Seismic Refraction Measurements and Continuous Seismic Profiling on the Continental Margin off Norway between 60°N and 69°N

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The present study is mainly based on seismic measurements on the continental margin off Norway between 60°N and 69°N carried out by the Seismological Observatory, University of Bergen. Available information from other studies has also been utilized.

The sedimentary basin off Norway wedges out near the Norwegian coastline. The ocean side of the sedimentary basin is in contact with oceanic crust along escarpments and the Jan Mayen Fracture Zone. The present study reveals that the contact zone between the crust of oceanic and continental origin on the continental margin may be very complex and difficult to identify confidently on the basis of work carried out to date.

The strike beneath the base of Pleistocene deposits is generally parallel to the coastline. The dip just beneath the base of the Pleistocene deposits reflects the uplift of the landmasses from the coastline across the continental margin. The steep dips observed between the coastline and the Storegga region together with major submarine slides suggest that the shelf region between the coastline and Storegga may have undergone greater uplift relative to the rest of the shelf area (except for the Lofoten and Vesterålen shelf area).

Seismic velocity-information and the velocity-age relation suggest that the continental margin consists of extensive areas of sedimentary rocks of Cenozoic, Mesozoic and Paleozoic age.

Isopach maps show the calculated distribution of assumed Cenozoic and Mesozoic sedimentary rocks on the continental margin. Cenozoic deposits cover a great part of the continental margin and reach the greatest thickness between 62°N and 67°N. A deltaic structure which is probably of lower Tertiary age is especially well developed between Frøyabanken and Sklinnabanken. A large diapiric structure is observed in the Cenozoic sediments at 64½°N, 01°E, in a water-depth of about 2500 m. Extensive areas on the continental margin are covered by Mesozoic sediments, reaching a maximum thickness of about 2.7 km.

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Introduction

The continental margin north of 60°N is of interest because of recent oil discoveries to the south, and the geology and structures of the outer and deeper marginal areas are of great interest in view of the latest ideas on the plate-tectonic evolution of the Norwegian–Greenland Sea. Thus, it is also of special interest to locate the boundary between the oceanic and continental crust.

A long-term study of the continental margin off Norway has been carried out by the Seismological Observatory, University of Bergen, as a part of the

'Continental Shelf Project', sponsored by the Royal Norwegian Council for Scientific and Industrial Research (NTNF) from 1967 up to 1972, and from 1973 onwards by Statens Oljedirektorat. The main objective of this long range project has been to study the distribution and structure of the sedimentary rocks underlying the continental margin off Norway north of 62°N.

The principal objective of the present study was to study the distribution, thickness and structures of Pre-Quaternary sedimentary rocks on the continental margin off Norway between 60°N and 69°N mainly on the basis of seismic data. Results from earlier seismic reflection and refraction data as well as from magnetic data (Ewing & Ewing 1959; Johnson & Heezen 1967; Eldholm & Nysæther 1969; Eldholm 1970; &m 1970; Sundvor & Sellevoll 1971; Sundvor 1972; Talwani & Eldholm 1972; Hinz 1972; Sellevoll & Sundvor 1974; Sellevoll 1974) are also included to give the most complete geological picture.

Several writers have previously discussed the distribution of the Pleistocene sediments and the development of the Pre-Pleistocene rocks and structures on the continental margin off Norway (O. Holtedahl 1940, 1960; H. Holtedahl 1955; Nysæther et al. 1969; Holtedahl & Sellevoll 1971, 1972; Talwani & Eldholm 1972).

Seismic refraction studies and continuous profiling

Continuous seismic profiling has been done along the track locations indicated in Fig. 1. Heavy lines indicate where deep seismic reflection measurements have been carried out recently using a DFS–10,000 instrumentation and a 12-section streamer. The processing of the multicovered reflection lines is in progress at the Observatory.

The seismic refraction data (Fig. 2 and Table 1) used in the present study are partly from two-ship refraction measurements and partly from expandable sonobuoy experiments using an air gun as energy source. The apparent velocities are calculated by visually fitting straight lines to segments of travel time curves and measuring their slopes relative to the slope of the direct water wave. These refraction data have been gathered by scientists from the Seismological Observatory, University of Bergen, and from the Lamont Doherty Geological Observatory of Columbia University. Profile locations, P-wave velocities and thicknesses of the sedimentary layers are shown in Fig. 2 and Table 1. All of the profiles shown on Fig .2 are short, and thus not amenable for acquisition of information on the deep crust or the mantle.

Seismic crustal studies have also been performed along a profile line on the Vøring Plateau during a cooperative geophysical programme between Bundesanstalt für Bodenforschung, Hannover, and Seismological Observatory, University of Bergen. These data have been interpreted by Hinz (1972).

The histogram in Fig. 3 shows the seismic P-wave velocities obtained from the refraction measurements presented in Table 1. It is well known that velocities of seismic waves in sedimentary rocks are a function of thickness,

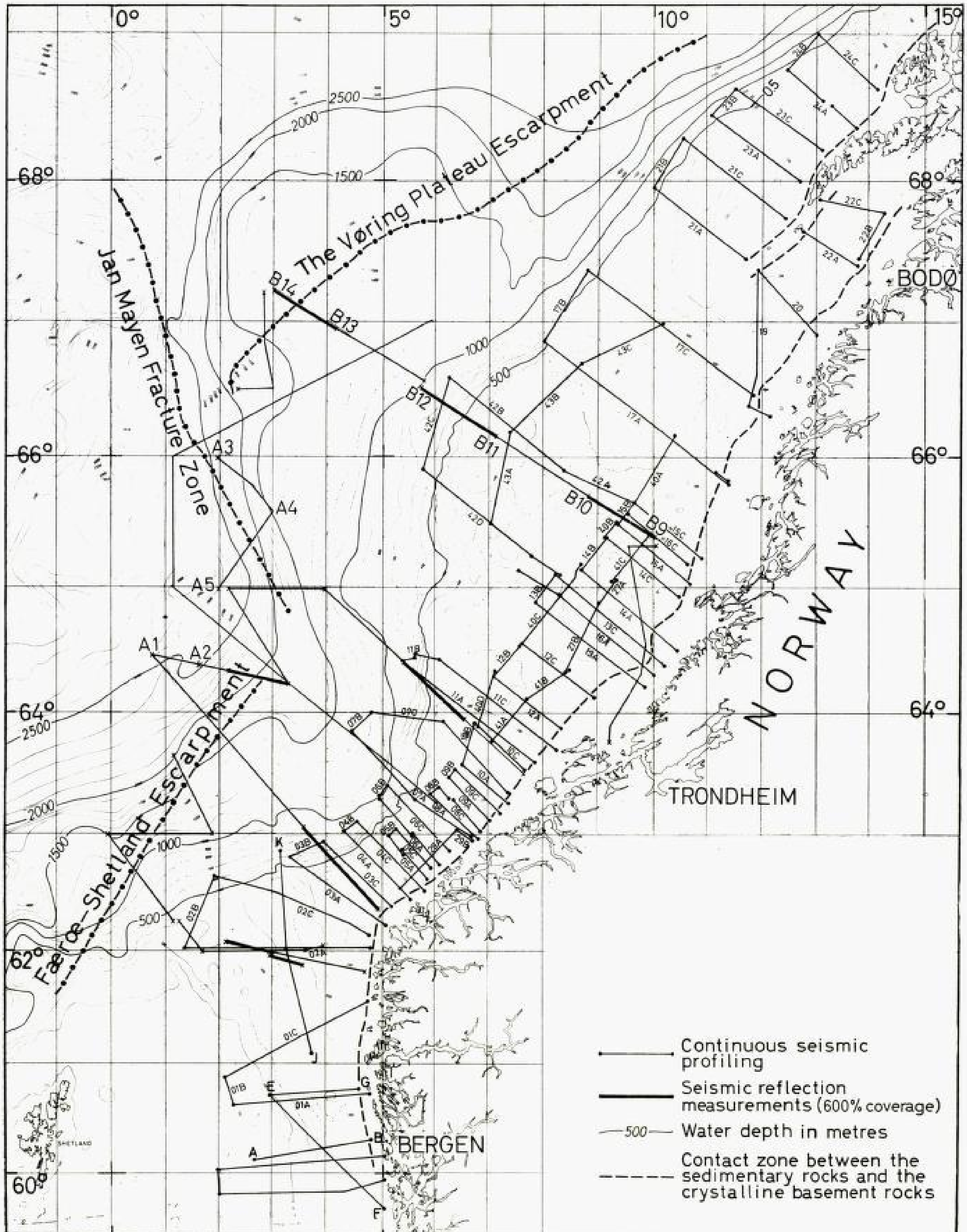

Fig. 1. Tracks on the continental margin off Norway. Measured by the Seismological Observatory, University of Bergen. (Escarpments and fracture zone after Talwani & Eldholm 1972).

