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PRELIMINARY REPORT OF GEOLOGICAL AND GEOPHYSICAL SURVEYS OFF AMERY ICE SHELF, EAST ANTARCTICA

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Abstract: Geological and geophysical surveys off the Amery Ice Shelf, East Antarctica, were carried out during the 1984–1985 Antarctic summer season. The surveyed area involves the continental shelf, slope, rise, the abyssal plain and part of the Kerguelen Plateau.

Thickness of the sedimentary layer beneath the continental shelf is estimated to be more than 3.5 km from a sonobuoy result. A series of upper strata progrades seaward and is eroded at the sea bottom.

In the continental slope, rise and the abyssal plain, the presence of sediments whose thickness exceeds 6 km is confirmed. The sediments seem to become thicker toward the continent, particularly the center of Prydz Bay to which the Lambert graben is thought to extend from the inland of Antarctica.

In the southwestern margin of the Kerguelen Plateau, the acoustic basement rises toward the Plateau, and is thinly covered by an acoustic transparent layer whose age is relatively old. Dipping strata suggest that the acoustic basement consists of highly consolidated sedimentary layers which have been subjected to a complex tectonic movement related to the origin of the Plateau.

1. Introduction

Since 1980, we have been conducting marine geological and geophysical surveys of the Antarctic Ocean in order to reveal general features of the Antarctic continental margin. The results of the previous cruises have already been published (KIMURA, 1982; OKUDA *et al.*, 1983; SATO *et al.*, 1984; TSUMURAYA *et al.*, 1985).

Between December 1984 and February 1985, the TH-84 cruise employed the R. V. HAKUREI-MARU in the offing of the Amery Ice Shelf including part of the Kerguelen Plateau (Fig. 1).

The Lambert Glacier, which is the largest outlet ice stream in Antarctica, flows into the surveyed area through the Amery Ice Shelf. A major graben extends for almost 700 km beneath the Lambert Glacier and the Amery Ice Shelf. The basement depression in the graben is 5 km or more deep (FEDOROV *et al.*, 1982).

Prydz Bay, the continental shelf part off the Amery Ice Shelf, was surveyed geophysically by the Australian Bureau of Mineral Resources (BMR) (STAGG *et al.*, 1983; STAGG, 1985). Their result indicates the presence of a sedimentary basin with the sediment thickness of more than 5 km.

The region from the continental slope to the abyssal plain (Cooperation Sea), where few surveys have been carried out, is typically interpreted as an Atlantic-type continental

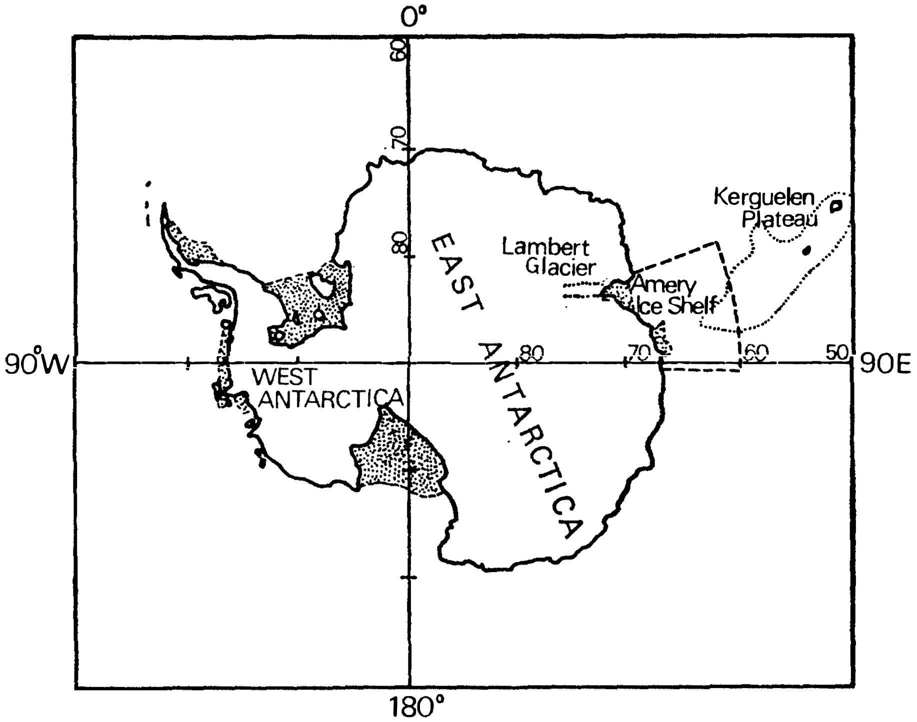

Fig. 1. Location of the survey area.

margin formed by the splitting of the Gondowanaland. This implies that there must be a thick sedimentary basin in the boundary area between the oceanic crust and the continental crust.

The Kerguelen Plateau is an extensive plateau situated between Antarctica and the Southeast Indian Ridge. This area was surveyed geophysically and geologically in the cruise of USNS ELTANIN (HOUTZ *et al.*, 1977). The TH-84 cruise was carried out between the surveyed areas of BMR and ELTANIN.

This paper reports the preliminary results of the TH-84 cruise and briefly describes the general feature of the sedimentary basin off the Amery Ice Shelf.

2. Outlines of Surveys

The TH-84 cruise involves multichannel seismic reflection survey, sonobuoy seismic

Table 1. Summary of the TH-84 cruise.

