…netic Profile …tal Shelf and …ring Plateau [1]

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The upper part of the continental slope in the Storegga region dips at approximately 30° and from the foot of this feature an undulating surface continues to the base of the slope. In some places these undulations have a sinusoidal form which diminishes in amplitude with depth. The lower part of the continental slope consists of a convex front approximately 200 m high, which is thought to have developed along with the undulating surface by repeated slumping of unconsolidated material from the shelf edge. A very shallow crystalline basement exists on the outer part of the continental rise, while beneath the abyssal plain a layered structure is indicated. The south-western part of the Vøring Plateau is bounded by an escarpment. The plateau itself consists of layered sediments with an observed maximum thickness of 1.7 km and is assumed to be Cenozoic in age.

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Introduction

The data presented in this paper are based on a continuous seismic profile between 63°12′N, 5°57′E on the continental shelf of Norway and the outer part of the Vøring Plateau. The route followed during the traverse is indicated in Fig. 1. It follows the continental shelf in the Møre region, across the slope and adjacent oceanic basin, to the slope and outer part of the Vøring Plateau. Magnetic measurements were also made along this traverse and are presented together with the continuous seismic profiling data, but the former observations are not discussed in detail here. The purpose of this paper is to discuss some of the major features found along the measured profile. This will be done in three sections as follows:

1. The continental shelf edge and slope
2. The continental rise and the ocean floor
3. The Vøring Plateau and its outer slope.

The continental shelf edge and slope

The continental shelf edge (the Storegga Region) and the continental slope were crossed three times during the survey (between 21.00 hours [22/8] and

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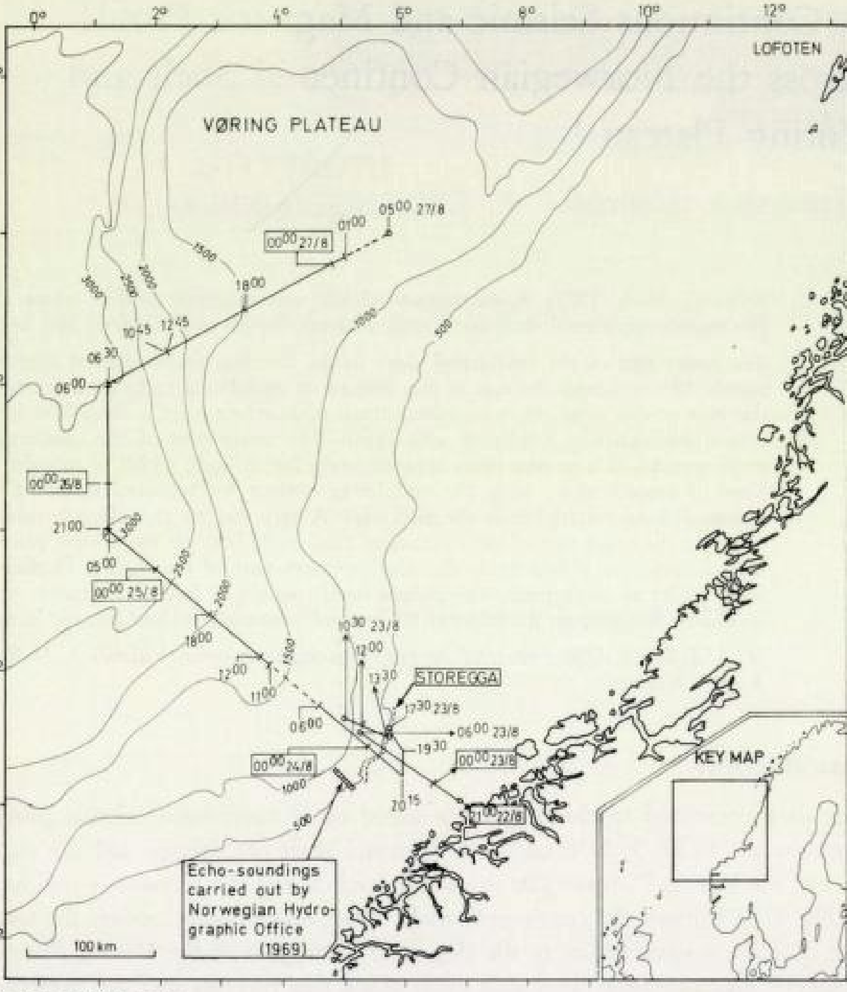


Fig. 1. Location map.

