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The initiation of opening of the Norwegian Sea

Tertiary volcanogenic deposits
Early opening
Vøring Plateau
Norwegian Sea

Dépôts volcanogéniques tertiaires
Ouverture précoce
Vøring Plateau
Mer de Norvège

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ABSTRACT

Multichannel seismic reflection profiling has revealed that the basalt layer on the Outer Vøring Plateau is underlain in places by steeply dipping layered reflectors.
Two opposing theories have been considered for the origin of the layered reflectors :
1) They are Mesozoic sediments deposited before the Tertiary opening of the Norwegian Sea.
2) They are Tertiary deposits formed during the early stage of opening of the Norwegian Sea by seafloor spreading.
The multichannel seismic results combined with earlier shipboard geophysical measurements as well as aeromagnetic profiles obtained by the Norwegian Geological Survey help discriminate between these theories.
As a result of our investigations we find that :
a) magnetic anomaly 24 can be traced continuously from the Lofoten Basin on to the Vøring Plateau. This anomaly is associated with the oldest seafloor generated in the opening of the Norwegian Sea ;
b) the layered reflectors form a characteristically shaped wedge that coincides with anomaly 24 ;
c) the material comprising the wedge possesses seismic velocities which increase from about 2.6 km/sec. in the upper part to about 6.4 km/sec. in the lower part.
The above observations strongly support a Tertiary age for the material comprising the wedge, which we believe consists of basaltic flows and volcanogenic sediments and which is associated with sea floor created a few million years after the start of spreading. The data are used to make inferences about events occurring during the time span between initiation of opening and establishment of a normal pattern of sea floor spreading.

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RÉSUMÉ

Le début de l'ouverture de la mer de Norvège.

Les profils de sismique réflection multitrace ont montré que la couche de basalte du Vøring Plateau externe surmonte localement des réflecteurs stratifiés fortement inclinés.
Deux hypothèses contradictoires concernant ces réflecteurs peuvent être avancées :
1) Il s'agit de sédiments mésozoïques déposés avant l'ouverture de la mer de Norvège au Tertiaire.
2) Ce sont des dépôts Tertiaire formés lors de la phase précoce d'ouverture de la mer de Norvège.
Les résultats de la sismique multitrace, les données géophysiques antérieurement acquises et les profils aéromagnétiques obtenus par le Service Géologique de Norvège permettent de trancher entre ces deux théories.
a) L'anomalie magnétique 24 peut être dessinée continuement depuis le Bassin des Lofoten jusqu'au Vøring Plateau. Cette anomalie correspond au plancher océanique le plus ancien associé à l'ouverture de la mer de Norvège.
b) Les réflecteurs stratifiés forment un prisme caractéristique coïncidant avec l'anomalie 24.

c) Le matériel constituant le prisme a une vitesse sismique variant de 2,6 km/s dans la partie supérieure à 6,4 km/s dans la partie inférieure.
Les observations précédentes renforcent l'hypothèse d'un âge tertiaire pour le matériel constituant le prisme, qui est probablement composé d'écoulements basaltiques et de sédiments volcanogéniques, et qui est associé au plancher océanique créé quelques millions d'années après le début de l'accrétion. Les données présentées permettent d'aborder l'étude des événements ayant eu lieu entre l'initiation de l'ouverture et l'établissement d'un régime d'accrétion océanique normal.

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INTRODUCTION

Most studies concerned with details of the process of sea floor spreading are carried out at the axis of the mid-ocean ridge, and they deal with steady state phenomena. In order to get a fuller understanding of the process of crustal accretion we also need details of events at the time of initiation of spreading. Passive margins are the appropriate place for this study, and we believe that the Norwegian margin north of 66°N is very well suited for this purpose.

The Norwegian margin is a young margin — the Norwegian Sea opened in the early Tertiary and, in contrast to many older Mesozoic margins, the oceanic part of the margin is covered by a relatively thin layer of sediments. In the last decade this margin has been extensively studied by geophysical means, especially in the area where the ocean-continent boundary is expected to lie. Closely spaced magnetic surveys clearly indicate sea floor spreading type anomalies which serve to distinguish areas that are oceanic and also help to define the history of opening. Multichannel seismic reflection surveys have most recently been employed to investigate sub-basement structures which are crucial to understanding the evolution of this area.

The fact that the basement underlying the Outer Vøring Plateau is unusually shallow has led some investigators to question whether the results obtained here would have applicability elsewhere. In general the oceanic crust formed at the time of initiation of sea floor spreading is covered by a thick sedimentary cover and is poorly known in detail. The few studies concerned with the subject do suggest (Rabinowitz, La Brecque, 1977 ; Veevers, 1977) that shallow crust is formed at the time of initial opening. Furthermore, we will show that similar crustal structures continue from the anomalously shallow Vøring Plateau to the normal oceanic depths of the Lofoten margin to the north. Thus the Outer Vøring Plateau instead of being considered unsuitable for studies concerned with early opening might be considered especially suitable in that structures related to the phenomenon of initiation are particularly well developed here.