	Total
Survey period	30 days
Seismic reflection survey	2350 km
Sonobuoy refraction survey	10 sites
Magnetic and gravity survey	17140 km
Heat flow measurements	8 sites
Piston coring	7 sites
Gravity coring	5 sites
Smith-McIntyre grab	1 site
Dredging	2 sites

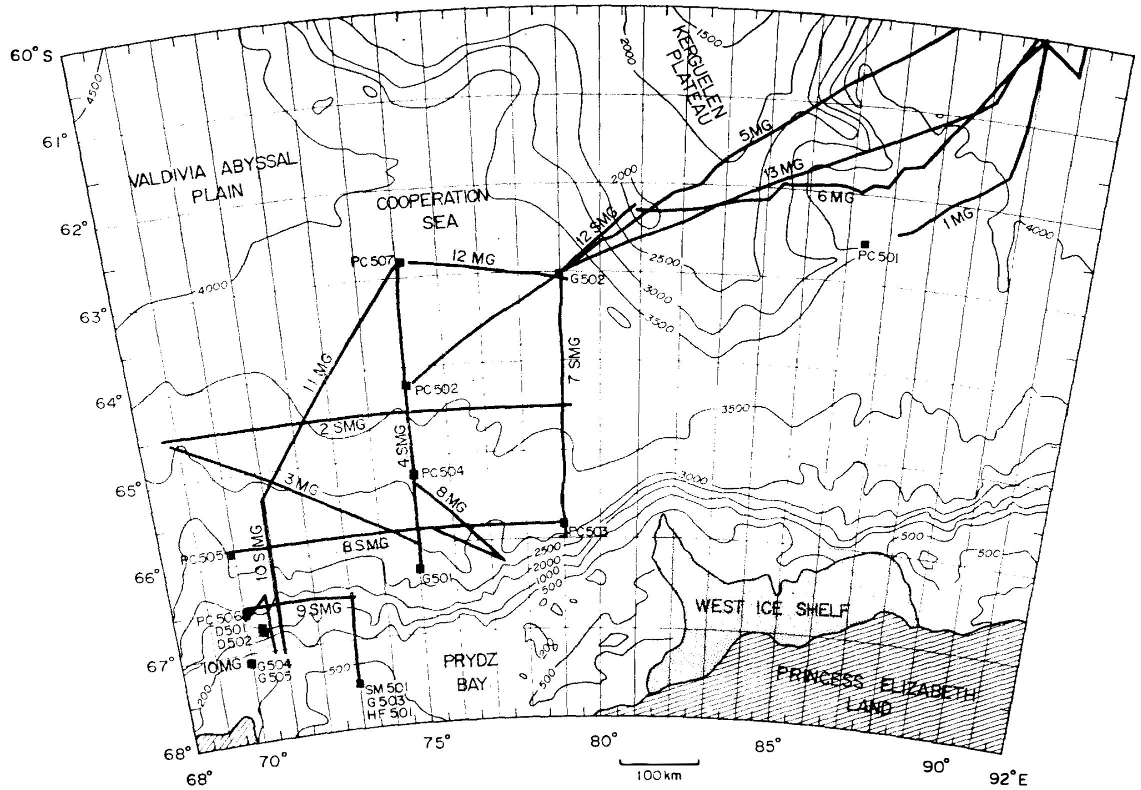

Fig. 2. Lines of geophysical survey and sampling stations off the Amery Ice Shelf. SMG: seismic, magnetic, gravity; MG: magnetic, gravity; PC: piston core; G: gravity core; D: dredge; SM: Smith-McIntyre grab; HF: heat flow.

refraction survey, gravity survey, magnetic survey, heat flow measurements and bottom samplings (Table 1).

Lines of the geophysical surveys and stations of the bottom samplings are shown in Fig. 2. The survey instruments and methods are briefly summarized in Table 2.

3. Results of the Surveys

3.1. Gravity and magnetic anomaly

Free-air gravity anomalies and magnetic anomalies in the surveyed area are shown in Figs. 3 and 4.

Free-air gravity anomalies have a positive bias which may be attributed to a regional sub-crustal structure of the area. At the continental shelf edge, a large positive anomaly, being more than 70 mgal, can be seen. Small amplitude, long-wavelength anomalies characterize the continental rise and the abyssal plain (Cooperation Sea), and they have a tendency to decrease in value toward the Antarctic continent.

There is a remarkable negative anomaly near the continental shelf edge of the eastern part of Prydz Bay. It may be considered a negative one of typical paired anomalies, which are attributed to the edge effect caused by the abrupt change of water depth and crustal thickness.

Magnetic anomalies in the southern part of the Cooperation Sea are relatively

Table 2. Summary of survey instruments.

Survey name	Instrument	Remarks
Multichannel seismic reflection	Source: H400 water gun (400 cu. in.)×2 Receiver: SEC ministreamer cable (24 ch×25 m) Recorder: TI DFSV	Record length 5 s Sampling rate 4 ms Shot interval 50 m CDP coverage 600%
Seismic refraction (Sonobuoy)	Source: H400 water gun (400 cu. in.)×2 Receiver: OKI OC-1 Sono-radio-buoy: OKI SZ 1038 Sonobuoy receiver	Refraction method Wide-angle reflection method
Gravity	Lacost & Romberg S-79 Sea-air gravimeter	Normal gravity: IGSN71
Magnetic	Geometrics G-866 proton magnetometer	Reference field: IGRF1980
Navigation	Magnavox MITI-1 Integrated satellite navigation system	Geodetic datum: WGS-72
Bottom sampling	Piston corer Gravity corer Cylinder dredger Smith-McIntyre grab	
Heat flow	Nippon Oil & Futs GH80 Nichiyu Giken NTS-5DR	

small, although short wavelength anomalies which have sources in the earth's exterior are found. They increase in amplitude along the lines from the Cooperation Sea to the Kerguelen Plateau, and seem to have a trend paralell to it. On the Plateau, there are large amplitude anomalies related to the complex geological structure and bathymetry.