06.00 hours [24/8]) (Fig. 1). The Storegga region has formerly been studied in detail by Holtedahl (1955) by means of echo-soundings, dredging and coring. Holtedahl considered that the present shelf topography suggested a bottom consisting of consolidated rocks covered to a greater or lesser extent by sediments. On the basis of the submarine relief a former relative sea level at about 270 m was suggested, while another sea level 400–500 m below the present one was also tentatively proposed.

Recent geophysical and geological investigations have shown that the Norwegian Continental Shelf consists of large sequences of unconsolidated, semiconsolidated, and consolidated sediments of assumed Cenozoic and Mesozoic age, resting on a crystalline basement (Holtedahl & Sellevoll, 1971). A characteristic feature, almost everywhere in the shelf region, is that the sedimentary rock sequence is cut by an erosional surface on which unconsolidated deposits, presumably of Quaternary age, were deposited.

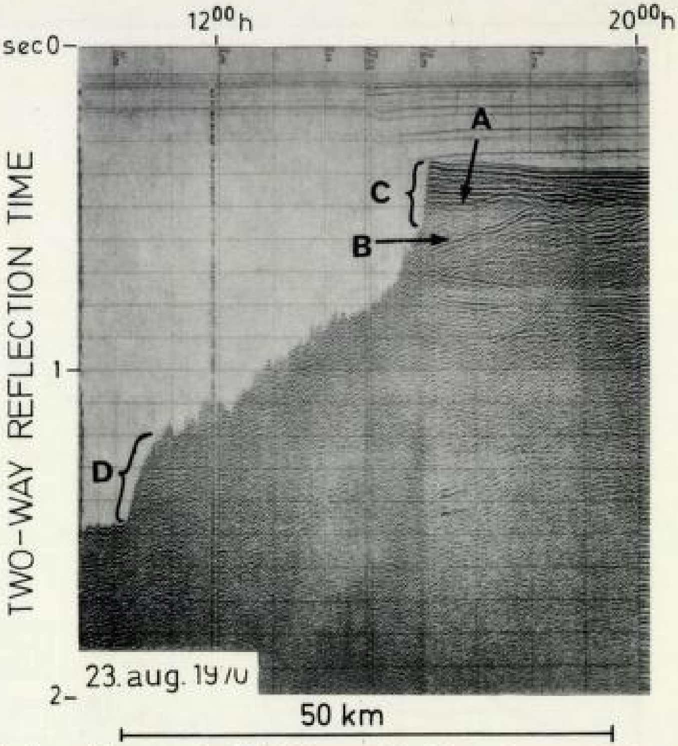


Fig. 2. Continuous seismic profile across the Shelf Edge and the Upper Continental Slope.

In Fig. 2, which represents a seismic profile across the shelf edge and slope, the A-horizon is assumed to be the discontinuity between horizontally layered Quaternary deposits and the pre-Quaternary sedimentary rocks beneath. The horizon named B is another interface of similar type to A but of unknown age. These two good reflecting horizons (A and B) presumably represent oversedimented former erosion surfaces, which are now strongly discordant to the present and upper slope. The shelf edge forms a pronounced physical feature, 150 m high, with a dip of 20°–35°. Features such as those described above are often observed along the shelf edge, but are especially well developed in the Storegga region.

Fig. 2 also illustrates the fact that the greater part of the slope has a very uneven surface, though unfortunately the resolution used during this survey was too low for a detailed study of these slope features. On the basis of the echo-soundings presented by Holtedahl (1955) it seems likely that these same uneven bottom features also occur in other parts of the Storegga region. Four echo-sounding profiles from a region adjacent to that of our profile, run in 1969 by the Norwegian Hydrographic Office, illustrate in far greater detail than our recordings the form of this undulating slope surface (Fig. 3). These undulations vary from 30 m to a few meters in height and are between 100 and 250 m in breadth at their base in the downslope direction. The sounding data were studied and discussed by Holtedahl & Sellevoll (1971), who