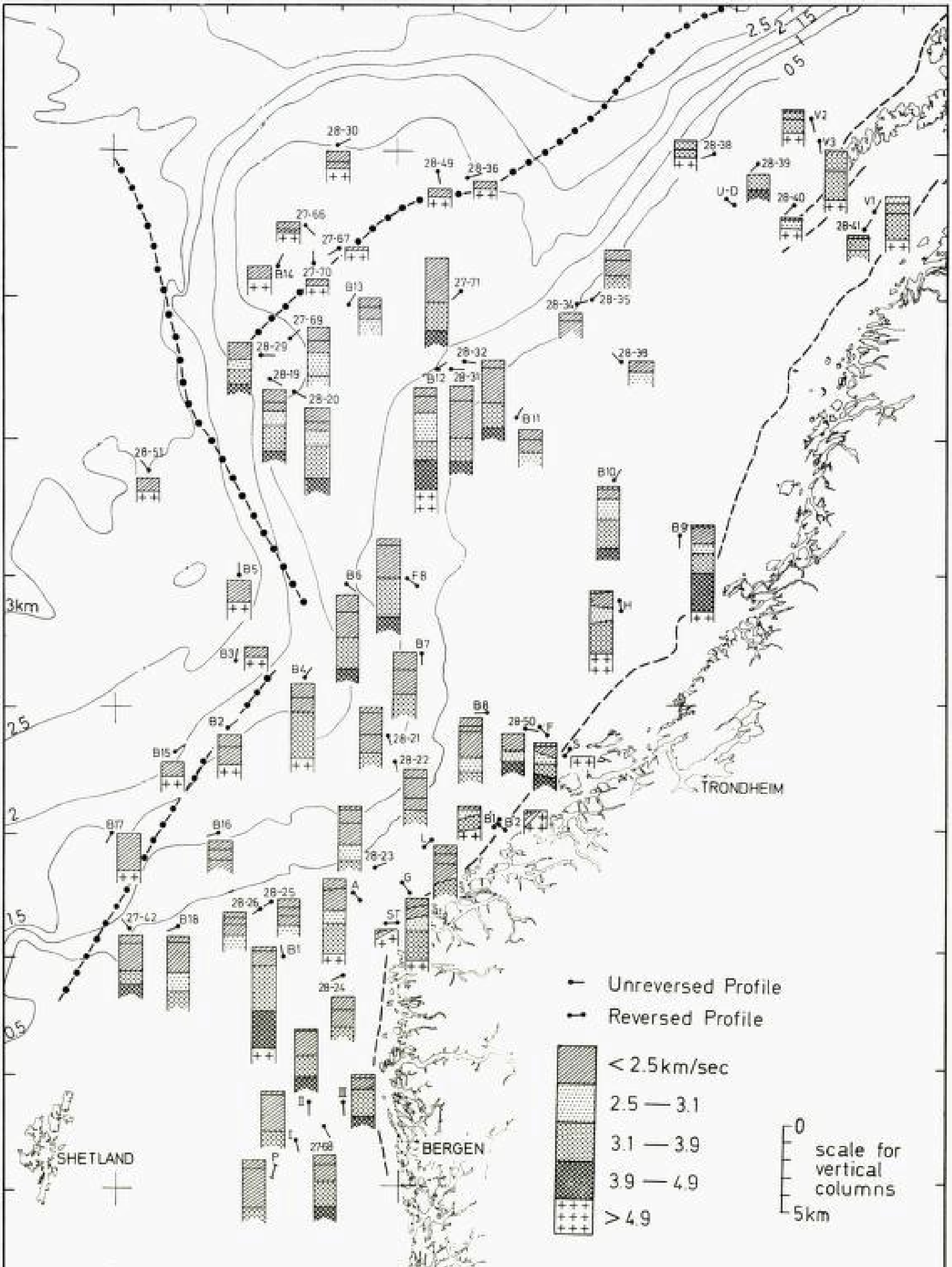

Fig. 2. Map showing seismic refraction data (see Table 1 and text).

Table 1. Listing of seismic refraction results. All units are in km and km/s. Parentheses indicate assumed veloc

Profile	Lat. (N)	Long. (– = W)	Water depth	V1	H1	V2	H2	V3	H3	V4	H4	V5	H5	V6	Data sourc
B1	61°58.0′	2°57.0′	0.40	(1.80)	0.25	2.40	0.64	3.35	2.70	4.30	2.02	5.20			Seism
B2	63°50.8′	2°00.0′	1.66	1.75	0.59	2.10	1.00	5.00							Obsv
B3	64°09.0′	2°09.0′	1.50	2.00	0.56	5.05									1973
B4	64°13.5′	3°22.0′	1.85	1.82	0.80	2.20	0.76	3.50	2.57	5.20					”
B5	65°00.0′	2°08.0′	2.50	2.15	1.08	5.10	1.00	6.45							”
B6	64°57.0′	4°04.0′	1.05	1.85	0.87	2.20	1.39	3.55	1.68	4.00					”
B7	64°26.5′	5°23.5′	0.93	1.80	0.97	2.10	1.40	3.30							”
B8	63°56.5′	6°33.0′	0.25	1.85	0.39	2.10	0.27	2.35	1.40	2.70	1.40	3.20			”
B9	65°17.8′	10°00.5′	0.16	(1.80)	0.23	2.10	0.61	2.60	0.56	3.70	1.17	4.40	2.10	5.50	”
B10	65°42.8′	8°52.0′	0.43	(1.80)	0.16	2.35	0.51	2.90	1.02	3.55	1.65	4.45			”
B11	66°10.2′	7°09.5′	0.35	1.85	0.54	2.30	0.68	2.70							”
B12	66°32.0′	5°46.5′	0.90	1.85	0.47	2.10	0.89	2.55	1.57	3.90	1.02	4.45	1.61	4.90	”
B13	66°58.0′	4°10.2′	1.33	1.75	0.49	2.10	0.74	2.80	0.80	3.45					”
B14	67°14′8	2°50.0′	1.30	2.30	0.77	5.25									”
B15	63°40.0′	1°11.0′	1.90	2.30	0.88	5.10									”
B16	63°00.0′	1°36.0′	1.05	(1.80)	0.37	2.05	0.51	2.30							”
B17	63°00.0′	-0°10.0′	1.44	2.25	2.06	5.30									”
B18	62°15.8′	1°06.5′	0.50	(1.80)	0.32	2.10	1.68	2.55	1.02	3.95					”
27–42	62°13.0′	0°16.0′	0.67	(1.85)	0.43	2.02	1.51	3.32	0.70	4.65					Talwan
27–66	67°29.0′	3°21.0′	1.28	1.56	0.41	2.26	0.15	5.20							Eldhol
27–67	67°21.0′	3°59.0′	1.21	2.12	0.14										1972
27–68	60°32.0′	3°42.0′	0.30	1.85	0.49	2.25	0.94	3.45	1.44	4.50					”
27–69	66°42.0′	3°05.0′	1.44	1.78	0.73	2.02	0.69	2.95	1.22	4.15					”
27–70	67°15.0′	3°30.0′	1.19	1.71	0.34										”
27–71	67°03.0′	6°05.0′	1.31	(2.30)	2.30	3.70	1.55	4.70							”
28–19	66°25.0′	2°42.0′	1.59	1.86	0.69	2.24	0.49	2.47	0.86	3.59	1.41	4.09			”
28–20	66°20.0′	3°10.0′	1.48	1.87	0.81	2.24	0.39	2.54	0.86	3.64	1.82	4.43			”
28–21	63°45.0′	4°48.0′	1.37	(1.85)	0.23	2.11	1.24	2.49	1.01	3.48					”
28–22	63°33.0′	4°56.0′	1.19	(1.85)	0.49	2.09	1.15	2.44	0.71	3.43					”
28–23	62°42.0′	4°35.0′	0.19	1.85	0.22	2.17	0.73	2.45	1.19	3.10	0.92	3.85			”
28–24	61°50.0′	4°01.0′	0.20	(1.85)	0.69	1.98	0.99	3.76							”
28–25	62°26.0′	2°45.0′	0.40	(1.85)	0.47	1.94	0.43	2.28	0.51	2.85					”
28–26	62°23.0′	2°35.0′	0.40	(1.85)	0.34	1.97	0.32	2.38	0.58	2.88					”
28–29	66°35.0′	2°34.0′	1.60	1.76	0.95	2.46	0.54	3.17	0.80	4.26					”
28–30	68°07.0′	3°57.0′	1.55	1.74	0.62	2.23	0.37	5.35							”
28–31	66°30.0′	5°58.0′	0.85	1.94	0.81	2.48	2.11	3.70	1.24	4.65					”
28–32	66°33.0′	6°09.0′	1.03	(1.85)	0.40	2.23	1.99	3.62	1.38	4.32					”
28–33	66°33.0′	8°56.0′	0.30	2.00	0.65	2.63									”
28–34	66°57.0′	8°11.0′	0.46	1.94	0.46	2.38									”
28–35	67°00.0′	8°27.0′	0.31	1.93	0.47	2.35	0.92	3.25							”
28–36	67°49.0′	6′15.0°	1.23	1.75	0.34										”
28–38	68°00.0′	10°37.0′	0.23	3.75	0.54	4.65	0.48	5.24							”
28–39	67°56.0′	11°24.0′	0.18	3.57	0.91	4.23									”
28–40	67°39.0′	12°03.0′	0.16	(2.00)	0.10	2.75	0.48	5.35							”
28–41	67°29.0′	13°19.0′	0.27	(2.00)	0.14	3.07	0.62	3.70							”
28–49	67°52.0′	5°42.0′	1.38	1.77	0.43	5.10									”
28–50	63°49.0′	7°13.0′	0.18	1.97	0.98	2.75	0.56	4.10							”
28–51	65°46.0′	0°37.0′	3.15	2.20	0.77										”
A	62°27.1′	4°19.6′	0.17	1.82	0.38	2.28	1.10	2.79	0.75	3.33	1.70	5.00			Eldholt
	62°30.5′	4°10.0′			0.59		1.10		0.75		1.70				1970
G	62°35.0′	5°05.6′	0.10	1.95	0.30	2.17	0.56	2.62	0.92	3.57	1.61	5.25			”
	62°40.1′	4°58.9′			0.56		0.59		0.64		1.57				
L	62°51.9′	5°29.4′	0.10	1.94	0.46	2.09	0.52	2.45	0.78	3.60					”
	62°49.0′	5°19.7′			0.46		0.54		1.05						