3.2. Seismic reflection survey

A shot point map of the 6-fold seismic reflection survey is given in Fig. 5, including the sites of sonobuoy seismic refraction survey. The survey lines are mainly in the Cooperation Sea except lines 9 SMG, 10 SMG and 12 SMG. Lines 9 SMG and 10 SMG partly cover the continental shelf. Line 12 SMG runs from SW to NE over the southwestern margin of the Kerguelen plateau.

Some interpreted geologic sections are given in Figs. 6–8. Six horizons are defined as remarkable seismic sequence boundaries. Since there is no geological information by which the age is determined in the surveyed area, geologic time of each horizon cannot be specified.

STAGG (1985) defined five seismic sequences, PD1–PD5, over the continental slope and rise, and speculated the age of them. Our horizon B is correlated with the boundary between PD1 (Pliocene and younger) and PD2 (early Cretaceous–Quaternary), and

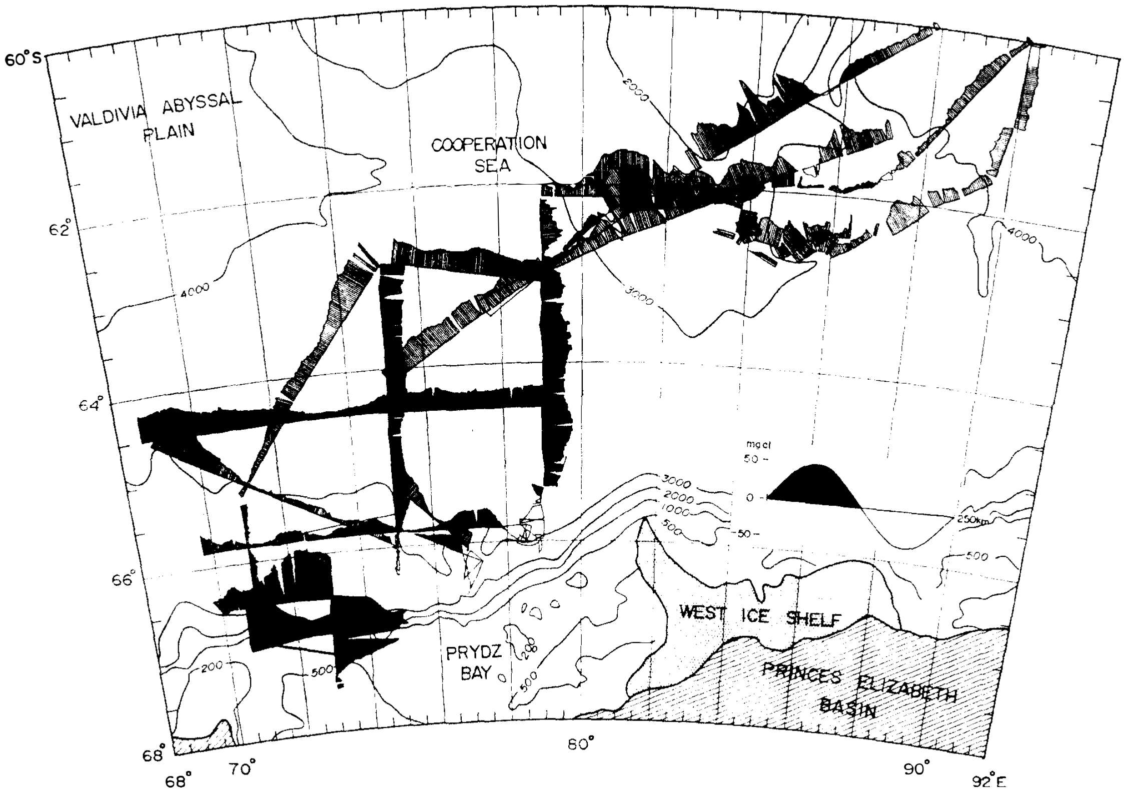

Fig 3. Free-air gravity anomaly profiles along the vessel tracks. Reference field: IGSN71.

