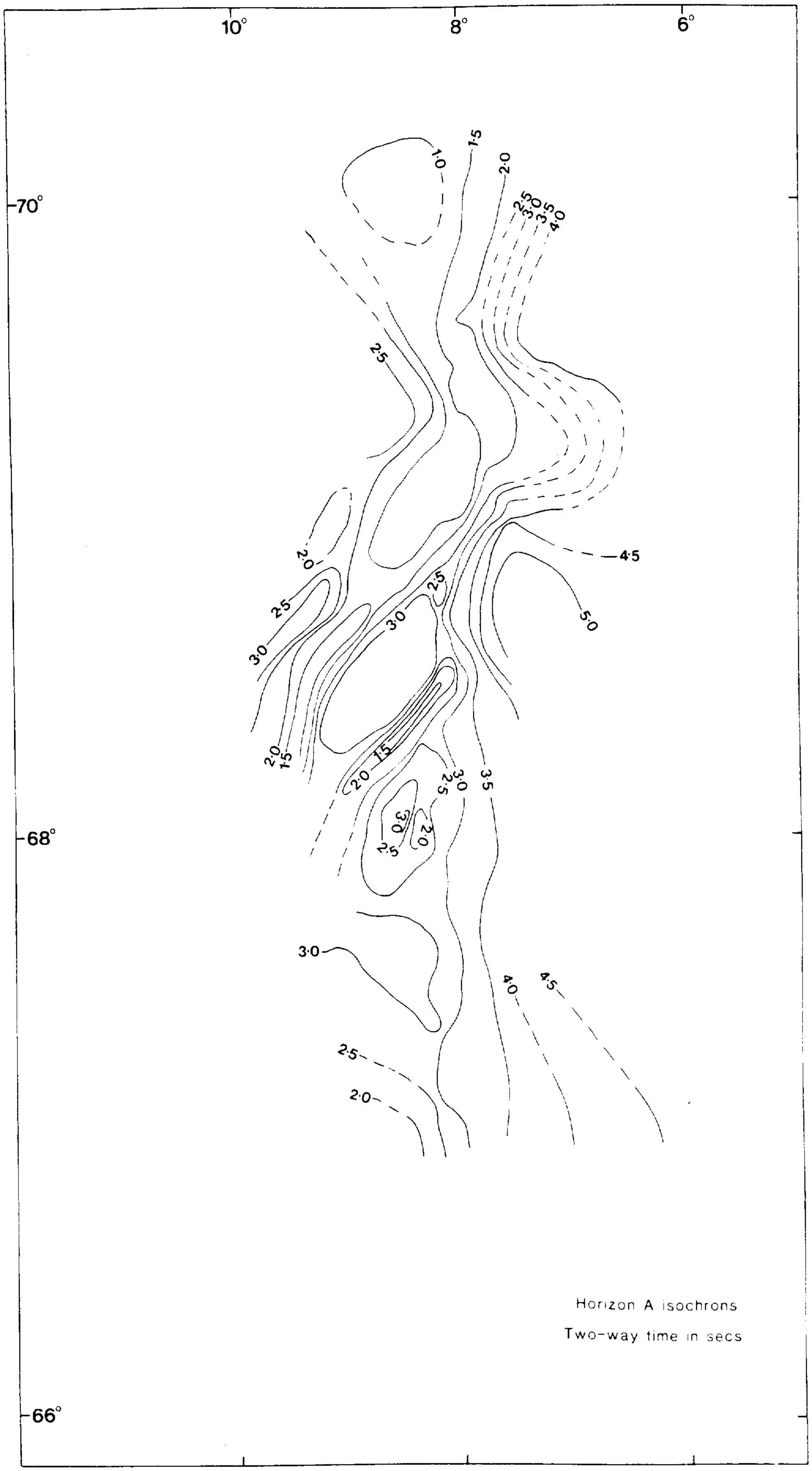

Figure 7 Isochron map to Horizon A, contoured in seconds two-way time, at 0.5 sec intervals.