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file	Lat. (N)	Long. (– = W)	Water depth	V1	H1	V2	H2	V3	H3	V4	H4	V5	H5	V6	Data source
	62°15.5′	4°57.6′	0.18	2.01	0.00	2.51	0.00	5.60							"
	62°16.3′	4°47.9′			0.23		0.22								
I	63°03.0′	6°41.6′	0.08	2.05	0.11	2.56	0.59	3.79	0.56	5.24					"
	63°08.4′	6°49.0′			0.19		0.23		0.79						
II	63°02.0′	6°55.5′	0.12	2.08	0.00	2.76	0.00	3.50	0.00	5.20					"
	63°04.6′	6°45.8′			0.13		0.34		0.44						
	63°35.5′	7°57.0′	0.20	5.02											"
	63°38.5′	8°00.5′													
	63°45.3′	7°37.8′	0.17	1.80	0.19	1.96	0.23	2.60	0.70	3.28	0.54	4.38			"
	63°47.7′	7°29.0′			0.19		0.63		0.23		0.82				
	64°40.2′	8°57.0′	0.12	2.00	0.12	2.16	0.70	2.58	1.02	3.54	1.64	5.50			"
	64°46.7′	8°55.2′			0.00		0.91		0.60						
	67°36.0′	13°28.8′	0.25	2.69	0.32	3.22	0.51	3.76	1.48	5.15					Sundvor &
	68°13.8′	12°21.0′	0.24	(1.90)	0.05	3.29	0.41	3.76	0.83	5.18					Sellevoll,
	68°04.8′	12°28.2′	0.19	(1.90)	0.13	3.20	0.92	3.81	1.76	5.20					1971
D	67°38.0′	10°59.0′	0.18	1.90	0.25	2.40	1.10	3.50							Eldholm &
	67°40.0′	10°53.0′			0.25		1.10								Nysæther, 1969
	60°24.5′	3°09.3′	0.13	(1.85)	0.14	2.15	2.06	3.35							Sellevoll &
	60°44.3′	3°24.0′	0.30	(1.85)	0.11	2.20	1.34	3.25	1.18	4.50					Sundvor,
	60°44.4′	4°06.5′	0.30	(1.85)	0.23	2.10	0.58	3.05	1.49	4.70					1974
	60°11.6′	2°41.7′	0.09	1.82	0.37	2.08	2.23	2.97							Sundvor, 1972
	60°04.7′	2°28.3′													
	64°55.0′	5°19.0′	0.64	1.66	0.36	2.08	1.78	3.44	2.12	4.01					Ewing &
	65°14.0′	4°35.0′			0.36		1.78		2.12						Ewing, 1959

geological age and lithology of the rocks. As a consequence it is impossible to get an exact correlation of the seismic velocities with geological age alone. Seismic velocity profiles at different parts of the continental margin off Norway are fairly similar to one another concerning the velocity so it should be possible at least to make correlation within the velocity-structure from one profile to another, although the stratigraphic ages suggested in Fig. 3 may be somewhat incorrect.

P-wave velocities in Tertiary rocks seldom exceed 2.25 km/sec in the North Sea (Hornabrock 1962; Wyvobeck 1969), and seismic velocities in Mesozoic rocks are generally less than 4.0 km/sec. Thus, on Andøya, the island in Northern Norway, P-wave velocities are about 2.5 km/sec in Cretaceous rocks and 3.1 km/sec in sedimentary rocks of Upper Jurassic age (Sellevoll & Sundvor 1972). The velocity structure of the upper sedimentary sequences on the westernmost part of the Barents Shelf is similar to the Norwegian shelf area farther south. Eldholm & Ewing (1971) and Sundvor (1971) interpreted the 2.2 km/sec layer to be of Tertiary age. The velocity-age relation used in the present study (Fig. 3) is the same that Talwani & Eldholm (1972) have used for almost the same region.