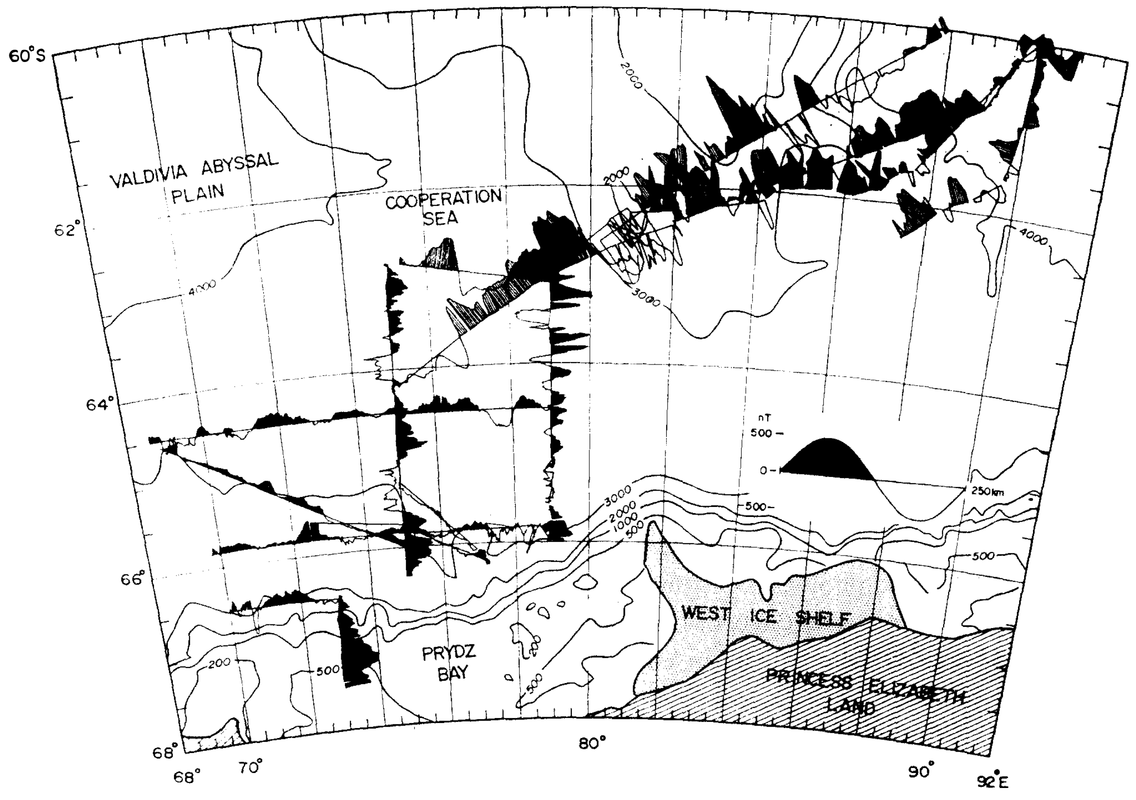

Fig. 4. Magnetic anomaly profiles along the vessel tracks. Reference field: IGRF1980.

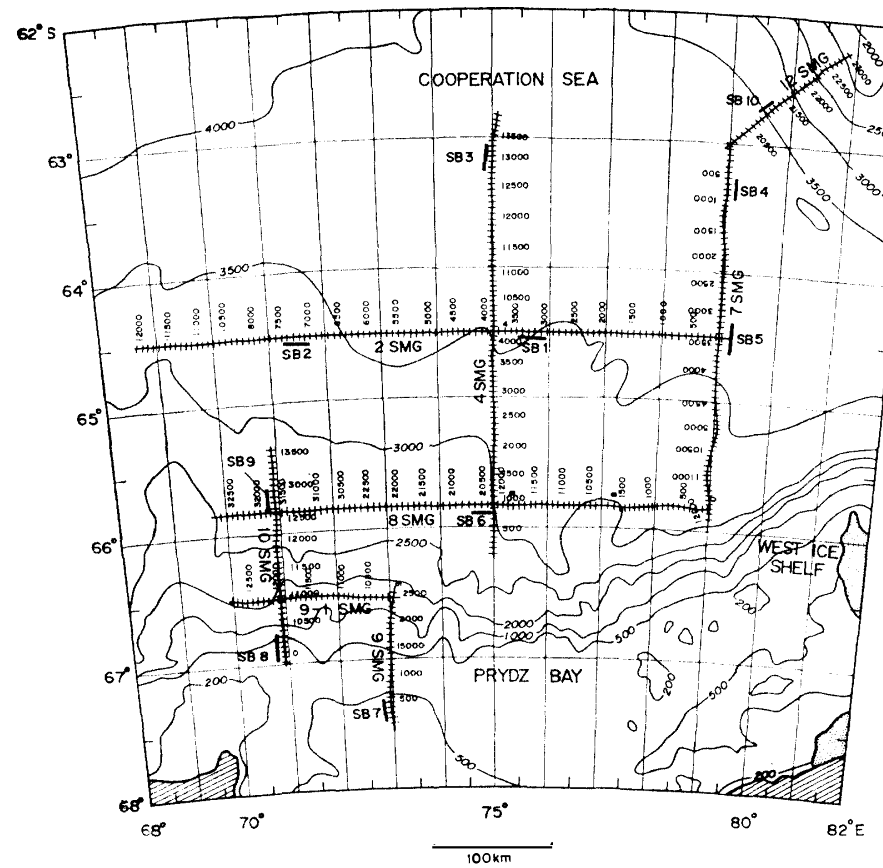

Fig. 5. Lines of seismic reflection survey and sites of sonobuoy seismic refraction survey off the Amery Ice Shelf. SB: Sonobuoy.

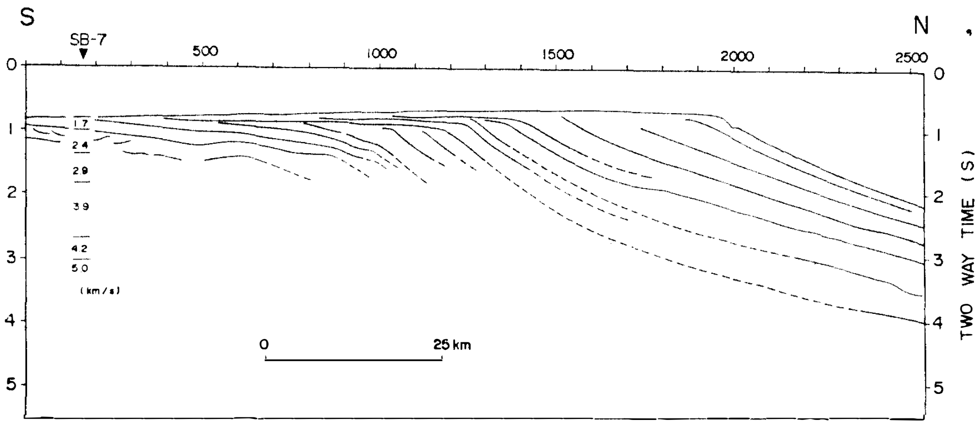

Fig. 6. Interpreted section of line 9 SMG.

our horizon D is almost equal to the top of PD5 (pre-Triassic?). It should be noted, however, that the ages mentioned above are very speculative.