DESCRIPTION OF THE MARGIN NORTH OF 66°N

The Vøring Plateau which is outlined quite accurately by the 1,500 fathom contour (Fig. 1) is a prominent feature of the Norwegian margin. The buried Vøring Plateau Escarpment which divides it into the inner and outer segments continues northward along the margin of the Lofoten Basin. From earlier studies it was deduced that the Vøring Plateau escarpment defines the ocean-continent boundary (Talwani, Eldholm, 1972). In this study we shall demonstrate with

Figure 1
Bathymetric chart (in nominal fathoms) of the area discussed showing location of DSDP/Joides drill sites on the Outer Vøring Plateau and the location of MCS lines mentioned in the text.

more complete magnetic data, as well as with multichannel seismic reflection data, that the earlier conclusion is substantiated.

The Norwegian Geological Survey has recently released a closely spaced aeromagnetic survey of the Norwegian Margin (Hagevang *et al.*, in prep.). In Figure 2 we have plotted some profiles from this survey together with available surface ship magnetic data. The magnetic anomaly sequence in the Lofoten Basin which is at normal oceanic depths is considered well established (Avery *et al.*, 1968 ; Talwani, Eldholm, 1977). The earliest magnetic anomaly is anomaly 24 (60 m.y. according to the Heirtzler *et al.* (1968) time scale or 56 m.y. according to the LaBrecque *et al.* [1977] time scale) and is approximately parallel to the northeastward extension of the Vøring Plateau escarpment.

Clearly, anomaly 24 continues from the Lofoten Basin on to the Vøring Plateau. The detailed shape of anomaly 24 does vary along its length, which is probably a manifestation of the difference in basement elevation and structure from the Vøring Plateau to the Lofoten Basin. We note that anomalies 21, 22, and 23 are all close to parallel to anomaly 24, and it is the continuity of the overall pattern of these anomalies that leaves very little doubt of the presence of anomaly 24 on the Vøring Plateau. Although anomaly 24 is generally parallel also to the escarpment, it is not exactly so. The only discontinuity in anomaly 24 occurs at about 68°N where the southern segment is offset to the east, with respect to the northern segment. A negative anomaly lies on

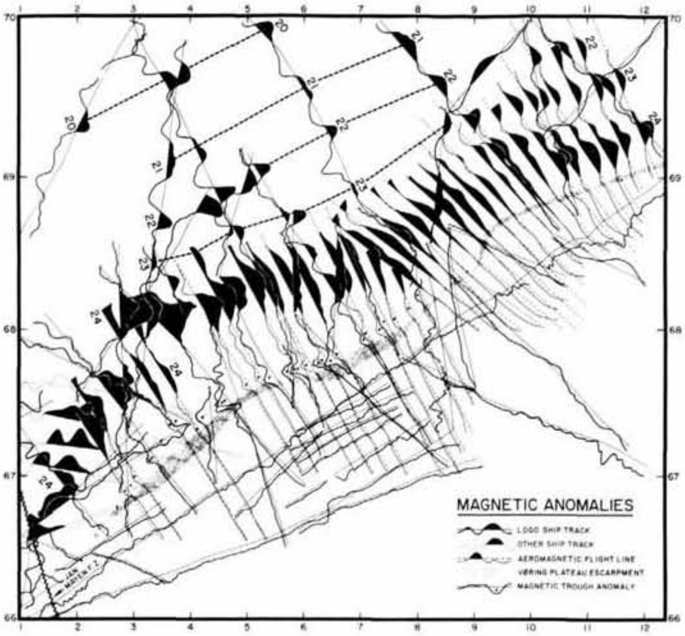

Figure 2

Compilation of surface ship magnetics and aeromagnetic data from the Norwegian margin. Aeromagnetic data are shown with a dashed base line and fine anomaly line. LDGO surface ship data are shown with a heavy anomaly line and continuous base line. Data from Planet (Roeser et al., *1975) are shown with dotted lines. Magnetic anomalies 24 to 20 are shown in solid shading. A prominent magnetic trough is identified by a dot, and the Vøring Plateau Escarpment, with which it is associated, is shown in dense shading.*

the seaward side of the Vøring Plateau escarpment but is well developed only on the plateau itself. We believe that it corresponds to the ocean-continent boundary.

That part of the margin which lies landward of the Vøring Plateau Escarpment is underlain by a thick sedimentary section. Over a seismic horizon which has been designated Horizon D by Rønnevik *et al.* (1975), and which has been identified by a number of investigators (e.g. Jorgensen, Navrestad, 1979) as a Late Kimmerian uncomformity lies a succession of undisturbed sediments. This suggests that the area landward of the escarpment is either continental in origin, or if it is floored by oceanic crust it is pre-Horizon D in age. In view of the presence of a magnetic quiet zone in this area (Fig. 2 and 3), we prefer to consider this area to be continental in origin — a basin which appears to have subsided almost continuously through the Mesozoic and the Tertiary (Talwani, Eldholm, 1972).