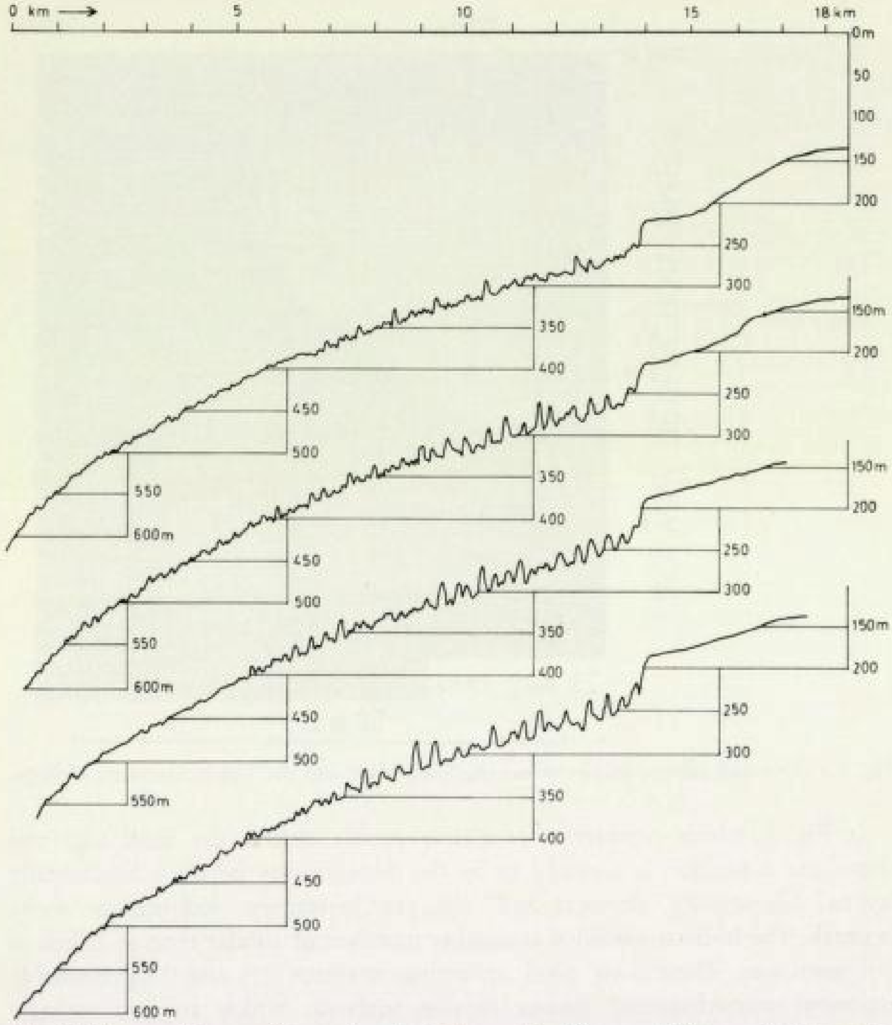


Fig. 3. Echo-soundings carried out by the Hydrographical Survey of Norway in the region marked on Fig. 1.

suggested that the undulating surface features on the upper continental slope were ridges, most likely representing terminal moraines formed during the last glaciation. The undulations show a successively diminishing 'amplitude' from the steep upper slopes down to a water depth of 450 m, where they die out. This interpretation by Holtedahl & Sellevoll was made before any continuous seismic record was available showing the sub-bottom structure in this region.

Figs. 2 and 4 show that the lower part of the continental slope at a depth of 1000 m (1.4 sec two-way reflection time) has a convex shape. Such a feature is sometimes observed at the lower parts of continental slopes. The height of this convex front is approximately 200 m in the present case, and the front itself has a maximum dip of 10°. The formation of such a feature may be explained in several ways. One is that it has been built up during the slumping