Figure 6 shows line 9 SMG which covers part of the continental shelf and slope. Extremely strong sea bottom multiple reflections prevent clarifying the deep structure. A series of sedimentary strata prograding seaward can be seen in shallow layers, and

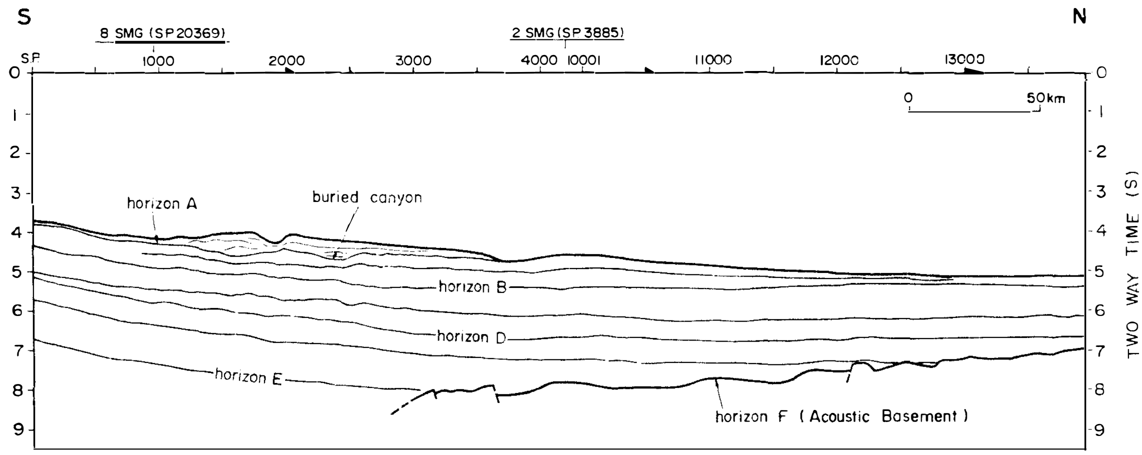

Fig. 7. Interpreted section of line 4 SMG.

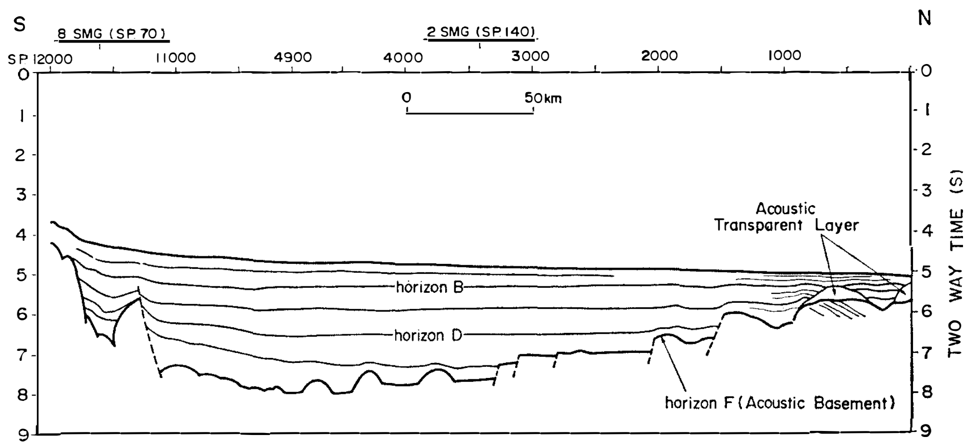

Fig. 8. Interpreted section of line 7 SMG.

they are locally eroded at the sea bottom. The erosion is thought to be caused by the advances of the Amery Ice Shelf. Such a sedimentary pattern is also recognized by STAGG (1985).

Line 4 SMG shown in Fig. 7 indicates that the acoustic basement gradually descends and the overlying sediments become thicker toward the Antarctic continent. This is consistent with the free-air gravity anomalies. With increasing depth, reflections from the acoustic basement become indistinct due to the limitation of the penetration of seismic waves. It is impossible to recogneize them in the south of S.P. 3000. In the shallow sequences, complex sedimentary patterns which may be influenced by turbidity currents and sea bottom currents are observed. A sequence above horizon A seems to be the latest turbidity fan.

Figure 8 shows line 7 SMG. The acoustic basement steeply rises toward the continent at the south end of the line. Toward the north, it gradually rises with some normal faults. This corresponds to the magnetic anomalies which increase in amplitude toward the Kerguelen Plateau.