The section in Figure 3 across the Vøring Plateau shows our interpretation of the structure along the margin. Landward of the escarpment a Tertiary and Mesozoic sedimentary sequence is present. Regionally this sequence is relatively undisturbed and flat lying except immediately adjacent to the escarpment. The deepest extensive well-identified Mesozoic horizon under the Norwegian shelf and shallow part of the slope is Horizon D, and it varies in depth from perhaps 3 to 9 km regionally beneath the margin (very close to the escarpment the identification of the Horizon D is not certain). A deeper Mesozoic Horizon — termed Horizon E — is found in some areas. Below it lies another horizon which is probably Caledonian basement. This has been identified close to the shelf where it dips steeply westward. The total sedimentary section on the Norwegian margin may, in places, be extremely thick — perhaps exceeding 10 km.

Seaward of the escarpment, the Tertiary section is well defined by a large amount of seismic data calibrated by three Joides/DSDP drill holes 338, 342 and 343 (Talwani, Udintsev, 1976). What lies below the Tertiary sediments has been a matter of considerable study and speculation. Earlier single-channel seismic reflection profiles revealed a strong reflector (B in Fig. 3) which, from samples recovered in drill holes 338 and 342, was found to be Early Tertiary basalt. However, multichannel seismic profiling revealed the presence of layered reflectors below B (Hinz, Weber, 1976) and "true" basement was believed to lie below B. Horizon C in Figure 3 may be this "true" basement according to them.

The identification of the layered reflectors lying beneath B

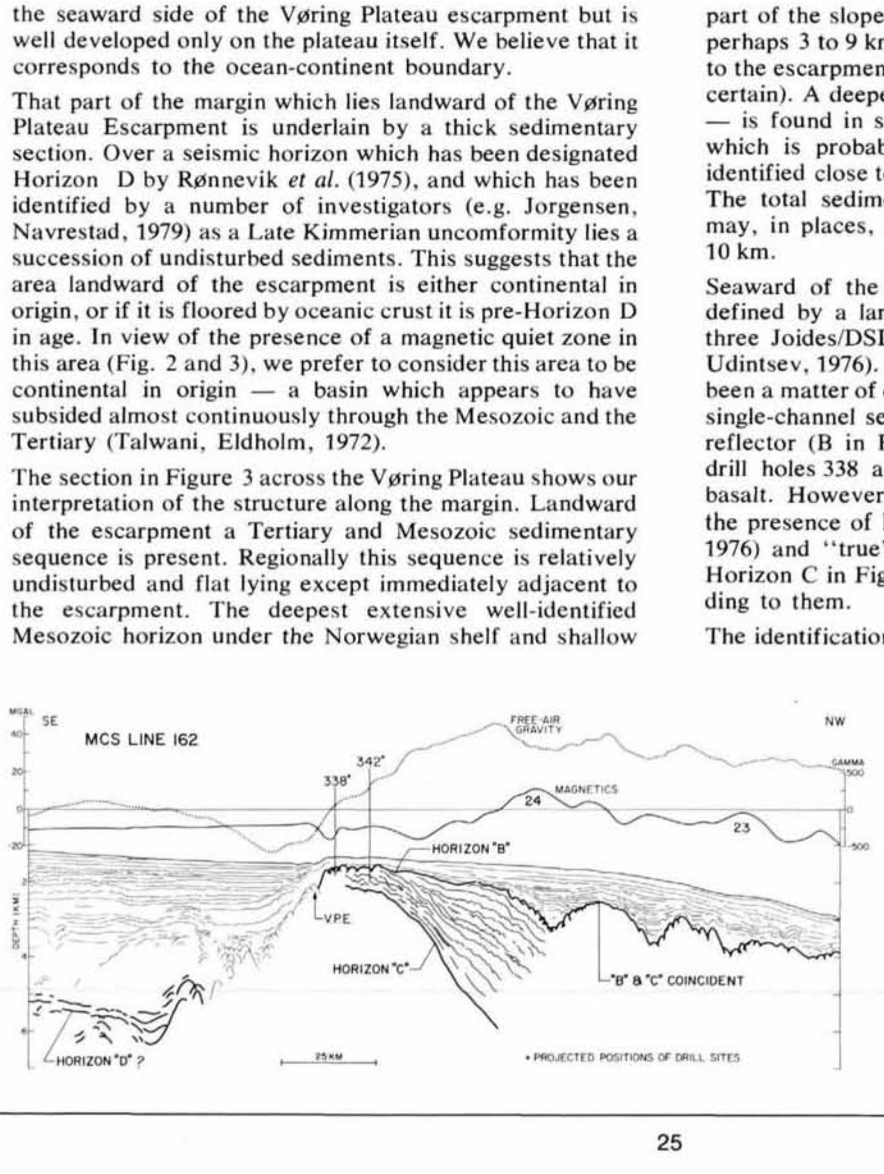

Figure 3

Line drawing interpretation of MCS line 162 acquired by R/V Conrad in 1978. The time section was converted to depth using velocity structures determined by methods described in the text. V.P.E. is Vøring Plateau Escarpment.

is extremely important. Some investigators have suggested that this layered sequence represents a Mesozoic sedimentary succession similar to that found landward of the escarpment, and the Tertiary flow B caps this sequence. On the other hand, our analysis strongly suggests that this layered sequence is Tertiary in age and is dominantly composed of volcanic products — a combination of lava flows and volcanogenic sediments. This view would imply that these reflectors can be considered a part of basement, rather than a sequence that overlies basement.