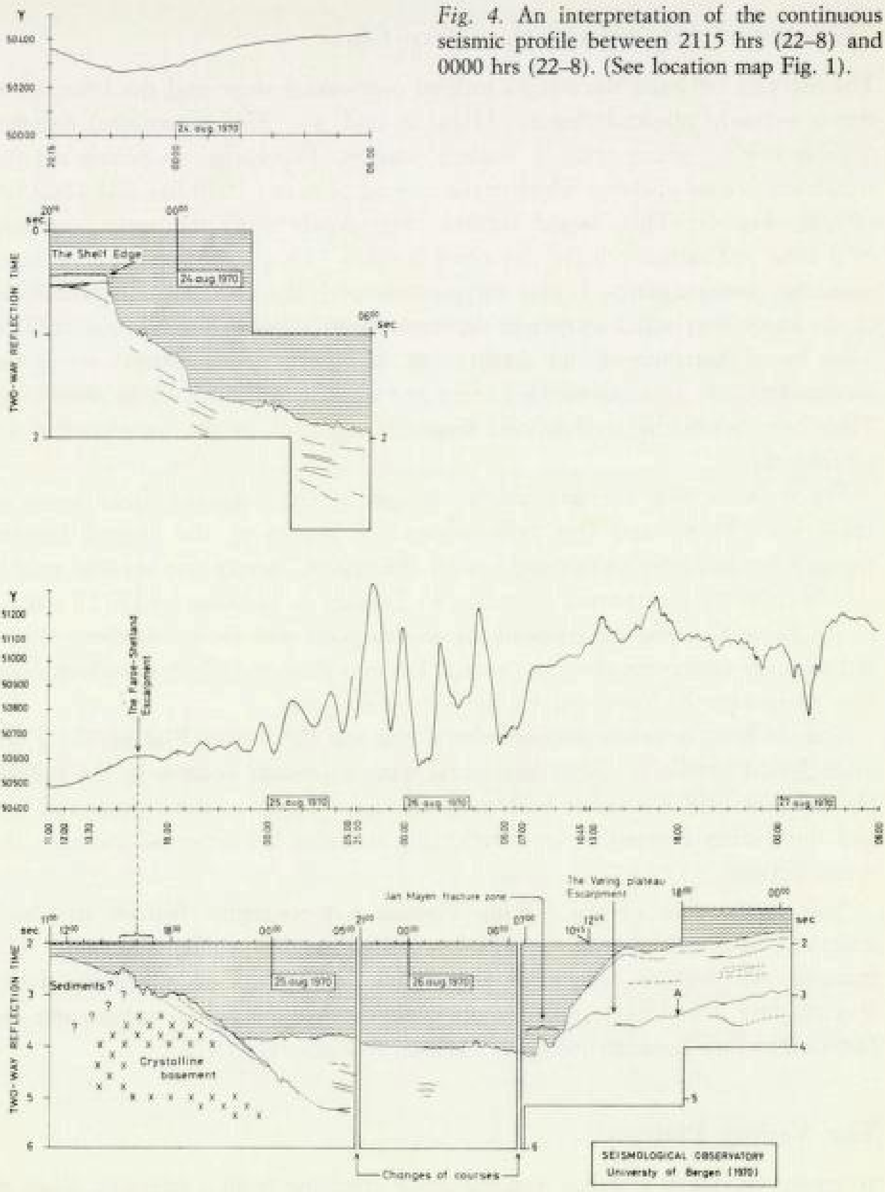


Fig. 4. An interpretation of the continuous seismic profile between 2115 hrs (22–8) and 0000 hrs (22–8). (See location map Fig. 1).

of material from the shelf edge and upper continental slope, which moves progressively downslope towards the continental rise. Another possibility is that the front represents an escarpment developed by the modification of the slump front by bottom currents.

Even though the recordings are poor, slightly reflecting horizons are observed underneath the continental slope surface. (Fig. 4).

The continental rise and the ocean floor

The junction between the convex-formed continental slope and the continental rise is a clearly marked feature (Figs. 2 and 4). The continental rise is a slightly sloping plane with a uneven surface. Especially noticeable are the rough and jagged surfaces which were crossed between 1600 hrs and 1800 hrs (24/8 – Fig. 4). This jagged surface corresponds with the outer boundary of a large sedimentary basin described by Åm (1970) on the basis of aeromagnetic measurements. It also corresponds with the northward continuation of the Faroe-Shetland Escarpment determined by Talwani & Eldholm (1972). They found that there is no doubt that basement depth changes across the escarpment, but its exact configuration and location are difficult to determine. They have taken the well-defined magnetic lineation as the location for the escarpment.

Fig. 4 shows that a characteristic change in the magnetic field occurs at 1600 hrs (24/8) and this falls within the region of the jagged bottom topography and also corresponds with the region where our seismic profile should cross the escarpment according to Talwani & Eldholm's (1972) tracing of the Faroe-Shetland Escarpment. From this point and sea-wards there are no sedimentary structures observed except for two shallow reflectors, which form two wedges on the lower part of the continental rise.