At the north end of the line, a mound-like reflection-free seismic sequence unit

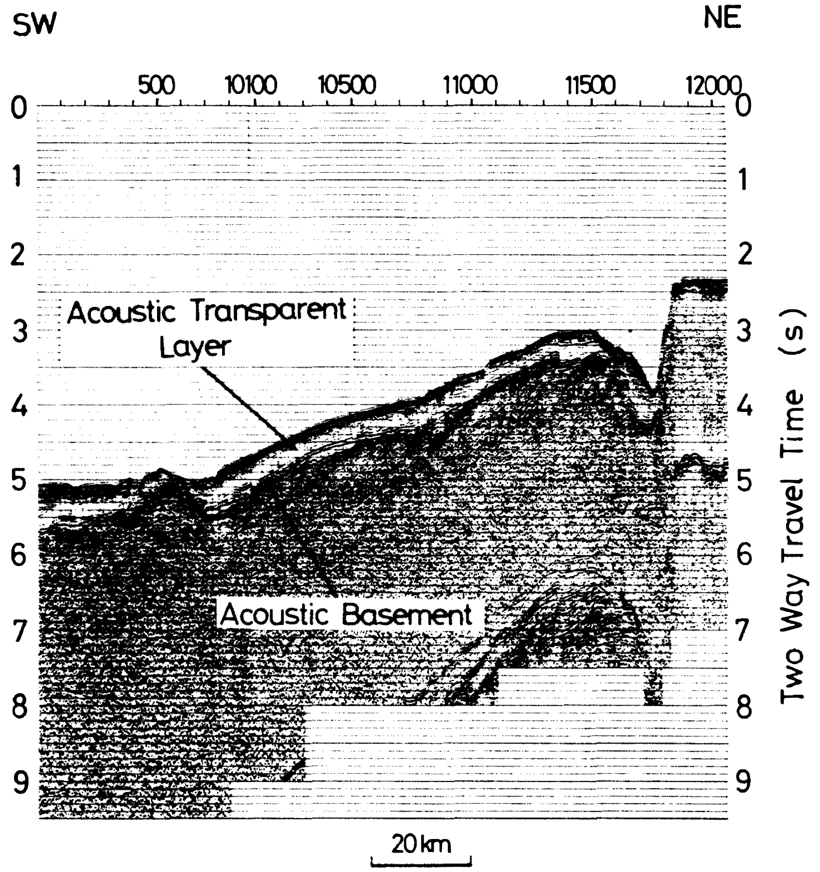

Fig. 9. Seismic profile of line 12 SMG. Dipping reflections are identified in the acoustic basement between S.P. 10500 and S.P. 11500.

exists on the acoustic basement, and is buried under well-stratified sequenses. This sequence is corresponding to the transparent layer which develops over the southwestern margin of the Kerguelen Plateau.

The seismic profile of line 12 SMG shown in Fig. 9 has some interesting geologic features. The transparent layer mentioned above thinly covers the acoustic basement. Dipping reflections, representing the stratification, are locally recognized in the acoustic basement, and the top of it shows an erosional unconformity. The unconformity may be correlated with the reflection B of HOUTZ *et al.* (1977) which is thought to be a peneplane formed in the Eocene period.

The precise interpretation of the profiles will provide the key to revealing the origin of the Kerguelen Plateau.

3.3. Sonobuoy seismic refraction survey

Sonobuoy seismic refraction survey was carried out at 10 sites on lines of seismic reflection survey, as shown in Fig. 5. The obtained data, except SB-4 which is of poor quality, were analyzed by means of the wide-angle reflection method as well as the conventional refraction method. Depth-velocity profiles derived from the sonobuoy analysis are illustrated in Fig. 10.

Two sonobuoys (SB-7 and SB-8) are located on the continental shelf. SB-7

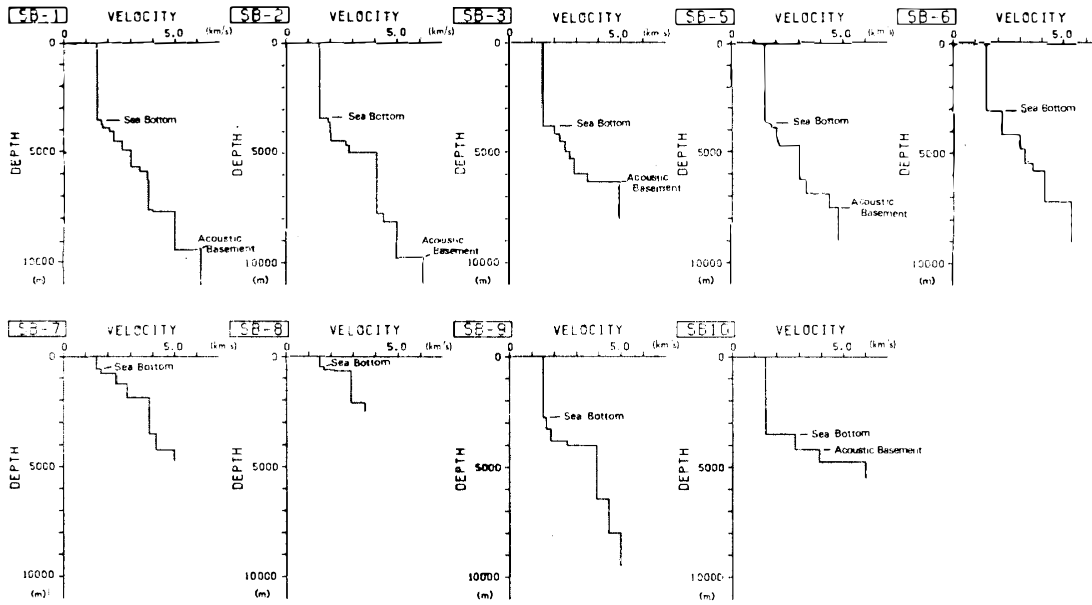

Fig. 10. Velocity-depth profiles derived from sonobuoy survey.

indicates that a 5.0 km/s layer exists at the depth of about 3.5 km from the sea bottom. Because the average velocity of the Antarctic continental basement is about 6.0 km/s according to the Soviet deep seismic soundings (KURININ and GRIKUROV, 1982), this layer may be a consolidated sedimentary layer, and the crystalline basement may exist beneath it.

Six sonobuoys (SBI-1–3, SB-5, SB-6, SB-9) were deployed over the Cooperation Sea. The acoustic basement at the north end of line 4 SMG (SB-3) has the velocity of 5.0 km/s, which is typical of layer 2 of the oceanic crust. The thickness of sediments is 5.8 km at SB-1 and 6.3 km at SB-2.

SB-10 on line 12 SMG shows that the transparent layer has a thickness of 0.7 km and an average velocity of 2.8 km/s, which is high for shallow sedimentary layers. In addition to the high velocity, the fact that well-stratified sequences abut on it at the southwest end of line 12 SMG (see Fig. 9) suggests that the transparent layer may consist of relatively old pelagic sediments. The acoustic basement with a velocity of 3.9 km/s, overlies a 6.0 km/s layer, which might be the crystalline basement.