The identification of these layered reflectors is not only fundamental to the problem of evolution of this area, it also bears on evaluating resource potential for oil and, paranthetically, on the question of whether scientific drilling into this sequence can be carried out without elaborate safety precautions. We note that the application of the multichannel seismic technique extensively over areas of oceanic basement has revealed such layered reflectors in many parts of the world ocean, and they are not unique to the Vøring Plateau.

The layered reflectors terminate rather abruptly, although the exact nature of the termination is not clearly observed (Fig. 3 and 6). Note that along the profile in Figure 3 the layered reflectors are associated with anomaly 24 but lie landward of anomaly 23. This association with anomaly 24 and lack of overlap with anomaly 23 is generally true for this entire area. Seaward of the wedge, B and C cannot be separated : in fact, they may be identical. Landward of the wedge, B and C are almost parallel to each other where separated, but it is often difficult to identify C. We also note that the average level of B deepens away from the escarpment reaching normal oceanic levels seaward of anomaly 23 (Fig. 4).

The Norwegian margin north of the Vøring plateau, that is, in the region where the Lofoten Basin lies adjacent to the narrow Norwegian shelf and slope, is basically similar to the margin at the Vøring Plateau. Many of the prominent features associated with the Vøring Plateau are, however, less well developed further north. Horizon B dips seaward, but its relief is less than that on the Vøring Plateau. The layered reflectors within basement occupy a smaller volume than they do in the Vøring Plateau, but they are similar in that they are associated with anomaly 24 but lie landward of anomaly 23. The depth to B is greater and correspondingly the escarpment is less steep in this area (see Fig. 8).

We also call attention to the association of the layered reflectors with smooth "basement" since B, which lies at the top of the wedge, has a rather smooth topography and has been identified as basement in early studies. Eldholm *et al.* (1979) noted the presence of this smooth basement in regions of oceanic crust close to the continent-ocean boundary.

DETAILED DESCRIPTION OF WEDGE OF DIPPING REFLECTORS

Typically the overall appearance of this reflecting sequence is that of a wedge. In fact, in many cases the reflectors appear to converge almost to a point in the section, and the point of convergence is always adjacent to a major structural high. However, a detailed examination of the structure of the wedge reveals that individual reflectors may not all pinch out at the same point.

Figure 4 shows the structure contours on horizon B. The correspondence of the bathymetric contours with the depth to horizon B clearly indicates that the bathymetry is controlled by the structure of B. We also note that the wedge is roughly parallel to the escarpment indicating that its position was probably controlled by the latter. The association of the wedge with anomaly 24 as shown in Figure 3 and 4 is clear. Given that anomaly 24 is part of a sea floor spreading sequence, this wedge which is of large horizontal extent would be expected to disrupt the magnetic pattern. The variation in the shape of anomaly 24, noted earlier, may indeed be caused by this disrupting magnetic influence of the wedge. At the same time we note that this disruption is not major enough to prevent identification of the anomaly.

We have made a detailed study of the seismic velocities of the material comprising the wedge. We have mainly concen-