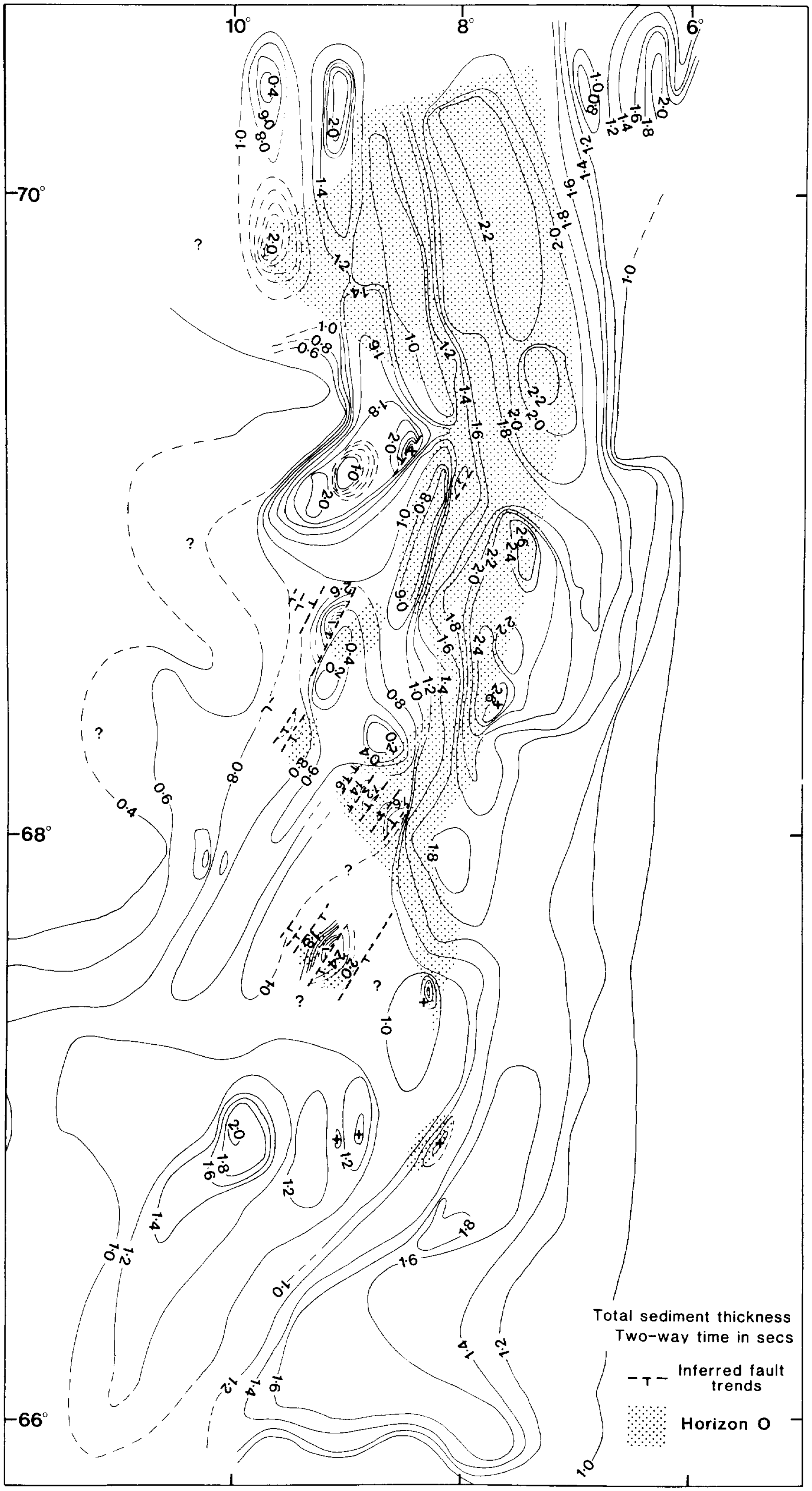

Figure 8 Isochron map of total sediment thickness, contoured in seconds two-way time at 0.2 sec intervals. Shading indicates extent of Horizon O from current data.