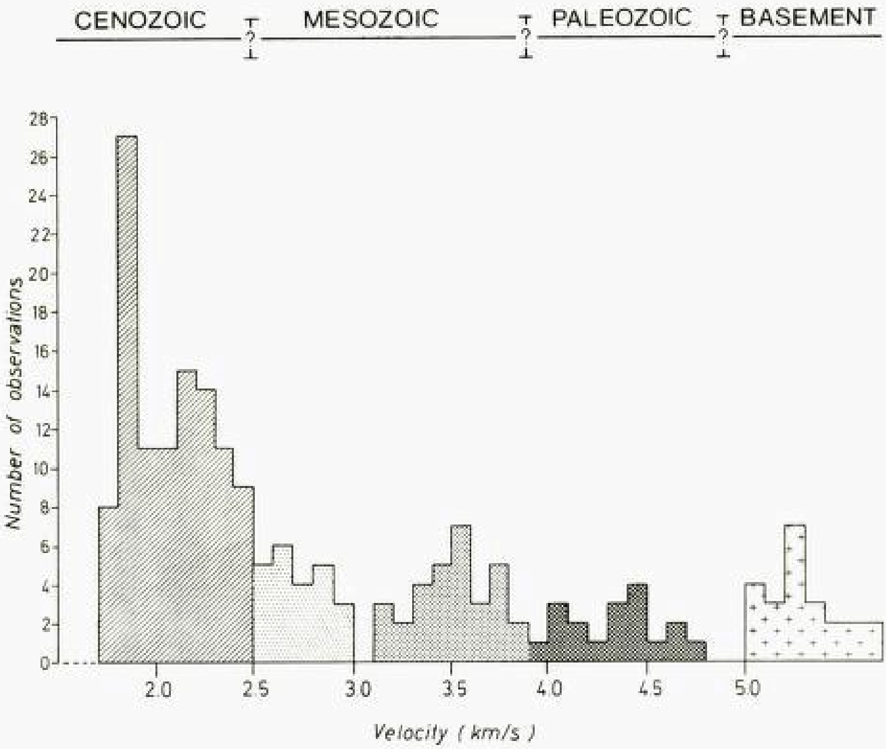
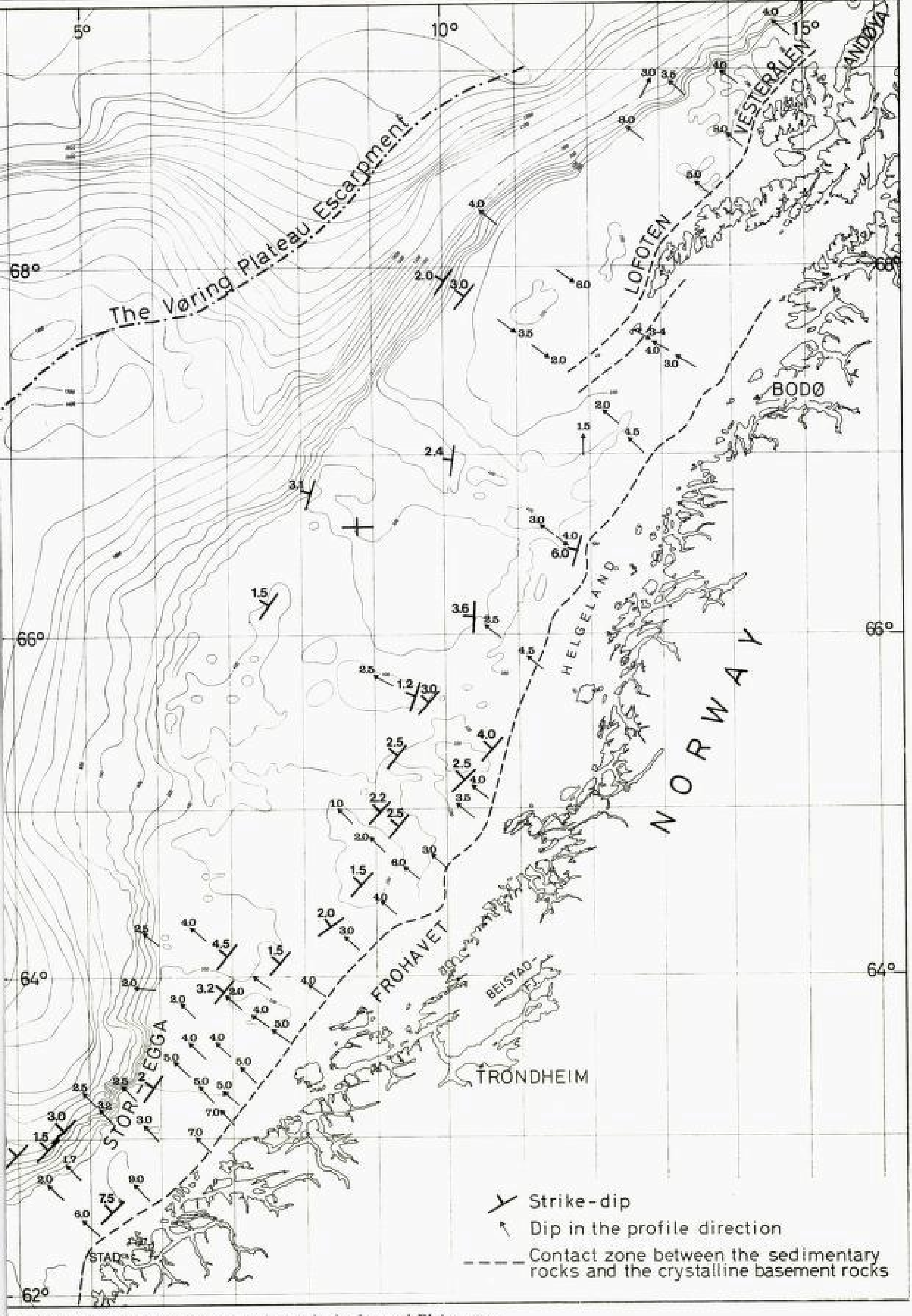


Fig. 3. Histogram of velocities from seismic refraction measurements with proposed velocity-age relation. (See text for discussion of these relations.)

The sedimentary basin between 60° and 69°N

The continental shelf varies in width from about 60 km seawards off Stad to 200 km off Helgeland to less than 60 km off Lofoten–Vesterålen (Fig. 1). Some of the boundaries of the main sedimentary basin on the continental margin off Norway are shown on Fig. 4. The contact between Phanerozoic sedimentary rocks and crystalline rocks on the Norwegian mainland is subparallel to the coastline as shown by continuous seismic profiling (Nysæther et al. 1969). The rate of change of dip measured just beneath the base of Pleistocene decreases seawards and across the shelf. The dip near the contact varies generally between 3° and 9° (predominantly to the northwest), as shown in Fig. 4 by some calculated strike-dip values and a number of apparent dip-indications along the continuous seismic profile lines. These apparent dips are equal to or less than the real dips. The dips are almost all northwesterly on the continental margin with two exceptions: one near the cost between 66°N and 67°N (Fig. 4) and another in the Lofoten region. The steep dips observed along the Norwegian coast are probably too steep to be primary dips. Nysæther et al. (1969) concluded that primary dips were steepened as a result of the uplift of the Scandinavian landmasses. Thus, according to Nysæther et al. (1969), the eastern part of the Vestfjorden area must have been a basin



ig. 4. Calculated strike–dip values beneath the base of Pleistocene

of Pre-Tertiary age, which was centred where the Lofoten Islands are situated today. The high grade metamorphic basement rocks were uplifted through the basin sediments and formed a horst. Smaller — probably downfaulted — sedimentary basins are also observed on the east side of the main contact zone near Frohavet and Andøya. Oftedahl (pers. comm., 1972) has reported one smaller basin beneath Beitstadfjorden.

Structure and development of the Vøring Plateau

An extensive study of aero-magnetic data between the Norwegian Coast and 15°W and from 60°N to 73°N has been completed by Avery et al. (1968). They found that a magnetic quiet zone covers a great part of the Norwegian continental margin, but his feature changes to linear magnetic anomalies on the seaward side of the Norwegian continental margin. This change is especially well marked on the Vøring Plateau.

The interpretation of the linear magnetic anomalies in terms of sea-floor spreading by Avery et al. (1968) indicates that the separation of Greenland and Norway started about 60–70 m.y. ago. Prior to this, Greenland and Norway were a part of the same crustal plate. According to Talwani & Eldholm (1972) the Vøring Plateau escarpment and the Faeroe–Shetland escarpment are remnants of the original rift zone between Norway and Greenland.

From geophysical studies of the Vøring Plateau, Johnson et al. (1968) pointed out that the magnetic anomalies over the outer edge of the plateau indicated a zone of volcanic activity, and that smooth anomalies over the crest of the plateau are characteristic of a thick sequence of overlying sedimentary rocks. Åm (1970) made a depth estimate to magnetic basement and found a marked change in the magnetic patterns on the western part of the Norwegian continental margin which corresponds to an abrupt shallowing of the magnetic basement. On basis of seismic data Hinz (1972) found that the abrupt change in the magnetic pattern on the Vøring Plateau corresponds to a fault which divides the Vøring Plateau into an eastern and a western part. Extensive seismic, magnetic and gravimetric studies by Talwani & Eldholm (1972) show that a prominent feature on the continental slope off Norway is an abrupt shallowing of the crystalline basement seawards along escarpments (Fig. 2 and 4).

On the basis of our crossings of the escarpments and Jan Mayen Fracture Zone we have noticed that the Vøring Plateau Escarpment is a well-defined contact between two contrasting lithologic units. Our measurements on the southern part of the Vøring Plateau and along Faeroe–Shetland Escarpment indicate, however, that a much more complicated and less distinct configuration of the contact-zone exists between oceanic and continental crust in this region. To some degree this can be demonstrated in Fig. 5, which show continuous seismic sections from A3 to A4 and from A4 to A5. Several 'escarpments' seem to exist indicating a rather complicated rifting of the crust combined