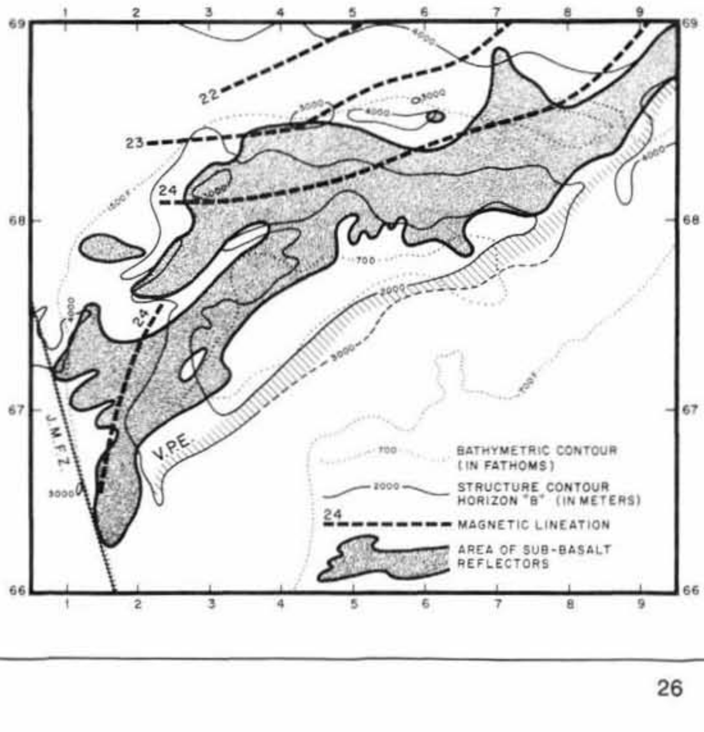

Figure 4

Structure contours on Horizon "B", the top of the basement. The depths were determined using an average sediment velocity for the Tertiary section of 2 000 m/sec. Also shown are the locations of anomalies 24, 23, and 22 and the mapped extent of the wedge of sub-basement reflecting material. The latter is determined from examination of Conrad multichannel reflection data and Vema single-channel data. On Vema data sub-basement reflections are not apparent, and the presence of the wedge is determined from the characteristic smoothness of the acoustic basement.

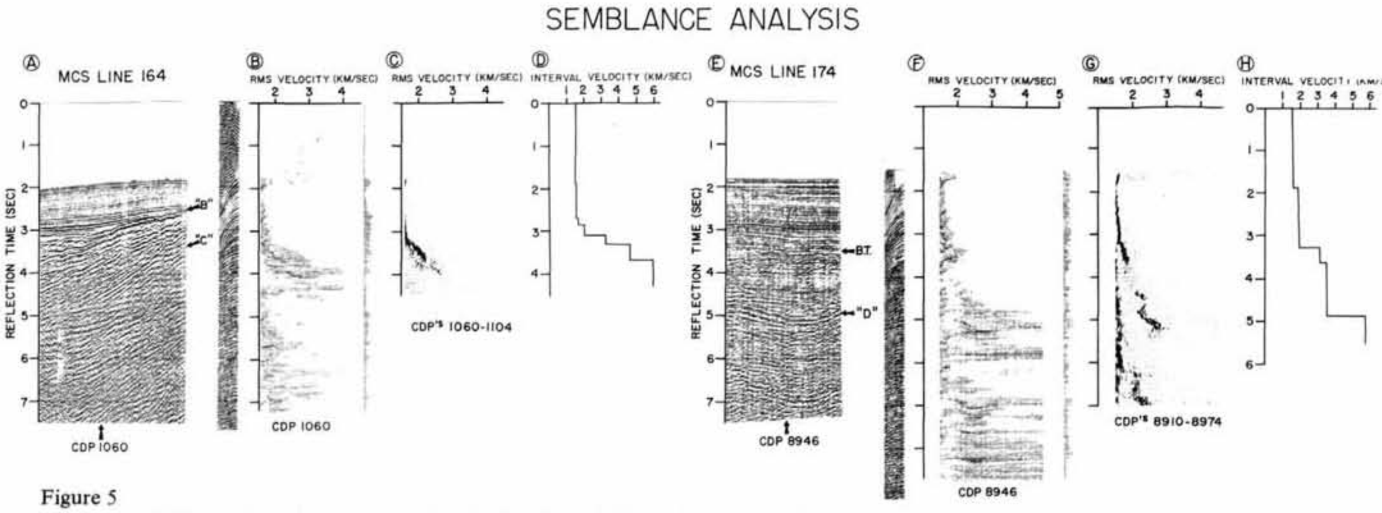

Figure 5

The series of illustrations shows the way in which velocity information is derived from the multi-channel seismic array. Parts A to D apply to MCS line 164 ; E to H apply to MCS line 174. Figure 5 A shows that part of the MCS line analyzed with Horizons "B" and "C" identified. Figure 5 B shows a semblance analysis for one CDP data shown at left. The semblance statistic is computed every 25 msec. of arrival time for RMS velocities ranging from 1,500 to 4,500 m/sec. in increments of 30 m/sec. using hyperbolic trajectories through the data. Semblance maxima appear as downward deflections on this plot. Only values above 0.1 are plotted (semblance values range from 0.0 to 1.0). In Figure 5 C twelve such semblance analyses have been combined. For the scan at each travel time increment three semblance maxima are automatically picked and displayed on a three level plot. This emphasizes the grouping of semblance maxima and clearly reveals a regular increase in RMS velocity with increased reflection time. In 5 D the RMS velocities and times are converted to interval velocities to show the deduced layer velocities as portrayed in Figure 6. Figures 5 E to 5 H show similar data for part of MCS line 174. Here B.T. refers to the location of the Base Tertiary level in the section, and D is the level of Horizon D.

trated on the analysis of moveout in the multichannel seismic reflection records and on sonobuoy results. The semblance statistic (Taner, Koehler, 1969) is used to estimate velocities from moveout analysis and is described in Figures 5 A to H. The tight grouping of semblance maxima define velocities quite precisely, and we note for the section in the Outer Vøring Plateau that below B the velocities increase sharply from about 2.6 km/sec to 6.4 km/sec. In contrast a similar analysis performed in the Inner Vøring Plateau in an area where the thickness of Tertiary sediments is similar, to that on the Outer Vøring Plateau, the underlying Mesozoic section has a much gentler increase in velocity with depth. Only below the deep Mesozoic Horizon D (?) is the rate of velocity increase comparable to the velocity increase below B on the Outer Vøring Plateau.