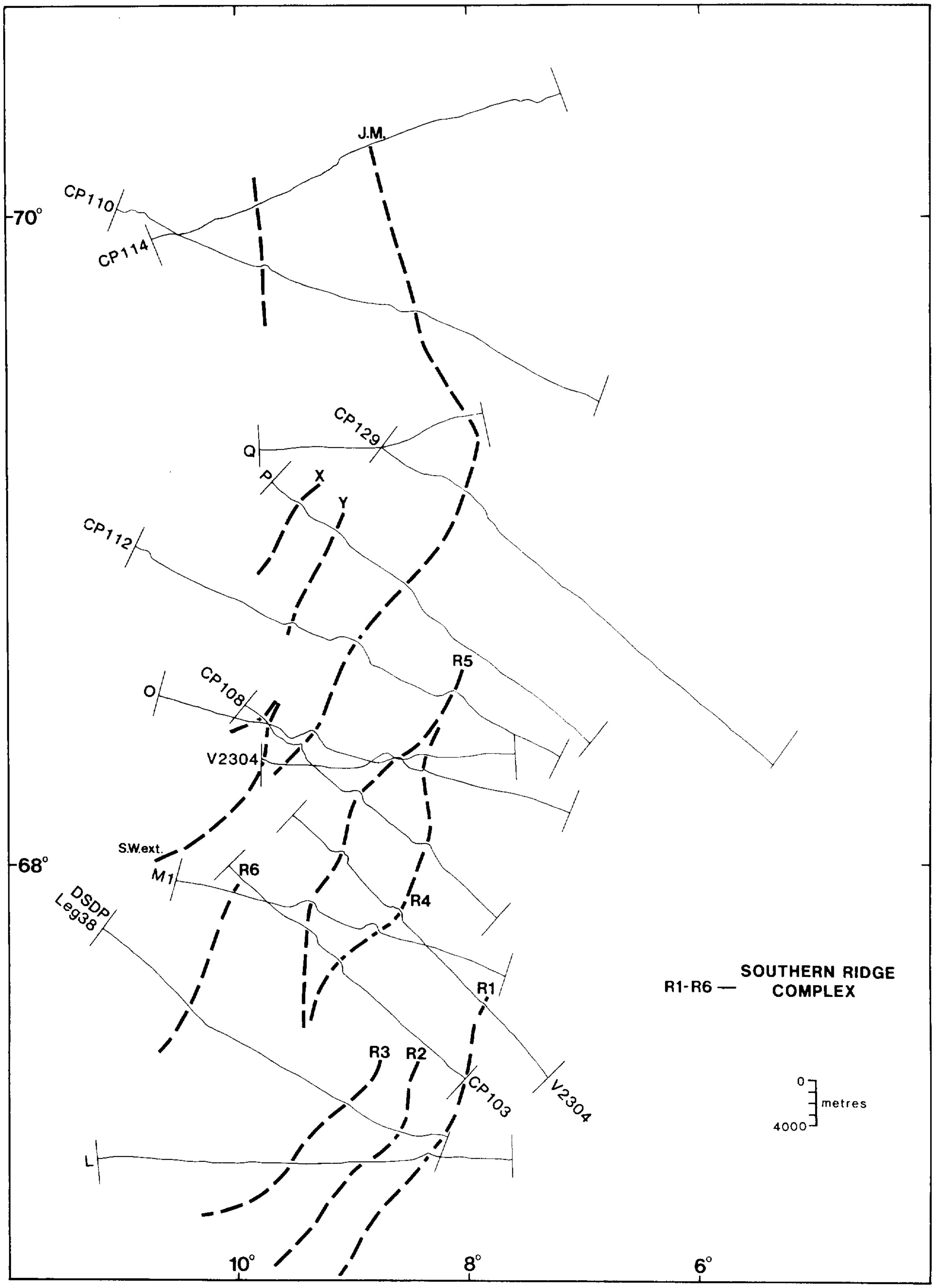

Figure 9 Selected bathymetric profiles of the Jan Mayen Ridge and Southern Ridge Complex. Dashed lines indicate the crests of the basement ridges. See Figure 3 for line identification.