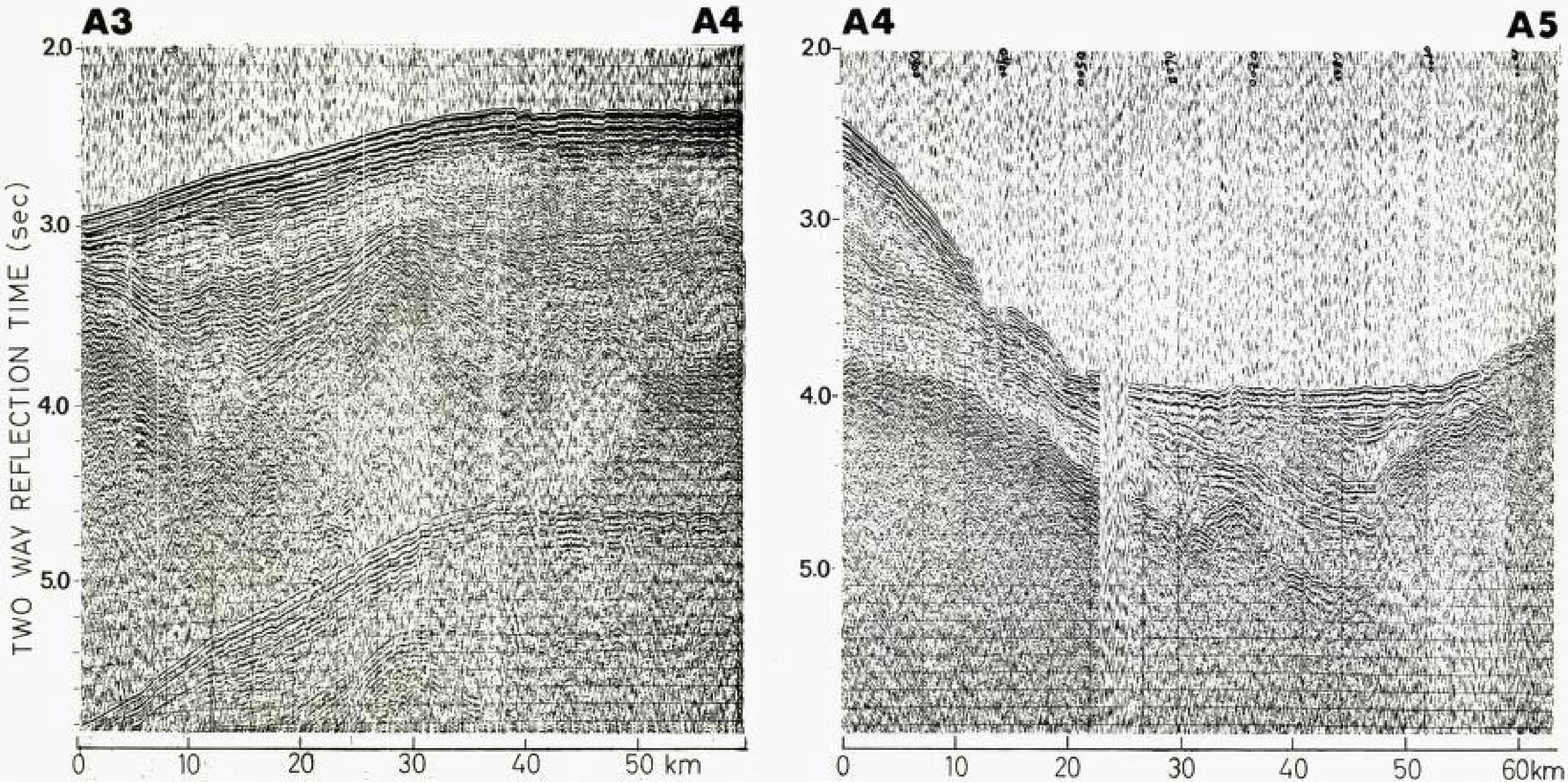


Fig. 5. Continuous seismic profiling between A3–A4 and A4–A5. (Profile locations shown in Fig. 1.)

with vertical block movements. Sediments have filled in between the blocks and as a consequence it is rather difficult to trace thicknesses of the sediments within the area between the Vøring Plateau Escarpment and the Faeroe–Shetland escarpment. The present study indicates that the Jan Mayen Fracture Zone may not be a single continuous fracture zone on the south-western side of the Vøring Plateau.

It is reasonable to assume that the initial opening of the Norwegian Sea started at the marginal escarpments, as proposed by Talwani & Eldholm (1972), but the configuration of these escarpments may vary considerably from one location to another according to the processes associated with the initial rifting and later spreading of the sea-floor.

Prior to the opening of the Norwegian Sea it is reasonable to assume that there was a very large sedimentary basin between Greenland and Norway, as suggested by Talwani & Eldholm (1972). This basin has probably developed in the same way as a normal basin with subsidence and sedimentation as the main processes. It is also reasonable to assume that the sedimentary basin between Greenland and Norway rested on a crust which could be classified as continental.

The opening of the Norwegian Sea was associated with intrusion of basaltic magma through the rifted crust and into the rifted sedimentary basin, and a new basaltic crust was created along rifts and the sea floor spreading processes separated Greenland from Norway during Tertiary time. Isostasy requires the newly formed oceanic crust and the continental crust to be in balance with each other, thus different crustal thicknesses across the transition zone between the oceanic and continental crust also require adjustments of the sea bottom elevation, resulting in development of the continental slope, rise and ocean floor.

The schematic model (Fig. 6) (Hinz 1972) presented to show the crustal structure beneath the Vøring Plateau and adjacent regions, indicates that the crustal and upper mantle processes may have been very complex in the transition zone between the continental and the oceanic crusts. The Moho is less than 20 km beneath the central part of the Vøring Plateau which is a crustal thickness intermediate between average oceanic and continental crustal thickness. Thus, Hinz (1972) has assumed that the Vøring Plateau to the east of the escarpment developed from a continental crust by subsidence and rising of mantle material beneath the Vøring Plateau as a result of the sea floor spreading.

That the outer part west of the escarpment on the Vøring Plateau also consists of a 'continental crust' overlain by basaltic lava cannot yet be completely ruled out. It is not unlikely that a 'contact' exists between the oceanic and continental crust in this area, and it is also reasonable to assume that the escarpments represent an important indication about where the contact is located; but there may exist several escarpments within the complex transition zone between the two crustal types and available data do not permit exact delineation of the contact.

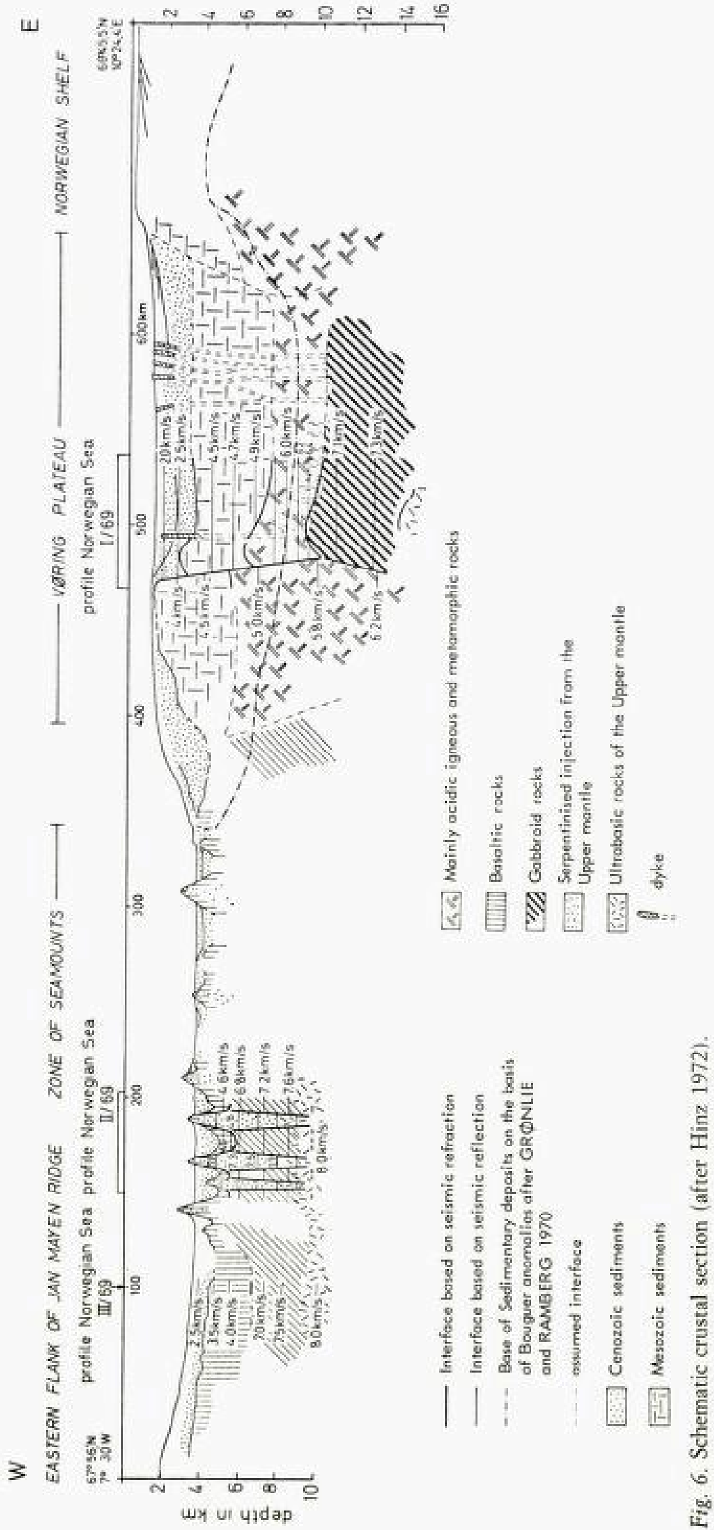


Fig. 6. Schematic crustal section (after Hinz 1972).