3.4. Bottom samplings

Samplings of unconsolidated sediments by the piston corer, the gravity corer and the Smith-McIntyre grab were carried out at 13 stations. The dredger was used at relatively steep slopes.

The results of bottom samplings are summarized in Table 3. Most of the unconsolidated sediments are composed of diatomaceous ooze and siliceous clay. The dredged rocks are subrounded pebbles of igneous rocks, metamorphic rocks and sedimentary rocks. All these pebbles are judged not to be autocthonous.

Assemblages of diatom fossills in six cored samples PC501 to PC506 are divided into *Nitzschia kerguelensis* Zone (0–0.195 Ma), *Hemidiscus karsxtenii* Zone (0.195-

Table 3. Summary of bottom samples of sediments and rocks.

Station No.	Date (GMT)	Lat. (S)	Long. (E)	Depth (m)	Description	Fossils	Recovery (m/m)
ST-1 PC501	354 06 05	62°32.23′	86°27.17′	3729	Pelagic clay	rare Diatom	7.73/8
ST-3 PC502	364 01 18	64 12.62	75 01.12	3538	Silic. clay	common Diatom	3.61/4
ST-5 PC503	023 01 32	65 50.29	78 59.59	3119	Silic. ooze-silic. clay	abundant Diatom	3.51/4
ST-6 PC504	025 04 20	65 12.37	75 01.52	3098	Pelagic clay	common Diatom	6.99/8
ST-7 PC505	028 02 40	65 51.76	69 52.55	2481	Silic. ooze-pelagic clay	common Diatom	6.95/8
ST-12 PC506	033 01 28	66 33.86	70 02.58	1921	Sand-silic. ooze-pelagic clay	common Diatom	3.54/4
ST-13 PC507	035 06 14	64 49.01	75 07.38	3805	Silic. ooze-calcareous clay	common Diatom/ Foraminifera	7.75/8
ST-2 G501	360 08 57	66 16.65	74 58.81	2697	Pelagic clay	common Diatom	1.43/2
ST-4 G502	020 01 15	62 5.392	79 04.93	3771	Fine sand-silic. ooze	abundant Diatom	0/3
ST-8A G503	029 07 10	67 30.06	72 59.95	590	Silic. ooze-firm pelagic clay	abundant Diatom	0.96/2
ST-9 G504	031 06 08	67 06.27	69 57.94	316	Silic. silt-sand	common Diatom	0/2
ST-9A G505	031 07 11	67 06.17	69 57.06	310	Fine sand	rare fossil	0/2
ST-10 D501	032 02 49	66 43.69	70 25.10	1632	Igne. R.-65%; Sedi. R.-10%;		
		66 43.76	70 25.00	1590	Meta. R.-25%		
ST-11 D502	032 05 59	66 46.99	70 27.88	1228	Igne. R.-44%; Sedi. R.-10%;		
		66 47.31	70 27.56	1147	Meta. R.-45%		
ST-8 SM501	029 03 37	67 29.66	72 59.14	589	Clay		

PC: Piston core; G: Gravity core; D: Dredge; SM: Smith-McIntyre grab.

0.35 Ma) and *Rouxia isopolica* Zone (0.35–0.66 Ma). Assemblage of PC507 is characterized by *Actinocyclus ingens* Zone (0.66–1.67 Ma) in addition to the above three zones. Dominant diatom species of all cored samples except G503 are *Nitzchia kerguelensis*, *Eucampia balaustium* and *Thalassiosira lentiginosa*. Assemblage of G503 core is characterized by *Nitzchia curta* and *Thalassiosia antarctica*, indicating an influence of icebergs or freezing. All of these diatomaceous zonations are based on AKIBA (1982).

Natural remanent magnetization was measured for five pistoncored samples. Average sedimentation rate derived from the data is estimated to be 6 mm/1000 year from 0.87 Ma to the present, and presumably 16 mm/1000 year during 0.97–0.87 Ma.

5.3. Terrestrial heat-flow measurements

Terrestrial heat-flow was measured at a station on the continental shelf by a probe type apparatus and at seven stations in other areas by a corer-installed type. The results are shown in Fig. 11.

On the shelf, a high heat-flow value of 91.4 mW/m^2 was recorded, which is about 1.5 times of the world average (60 mW/m^2). It is probably an apparent value caused by the truncation of surface sediments.