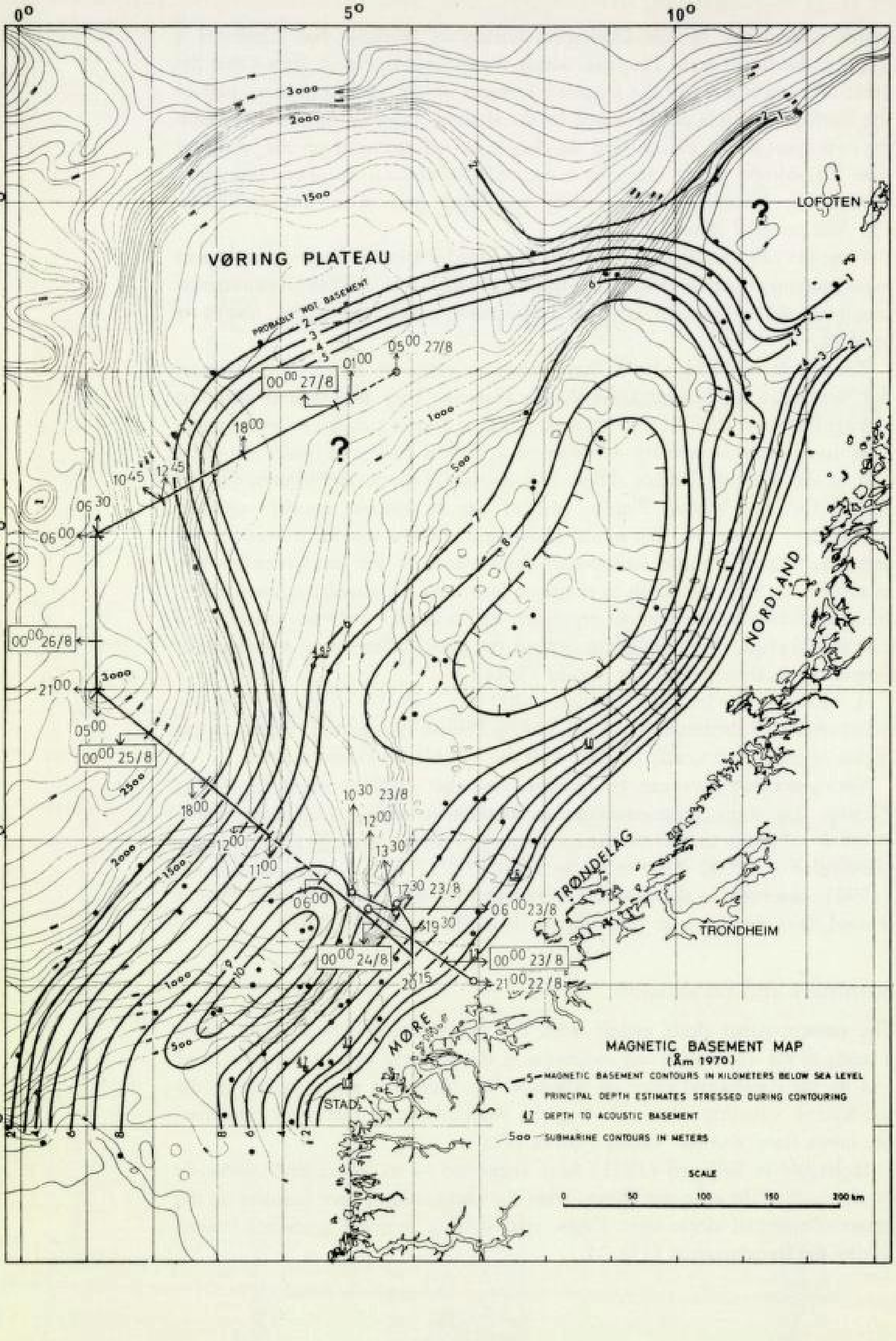
The sea-floor between the continental rise and the Vøring Plateau along our investigated profile is rather horizontal with a smooth bottom in the middle abyssal parts and a rougher bottom in the areas closer to the continental rise and the Vøring Plateau. Several reflecting horizons are observed beneath the ocean bottom.

Just at the foot of the Vøring Plateau a topographic feature has been observed, 200 m high and about 4 km 'broad' in the profile direction. The form of this feature cannot of course be determined on the basis of one traverse line. This topographic feature occurs where the profile crosses the Jan Mayen Fracture Zone according to Talwani & Eldholm (1972).