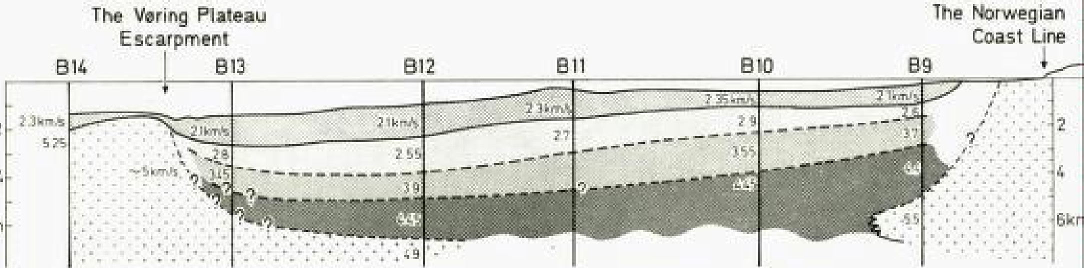


Fig. 7. Seismic structure section across the Norwegian continental margin. (Profile location shown in Fig. 1.)

A schematic cross-section of the sedimentary basin from the Norwegian coast to the western side of the Vøring Plateau is shown in Fig. 7. The assumed surface of the crystalline basement slopes rather steeply away from the mainland underneath the sedimentary rocks. Typical crystalline basement-velocities have not been observed at B10 and B11. This means that the deep crystalline basement is unusually deep along that part of the cross-section, as suggested previously on the basis of magnetic measurements (Åm 1970). Crystalline basements is observed a little deeper than 6.0 km below sea level at B12 on the eastern part of the Vøring Plateau (Fig. 7). The crystalline basement is not observed at B13 and little can be said about the structure of the deeper sedimentary layers in the vicinity of the escarpment (Fig. 7) on the basis of the available data.

According to the velocity-age relation (Fig. 3) Cenozoic, Mesozoic and Paleozoic rocks should exist along the profile from the Norwegian mainland to the escarpment on the Vøring Plateau. The cross-section (Fig. 7) indicates no major structural change at the shelf edge. Thus the present difference in the elevation of the shelf area and the Vøring Plateau area may be the results of differential subsidence along the shelf edge and continental slope.

TERTIARY SEDIMENTS

The calculated thicknesses of the Tertiary sediments compiled from seismic refraction and seismic continuous profiling data are shown on Fig. 8. These thicknesses include a layer of Quaternary sediments (from a few metres to 400 m, but normally less than 200 m), except along the contact between the Tertiary sediments and the Mesozoic rocks along the Norwegian coast. The Cenozoic sediments wedge out landwards, whereas they thicken rapidly seawards, especially in the southern part of the sedimentary basin, where they reach a maximum thickness of about 2.5 km at 64°N, 5°E. Farther west the thickness decreases at the marginal escarpments. On the shelf area between 66°N and 69°N the Tertiary sediments are rather thin or absent.

Correlations of the sonobuoy results obtained at B-9, B-10, B-11, B-12 and B-13 indicate a refractor with the respective velocities 2.6 km/s (B-9), 2.9 km/s (B-10), 2.7 km/s (B-11), 2.55 km/s (B-13). We consider this refractor to be the base of the Tertiary.

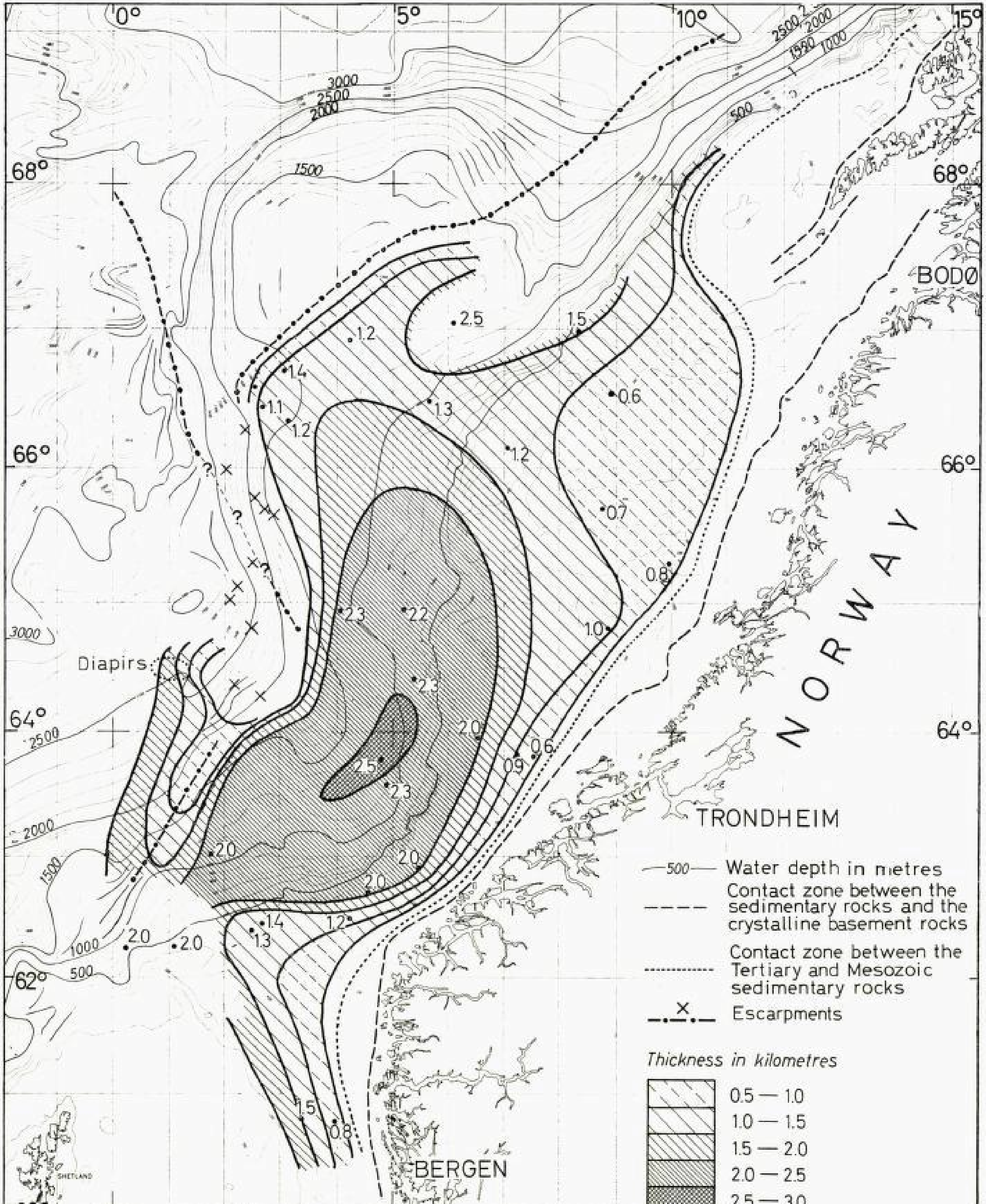


Fig. 8. Map showing thickness of the Tertiary sedimentary sequence (a thin Quaternary sequence is included), basement and Tertiary outcrops beneath the base of Pleistocene.

The sedimentary layer on the western part of the Vøring Plateau is relatively thin, suggesting that the escarpment has been an effective barrier to transportation of Cenozoic sediments. The area between the Vøring Plateau and the Færoe–Shetland Escarpment appears to be elevated in general, but the fracturing in this area reduced the effectiveness of the barrier and as a consequence of this a great amount of Cenozoic sediments have flowed over the 'barrier' into the ocean basin.

The northern part of the Færoe–Shetland Escarpment is rather easy to observe beneath a moderately thick sedimentary cover. Farther south the escarpment almost disappears beneath a constantly increasing sedimentary cover, and a great amount of Cenozoic sediments have flowed over the escarpment and accumulated on the western side of the Færoe–Shetland Escarpment. A large diapiric structure was observed within these sediments, as is shown on a continuous seismic section from A1 to A2 across the diapiric structure (Fig. 9). Unfortunately, the magnetometer broke down during profiling here, and as a consequence we have no observation of the magnetic field across the diapir. The seismic cross-section indicates, however, that the diapir has developed only within the sedimentary sequence.