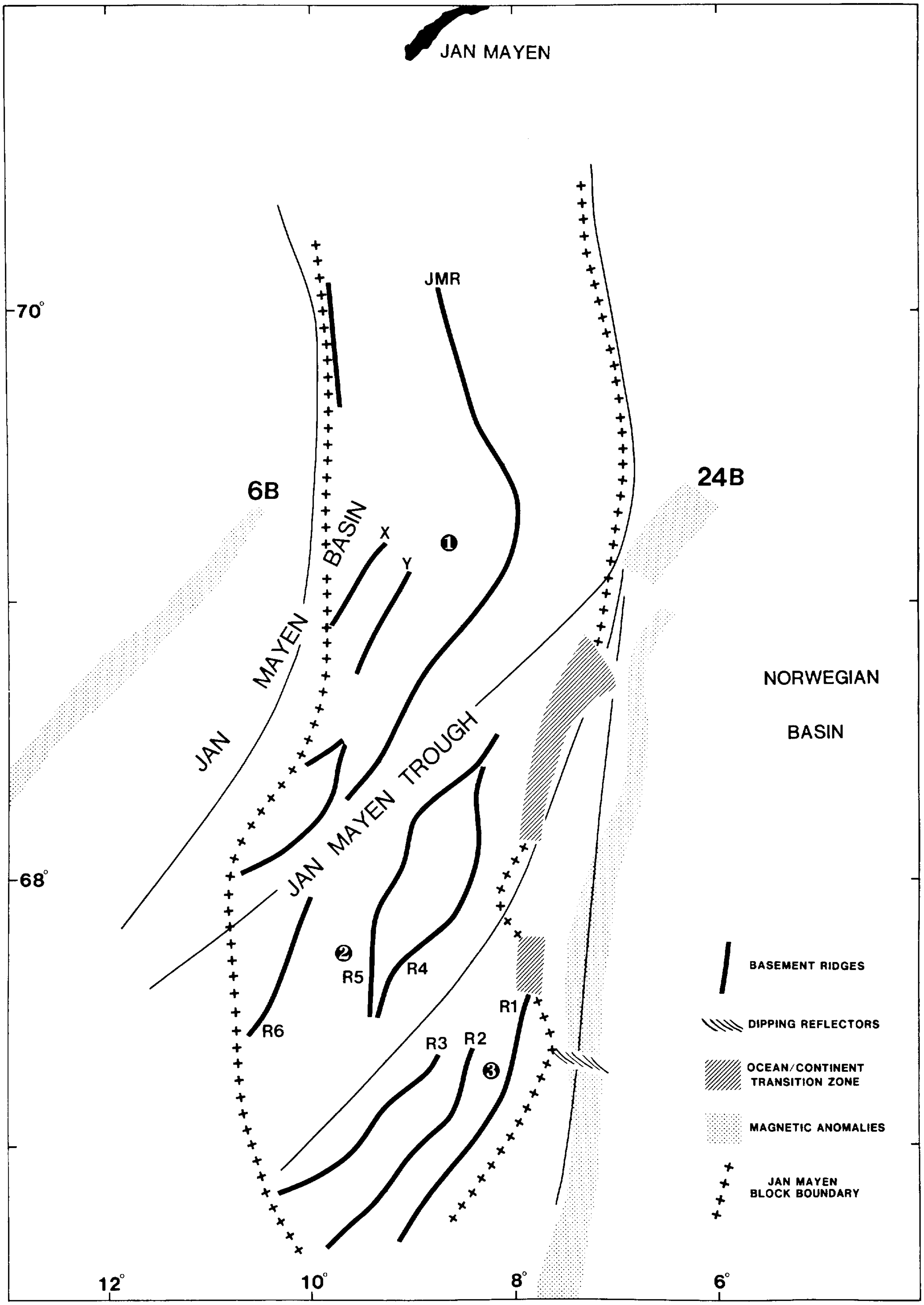

Figure 10 Delineation of the east and west boundaries of the Jan Mayen Block and the ocean-continent transition zone. Numbers 1-3 represent the zones of Talwani & Udintsev (1976).