The Vøring Plateau

In recent years this area has received much attention from a scientific point of view. Johnson et al. (1968) gave a short description of the area on the basis of continuous seismic profiling. Avery et al. (1968) presented an aeromagnetic map which included the Vøring Plateau. The map shows strong irregular and narrow anomalies on the outer part of the Plateau, while the inner part of the continental shelf between Trondheim and Lofoten shows a weak and featureless magnetic picture. Åm (1970), on the base of magnetic measure-

Fig. 5. Magnetic basement map of the Vøring Plateau and adjacent parts of the continental shelf after Åm (1970), with the locations of the continuous seismic profiles of the present study added.


0°
5°
10°
68°
66°
64°
62°
VØRING PLATEAU
PROBABLY NOT BASEMENT
LOFOTEN
NORDLAND
TRØNDELAG
TRONDHEIM
MØRE
STAD
00 00 27/8
00 00 26/8
00 00 25/8
00 00 24/8
00 00 23/8
21 00 22/8
MAGNETIC BASEMENT MAP
(Åm 1970)
5 MAGNETIC BASEMENT CONTOURS IN KILOMETERS BELOW SEA LEVEL
PRINCIPAL DEPTH ESTIMATES STRESSED DURING CONTOURING
4.7 DEPTH TO ACOUSTIC BASEMENT
500 SUBMARINE CONTOURS IN METERS
SCALE
0
50
100
150
200 km

ments carried out by the Geological Survey of Norway, has presented a magnetic basement map. The map, which is presented in Fig. 5, shows that the great difference between the magnetic features on the outer and inner part of the Vøring Plateau is partly caused by the shallow magnetic basement beneath the outer part of the Plateau and the deeply buried basement on the landward side. In addition there must be a marked difference in magnetic properties between the basement on the outer and inner part of the Vøring Plateau (K. Åm, personal communication).

Hinz (1972) found, on the basis of combined marine geological-geophysical investigations, that the Vøring Plateau is divided into a western continental fragment and an eastern Graben Zone under which the upper mantle is uplifted.

Talwani & Eldholm (1972) have made an extensive geophysical study of the Norwegian Sea including the Vøring Plateau. They also found that the Vøring Plateau is divided into a western and an eastern part by an escarpment. They have demonstrated the existence of a shallow basement under the outer part of the Vøring Plateau. Hinz (1972) and Talwani & Eldholm (1972) agreed that the Vøring Plateau east of the escarpment consists of thick sedimentary sequences. The model showing a shallow basement west of the escarpment and a thick sedimentary basin east of the escarpment, is also in accordance with the depth to magnetic basement calculated by Åm (1970). If, in addition, the escarpment represents the boundary between oceanic and continental crust, it is possible to explain the great difference in the magnetic properties observed within the Vøring Plateau.

A fault is clearly observed near 1300 hrs (26/8 – Fig. 4). This is interpreted as a continuation of the Vøring Plateau escarpment, which in this region seems to run nearly parallel with the Jan Mayen Fracture Zone.

Very good reflectors can be observed on the profile crossing the Vøring Plateau. The most prominent one is marked A on Fig. 4. The maximum two-way reflection time from the sea bottom to this reflector is 1.4 sec. If the same velocity (2000–2500 m/s) as Hinz (1972) and Talwani & Eldholm (1972) observed in the assumed Cenozoic sediments on the Vøring Plateau is used, then the depth to this reflector is of the order of 1.7 km.

Summary and conclusion

The present paper deals mainly with two somewhat different topics: first, a study of the unconsolidated sediments in the adjacent area to the shelf edge and on the continental slope of NW-Norway. Second, a study mainly of the sub-bottom structure observed along the profile crossing the continental rise, the ocean floor, and the Vøring Plateau (Fig. 1).

Holtedahl & Sellevoll (1971) have suggested — as mentioned previously on the basis of the echo-soundings – that the undulating surface features on the upper continental slope were ridges, representing terminal moraines formed during the last glaciation (Fig. 3).

Another possibility is that these undulations on Fig. 3 represent megaripples (sandwaves) produced by strong bottom currents sweeping over or across the shelf slope. An important consideration in this proposed explanation is the composition and the nature of the sediments which constitute these features. If, as Holtedahl (1955) suggested, (and personal communication) they are heterogenial glacial deposits, then the action of traction-currents would presumably not produce sandwaves of the type documented from the shallow continental sea and continental margin. This explanation is consequently not very likely.