The seismic refraction data obtained at profile 27–71 (see Figs. 2 and 8) on the Vøring Plateau indicate another Cenozoic depression, but the seismic data available from this region are too limited to permit a more detailed interpretation.

Several good reflectors have been observed within the Tertiary sequence. Some refractors can be correlated from one profile to another, but the profile spacing is in general too great to do so except for a few horizons, such as a deltaic structure which is well developed between Frøyabanken and Sklinnabanken. The seismic sections show that the deltaic sequence consists of smaller continuous deltas where the average transport direction has been from ESE to WNW. It has previously been assumed that the deltaic sequence marks the base of Tertiary, but seismic velocities indicate that the base of Tertiary reaches closer to the Norwegian coast-line than previously thought. This means that the deltaic structure is a younger sequence within the Tertiary succession than previously assumed.

PRE-TERTIARY SEDIMENTS

The thickness of the Mesozoic sedimentary sequence was compiled from seismic refraction and reflection data as shown in Fig. 10; one must keep in mind, however, the uncertainties of the velocity determination and velocity-age relationship.

It seems from Table 1 and Fig. 3 as if the main area of sedimentation during the Upper Mesozoic era is limited in the north-south direction by the parallels of 65°N and 67°N — in the east-west direction by 4°E and 10°E. The main area of sedimentation during the Lower Mesozoic era seems to have been between the parallels 61° and 66° in the north-south direction and on the western part of the continental margin between the Færoe–Shetland Escarpment and the Norwegian mainland. On both sides of the Lofoten Islands

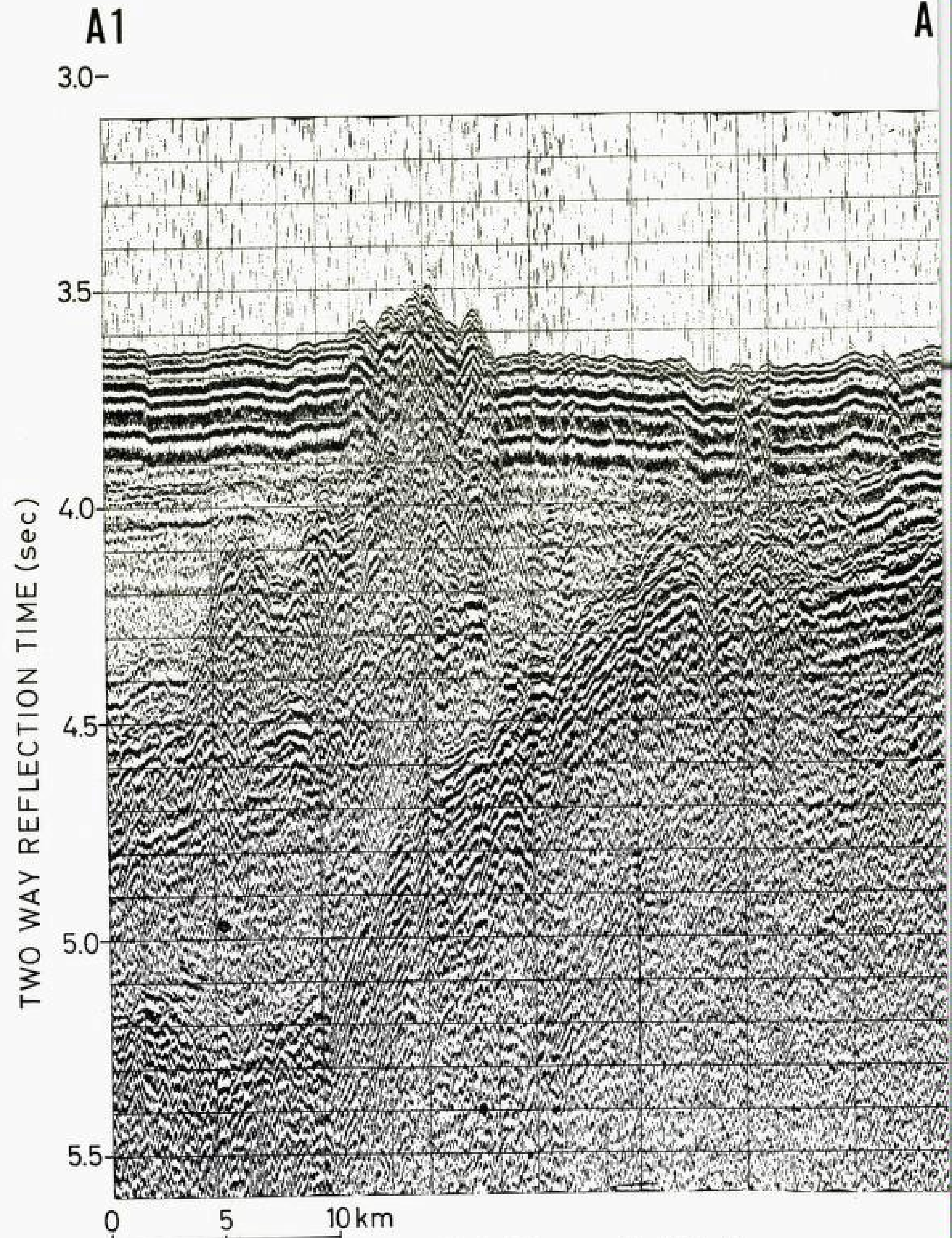


Fig. 9. Continuous seismic profile west of the Faeroe–Shetland Escarpment. (Profile location shown in Fig. 1.)

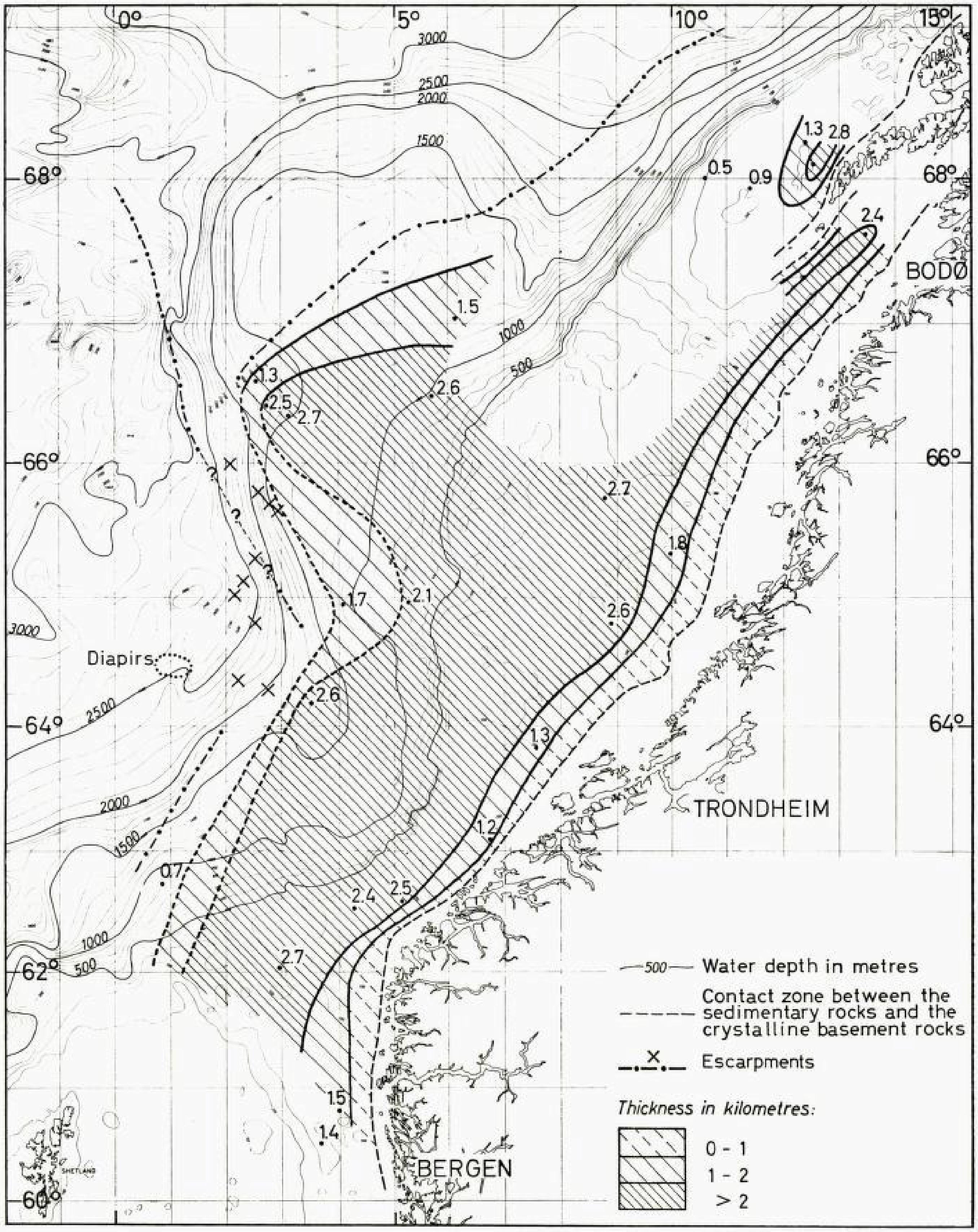


Fig. 10. Map showing thickness of Mesozoic sedimentary sequence.