We have made similar velocity analyses at a large number of points throughout the wedge, using data from the various multichannel seismic reflection profiles. We illustrate the analysis along line 164 in Figure 6. We note that appreciable

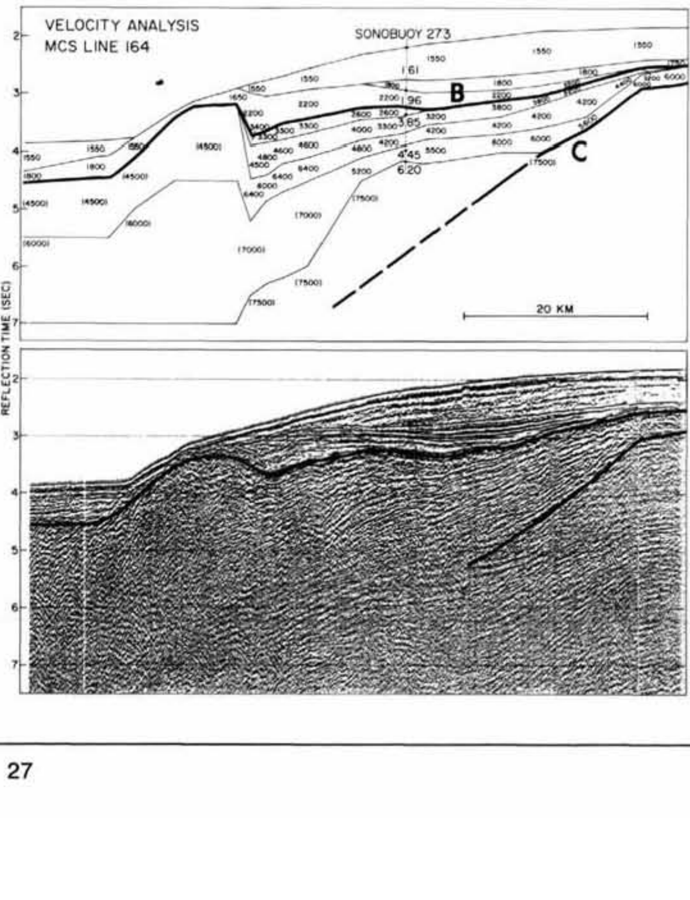

Figure 6

Part of MCS Line 164 on the Outer Vøring Plateau where semblance velocity analyses have been performed systematically along the profile. Figure 1 gives the location. Smaller numbers give semblance derived velocities in meters/sec., larger numbers are velocities derived from Sonobuoy 273 obtained while multichannel profiling. Horizons "B" and "C" are identified. Note the rapid increase in velocity with depth in layers beneath "B" and that velocity interfaces basically following reflecting horizons within the wedge.

velocity changes occur across the prominent reflecting horizons which constitute the wedge. The velocity within each layer comprising the wedge increases downdip although the velocity at a given horizontal level in the wedge tends to remain constant. The seismic velocities in the wedge range from about 2.6 km/sec to 6.4 km/sec. The vertical gradients are large ; this change in velocity from 2.6 to 6.4 km/sec occurs in 2 km. Refraction sonobuoy results, by and large, are consistent with the velocity analyses performed on the multichannel seismic reflection records. The wedge is shown along two other lines in Figures 7 and 8. MCS line 167 in Figure 7 lies in the northern part of the Vøring Plateau. MCS line 172 in Figure 8 runs from the Lofoten Basin to the Norwegian margin. The reflectors comprising the wedge can definitely be recognized here although they are not as prominent as on the Vøring Plateau.

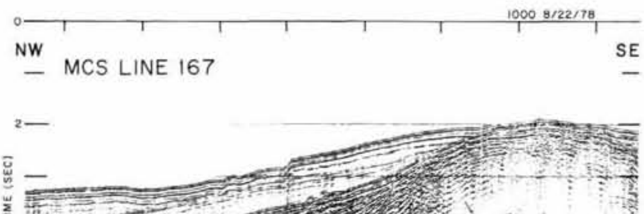

Figure 7
Part of MCS Line 167 on the Outer Vøring Plateau. Figure 1 shows the location. Dipping reflectors forming a wedge are clearly present here in the northern part of the Vøring Plateau as in the main part of the plateau.

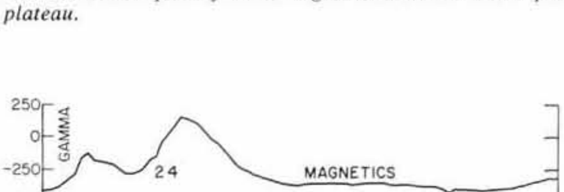

Figure 8
Part of MCS Line 172 in the Lofoten Basin showing development of a reflecting wedge between about shot points (SP) 2300 and 2750. The marginal escarpment here is about SP 2750. Figure 1 gives location.