The continuous seismic sections now available from the shelf edge region and the upper continental slope (Fig. 2) indicate that oversedimentation of the shelf edge results at some stage in the instability of the superficial deposits which slump downslope along a curvilinear shear plane. The downslope movement of this unconsolidated material constantly modifies the form of the shelf edge by erosion of the more consolidated pre-Quaternary deposits, as indicated by the present form of the continental edge and upper slope (Fig. 2). Succeeding slump masses will pile up on preceding slides, whose form will become modified by the later ones, as shown by the diminution in amplitude with depth of these 'ridges' (see Fig. 3).

The investigation of the structure beneath the continental rise, the abyssal plain and the Vøring Plateau is rather limited, but several interesting features show up along the profile-line in Fig. 1.

The northward continuation of the Faroe-Shetland Escarpment is observed in the neighbourhood of 1600 hrs (24/8), but the exact position is difficult to point out. The magnetic feature is changing from a smooth increasing anomaly on the land side of the escarpment to an 'oscillating' magnetic anomaly on the sea side. According to our interpretation the magnetic high represents the crystalline basement on the west side of the escarpment (Fig. 4). Our evidence for such an interpretation is not very strong, but both the magnetic, seismic as well as the topographic features, contribute to such an interpretation. It is also in agreement with the observation of Talwani & Eldholm (1972).

Beneath the abyssal plain we have observed reflections from a depth corresponding to 1.5 sec two-way reflection time. According to the interpretation this corresponds to the crystalline basement. Assuming a velocity of 2000 m/s gives this a thickness of the total sedimentary sequences of 1500 m in this region 0500 (25/8 – Fig. 4). Some strong 'oscillating' magnetic anomalies are observed between 2300 hrs (24/8) and approximately 0600 hrs (26/8 – Fig. 4) indicating magnetic properties which are characteristic of an oceanic crust.

Clearly recognizable sedimentary sequences are observed on the continuous seismic sections in the Vøring Plateau area. A very good reflector (A in Fig. 4) with a maximum depth of approximately 1.7 km beneath the sea bottom, is assumed to represent the Cenozoic basement. The very distinct escarpment observed on the south-western side of the Vøring Plateau is assumed to represent the continuation of the escarpment previously observed on the western part of the Vøring Plateau (Talwani & Eldholm, 1972).

The magnetic pattern is changing strongly from high amplitude anomalies which are associated with the sea floor spreading across the abyssal plain to smaller and less distinct anomalies on the Vøring Plateau.

The strong negative magnetic anomaly at 0200 hrs (28/8 – Fig. 4) is very peculiar. It may be due to diurnal variation, but since the rest of the magnetic anomalies are in good agreement with the maps of Avery et al. (1968), which also show similar anomalies on the Vøring Plateau, it is most likely a real anomaly. If the negative anomaly is real, it could be due to a shallow body with an essentially reversed magnetization, probably volcanic material in the sediments (K. Åm, personal communication).

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REFERENCES

Åm, K. 1970: Aeromagnetic investigation on the Continental Shelf of Norway, Stad–Lofoten (62°–69°). *Norges geol. Unders. 266*, 49–61.

Avery, O. E., Burton, G. D. & Heirtzler, J. R. 1968: An aeromagnetic survey of the Norwegian Sea. *J. Geophys. Res. 73*, 4583–4600.

Hinz, K. 1972: Der Krustenaufbau des Norwegischen Kontinentalrandes (Vøring Plateau) und der Norwegischen Tiefsee zwischen 66° und 68°N nach seismischen Untersuchungen. *'Meteor' Forsch. – Ergebnisse No. 10*, 1–16.

Holtedahl, H. 1955: On the Norwegian Continental Terrace, primarily outside Møre–Romsdal: Its geomorphology and sediments. *Årbok 1955, Mat.naturv. rekke nr. 14*, University of Bergen.

Holtedahl, H. & Sellevoll, M. A. 1971: Geology of the Continental Margin of the eastern Norwegian Sea and the Skagerrak. *Institute of Geological Sciences, Report No. 70/14*, 33–52.

Johnson, G. L., Ballard, J. A. & Watson, J. A. 1968: Seismic studies of the Norwegian Continental Margin. *Norsk Polarinstitutt, Årbok 1966*, 112–119.

Talwani, M. & Eldholm, O. 1972: Continental margin off Norway: a geophysical study. *Geol. Soc. Am. Bull. 83*, 3575–3606.