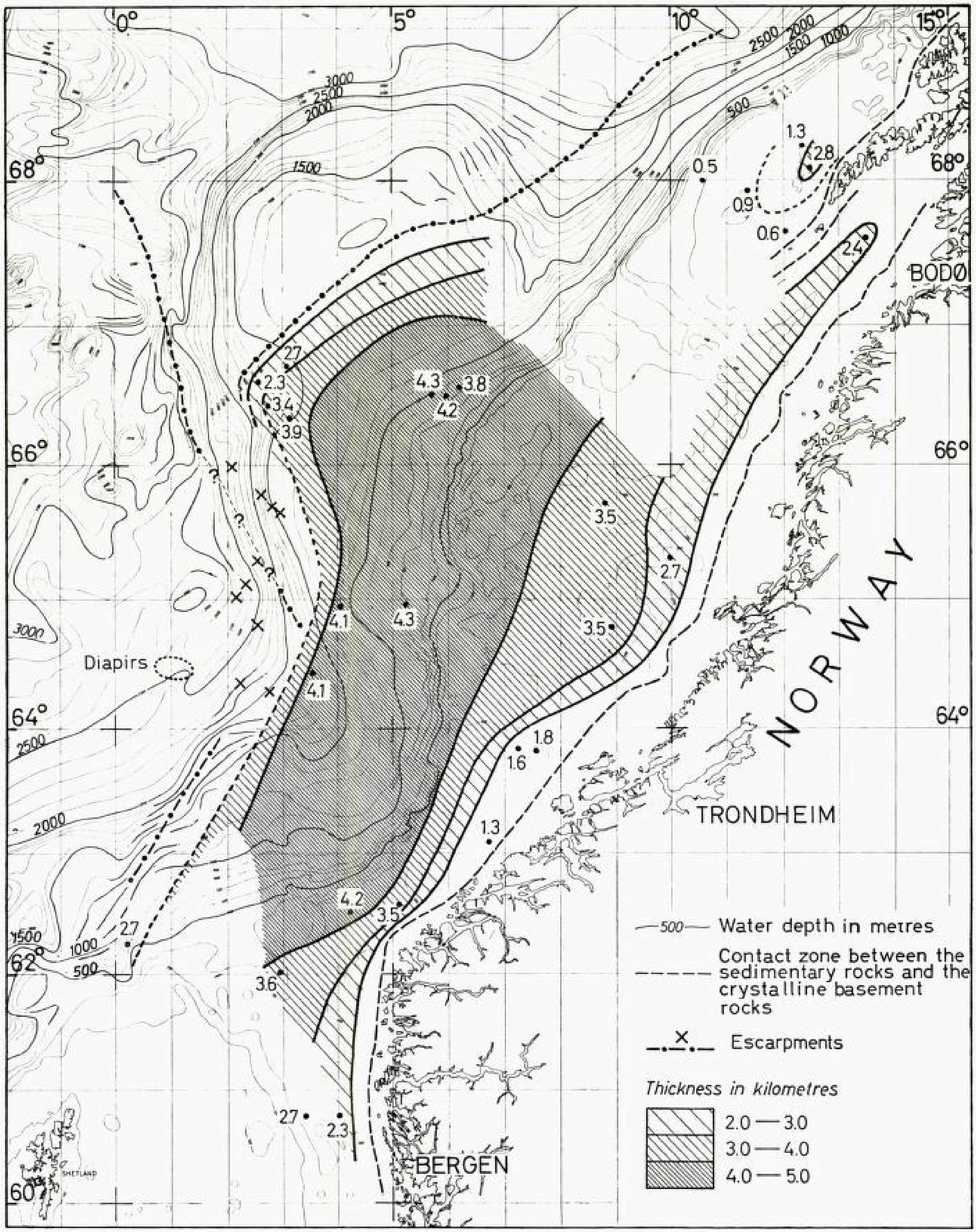


Fig. 11. Map showing total thickness of the Cenozoic and Mesozoic sequences.

smaller sedimentary basins are observed. As already mentioned, these two basins may once have been one single basin which has been divided into two basins by a horst which is now the Lofoten Islands.

The total thickness of the Cenozoic and Mesozoic sequences based upon the assumed relation between seismic velocity and geological age are shown in Fig. 11. This Figure shows an elongated sedimentary basin on the continental margin bounded to the east by the crystalline rocks along the Norwegian coast and to the west by the escarpments and the Jan Mayen Fracture Zone. The maximum thickness of the Cenozoic and Mesozoic sequences which has been observed is approximately 4.3 km, and a great area is covered by a sequence of more than 4 km in thickness.

Comments and remarks

Our seismic profiling has shown a well marked escarpment on the Vøring Plateau which coincides with the escarpment found by Talwani & Eldholm (1972) at all locations where we have crossed this escarpment. The Færoe-Shetland Escarpment has not been observed in all our crossings. Figs. 4, 8 and 11 show where we have observed the Færoe–Shetland Escarpments in the seismic sections.

The region between the southern end of the Vøring Plateau Escarpment seems to be strongly fractured and faulted, and we are not able to follow a single fracture zone along the southern part of the Vøring Plateau. More investigations are needed in this region to document and explain the complicated structure here.

There are many arguments that the crust west of Vøring Plateau Escarpment is oceanic. These arguments are supported by the basement velocity observed at shallow depth and by the typical, oceanic, magnetic features over the outer part of the Vøring Plateau. On the other hand it seems rather unlikely that an oceanic and continental crust should balance so well isostatically on the Vøring Plateau without any elevation difference on either side of the escarpment. The contrasting character of the magnetic and seismic velocities on both halves of the Vøring Plateau may be explained if we assume the western half to be covered by layers of flow basalt. This must be carefully investigated before the final conclusion can be drawn concerning the crustal structure beneath the Vøring Plateau. One more fact that should be taken into account is that the results obtained from seismic, magnetic and gravimetric measurements made by Bundesanstalt für Bodenforschung, Hannover, and the Seismological Observatory, Bergen University, Bergen, indicated that the western part of the Vøring Plateau is also underlain by continental crust (Hinz 1972).

The author fully realizes the limitation of determining the velocity-depth function by using the sonobuoy method as well as the limitation of the velocity-age correlation, but he considers that the seismic data used and the interpretation of these data reflect the main Cenozoic and Mesozoic structural trends on the continental margin off Norway.

The different isopach maps of the continental margin in the present paper show that subsidence and sedimentation have shifted from one part of the continental margin to another during the Cenozoic and Mesozoic time period.

The Pleistocene uplift of Fennoscandia is well 'recorded' by the dips (Fig. 4) which generally decrease from the mainland across the continental margin. Torske (1972) has discussed the relation between the uplift of Fennoscandia and the opening and spreading of the Norwegian Sea. His conclusion was that these two events were associated with each other. Talwani & Eldholm (1972) are also of the same opinion. It seems in general as if the dips are greatest in the two shelf areas between 62°N–64°N and 68°N–69°N (see Fig. 4). This should indicate a greater uplift in these two areas in relation to the shelf area in between. It is interesting to notice that these two areas are the most narrow shelf areas on the continental margin off Norway. It may be suggested that the Tertiary uplift may to some extent have caused the narrowing of these shelf areas by sliding, erosion and transportation of material from the outer part of the shelf. This may especially have been the case in the Storegga region where a great transportation of sedimentary 'material' has been observed downslope from the shelf edge (Sellevoll 1974). It is reasonable to assume that the shelf edge was previously located west of the Storegga region where it is located today, and that the uplift caused great mass-transport of sedimentary deposits downslope from the Storegga region. Thus the width of the shelf between the mainland and the Storegga region has been greatly reduced in the past and continues to be so reduced at present.

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