It could be argued that the material comprising the wedge represents high velocity pre Horizon D sediments. We think that this is unlikely because no similar structures have been seen anywhere else beneath the Norwegian margin even in areas where Horizon D is shallow and the Caledonian basement seen below it in seismic records. Furthermore, under a Mesozoic sediment hypothesis the association of anomaly 24 (in the Vøring Plateau and the Lofoten Basin) and the proximity of the magnetic edge anomaly to the wedge would have to be explained in some other way. This hypothesis would also require that the ocean-continent boundary lie at the seaward border of the wedge. But in contrast to the Vøring Plateau Escarpment (which is characterized by a large gravity gradient and a change in the character of the magnetic field, Fig. 3), we see no prominent changes in the gravity and magnetic signatures at the seaward boundary of the wedge.

We suggest instead that the wedge is dominantly composed of Tertiary volcanic products — a combination of lava flows and volcanogenic sediments. We believe that the rapid downward increase in velocity is a consequence of healing and self compaction of the pile of volcanic material. The wedge covers an area extending about 30 km seaward from a structural high lying close to the escarpment but never covers the crust produced at anomaly 23 time or later. Since the deepest reflectors at the base of the wedge appear to lie over roughly the same area as the shallowest reflectors in the wedge, it seems reasonable to suggest that the wedge was created in a relatively short amount of time just before anomaly 23 came into existence. The age of anomaly 23 according to the Heirtzler time scale is 58 m.y. ; this age is generally regarded as too great and the age from the LaBrecque time scale is 54.5 m.y. Even this age may be too great by a few million years. The radiometric ages obtained from the basalts in Joides/DSDP drill holes 338 and 342 (identified here with layer B at the top of the wedge) range from 44 to 46.6 m.y., while the faunal age for the immediately overlying sediments at site 338 is estimated at 49 to 53 m.y. (the small discrepancy between radiometric and faunally derived ages in probably best attributed to uncertainties in the radiometric measurements). These Early Tertiary ages for the overlying basalt are not inconsistent with our suggestion that the material comprising the wedge which lies below the basalt layer was produced prior to anomaly 23 time.

We note that the wedge is underlain by crust that lies shallower than the adjacent younger crust — which is the reverse of the usual relationship. In fact, we believe that the distribution of material in the shape of a wedge is governed by this anomalous relationship between depth and age of oceanic crust.

EARLY EVOLUTION OF THE NORWEGIAN MARGIN

Our ideas about the evolution of the Norwegian margin starting from the initiation of sea floor spreading are summarized by a series of sketches.

Figure 9 A depicts the situation just prior to opening. A continued Mesozoic sedimentary basin existed. Within the thick Mesozoic section in the region of the Inner Vøring Plateau we can identify a prominent reflector-probably Horizon D. From extensive multichannel seismic reflection coverage on the Norwegian Margin we see no evidence either of regional doming or of extensive normal faulting in

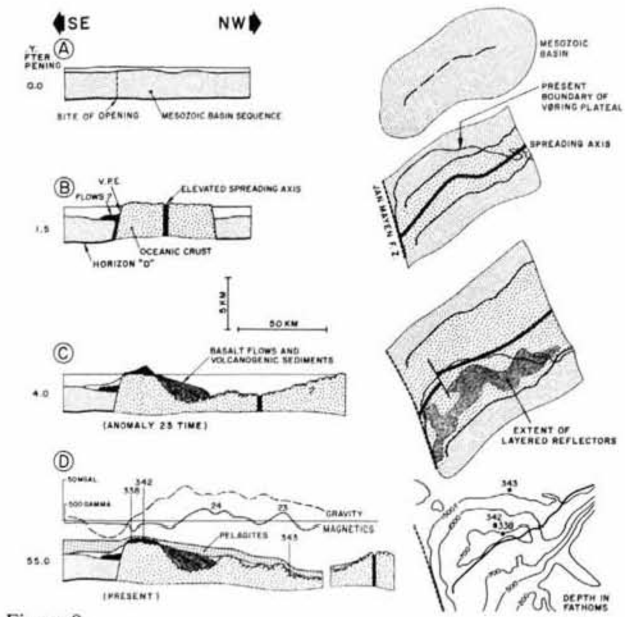

Figure 9
Sketches illustrating the various stages in the evolution of the Norwegian Margin.

the post-Horizon D section. This observation is in conflict with the generally accepted notion of the prevalence of normal faulting prior to the initiation of sea floor spreading. We note, in particular, the complete absence of any listric faults which are associated with extension and have been cited as evidence for it.

Figure 9 B is a cross section across the margin roughly 1.5 m.y. after the initiation of opening. The newly formed oceanic crust was emplaced close to or above sea level and the escarpment, which defines the boundary between continental and oceanic crust, came into existence as a result. The flows (?) lying above the Mesozoic sequence landward of the escarpment may well have used the escarpment as a conduit.

In the steady state generation of oceanic crust at mid-ocean ridges the youngest crust is emplaced at a constant elevation and is shallower than the immediately older crust which has subsided (Sclater *et al.*, 1971). However, along the Norwegian margin the oceanic crust is emplaced not at a constant level but at successively deeper elevations, so that, in spite of any subsidence following emplacement, the younger crust is actually deeper than the older crust. This progressive deepening of younger crust is most noticeable at the Vøring Plateau where the oldest oceanic crust was emplaced subaerially (Talwani *et al.*, 1976) ; it is also noticeable further north at the margin of the Lofoten Basin where the oldest crust again appears to be shallower than the crust in the deep part of the basin. This phenomenon of progressive deepening of the spreading axis during the early phases of opening has been noted by Rabinowitz and LaBrecque (1977).

We believe that because of the absence of any very large gravity anomalies (approaching hundreds of mgal) the crust underlying the Outer Vøring Plateau is probably considerably thicker than normal oceanic crust.

Figure 9 C envisages the scheme of crustal formation described above at the time of anomaly 23. The wedge of reflectors was created between anomaly 23 and 24 time. By analogy with the lava flows in Iceland which dip towards the rift zone (Pálmason, 1980), the layered reflectors of the Outer Vøring Plateau can be thought to have been generated as subaerial lava flows of considerable horizontal extent. Such a pile may typically comprise the upper part of the oceanic crust immediately adjacent to the ocean-continent boundary. We note that horizon B which is the top of the wedge is very smooth compared to the basement surface beyond the wedge. The reason for smooth basement in many part of the world's oceans has been a puzzle. The association with the layered reflectors may explain the smoothness of basement in many areas.

Subsequent to anomaly 23 time more normal conditions of ocean crust generation were established and new ocean crust is emplaced at shallower depths than the immediately preceding crust which has subsided. Figure 9 D illustrates this.

In constructing Figure 9 we have assumed that there was no differential vertical motion across the Vøring Plateau escarpment. However, some vertical motion, especially close to the time of opening, may have occurred.

TIME OF INITIAL OPENING AND RATES OF SEA FLOOR SPREADING

In Figure 10 we have plotted the average rates of spreading deduced from the position of magnetic anomalies 24, 23, 22, 21, and 20 measured along the azimuth of early opening (obtained from Talwani, Eldholm, 1977). The decrease in the rate of spreading at about anomaly 23 time agrees with earlier observations in the North Atlantic (Williams, McKenzie, 1971 ; Pitman, Talwani, 1972). While it is difficult to be absolutely precise about the rate of spreading between anomaly 24 and 25 time, the available data in the North Atlantic and Norwegian Sea requires that the initiation of spreading at the Vøring Plateau escarpment occurred very shortly after anomaly 25 time, and this anomaly is not seen on the Vøring Plateau or elsewhere in the Norwegian-Greenland Sea. Since the higher rate of spreading prior to anomaly 23 occurs both in the Norwegian Sea and in the North Atlantic, it cannot be directly attributed to the initiation of opening of the Norwegian Sea. It is also possible that there are errors in the reversal chronology near the time of anomaly 25 to anomaly 23. If such errors exist, our deduced rates of spreading will correspondingly change but our inference that the time of initiation of opening lies between anomaly 24 and anomaly 25 time will not change.

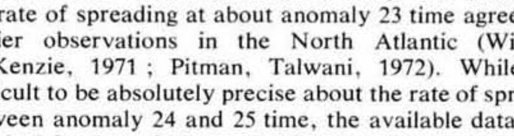

Figure 10
Rates of seafloor spreading obtained from analysis of the magnetic anomaly pattern presented in Figure 2. The various symbols show rates determined for various parts of the margin. We have made the calculations at six roughly equally spaced locations along the margin. Rates between anomalies 20 and 21 are plotted using the midpoint between anomaly 20 and 21 time for abscissa and so on (two points have been plotted for the interval between anomalies 20 and 22 where anomaly 21 was not observed).

CONCLUSIONS

1) Anomaly 24, the oldest anomaly found in the Norwegian Sea, can be followed without interruption from the Lofoten Basin, where it is well defined, to the Outer Vøring Plateau. This establishes a Tertiary age for ocean crust formed by sea floor spreading for the Outer Vøring Plateau.

2) We suggest that the reflectors detected by multichannel seismic profiling underlying the basalt flows of the Outer Vøring Plateau are comprised of flows and volcanogenic sediments generated subaerially during the first two million years following opening as the spreading axis deepened with time.

3) The phenomenon of emplacement of these reflectors is responsible for the appearance of smooth acoustic basement in this area. A similarly smooth basement is often seen especially on single-channel seismic records in many parts of the worlds oceans. The mechanism that we suggest above could be applicable in many other areas.

Acknowledgements

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