The average heat-flow value measured over the Cooperation Sea is approximately

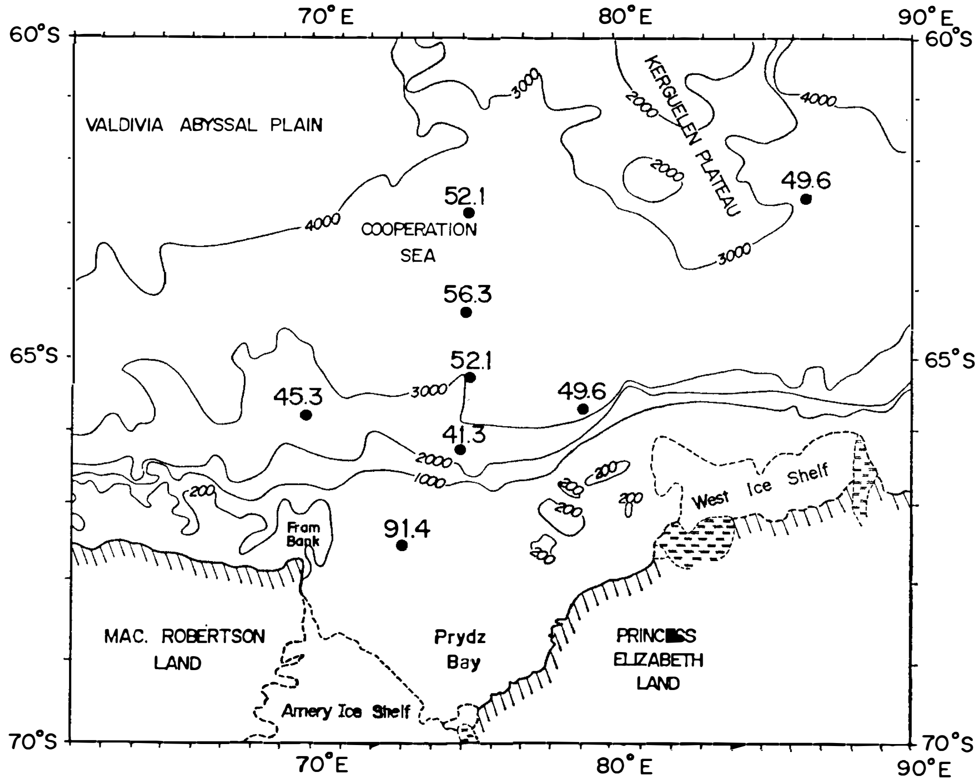

Fig. 11. Terrestrial heat flow distribution off the Amery Ice Shelf (unit; mW/m²).

50 mW/m² which is a little lower than the world average. It is nearly equal to the average value of the other continental rises off Antarctica.

4. General Feature of the Sedimentary Basin

A schematic acoustic basement map and a schematic isochron map of total sediments are given in Figs. 12 and 13. Strong multiple reflections make it impossible to clarify the depth of acoustic basement beneath the continental shelf and slope.

In the northeastern part of the surveyed area, the acoustic basement rises and the overlying sediments become thinner toward the Kerguelen Plateau. Contour lines, if they are drawn in both maps, must be nearly parallel to the trend of the Plateau, which is coincident with that of the geomagnetic anomalies.

A steep rise of the acoustic basement can be seen at the southeastern end of the surveyed area. Its position is corresponding to that of the negative free-air gravity anomaly attributed to the edge effect mostly caused by the changing crustal thickness. This implies that the ocean-continent boundary might exist there, and the rising basement would be the Antarctic continental basement which consists of Pre-Cambrian metamorphic rocks. A large fault at S.P. 11200 in line 7 SMG probably represents the boundary.

In the central and western parts, the acoustic basement, which is thought to be the basaltic layer of oceanic crust, descends toward the south, and no abrupt rise of the basement can be seen. No negative anomaly is identified under the continental

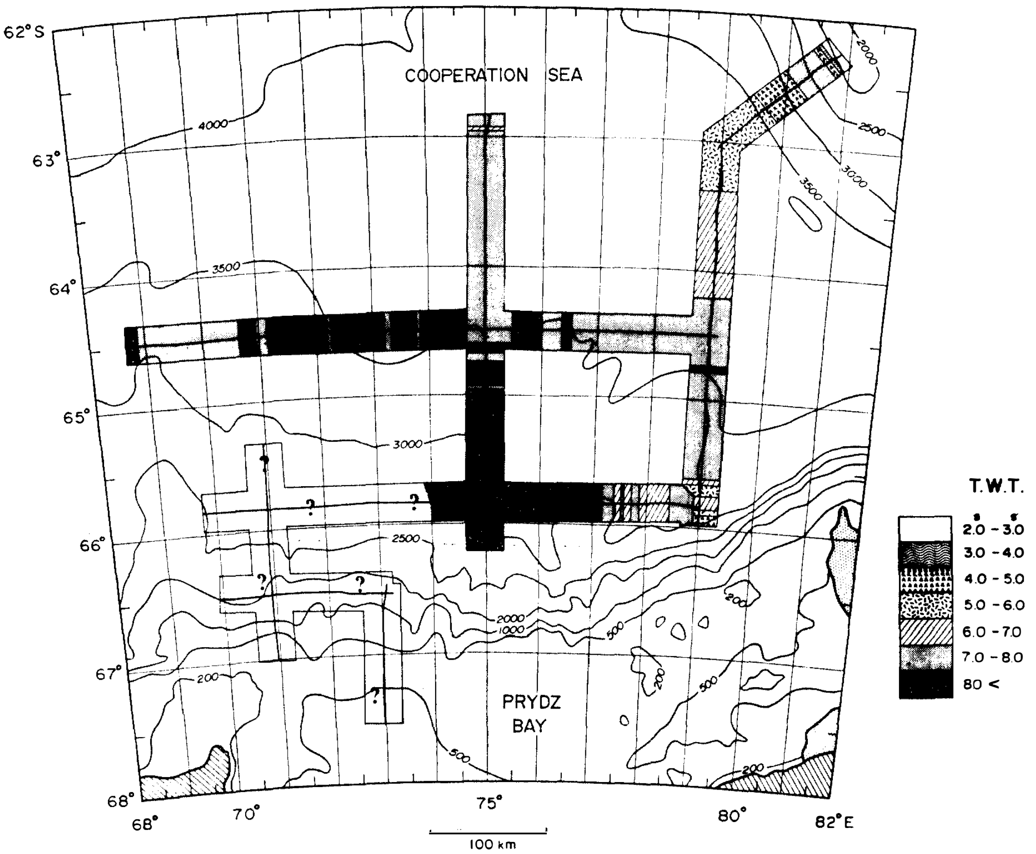

Fig. 12. Schematic acoustic basement map of two-way travel time (s) off the Amery Ice Shelf. The acoustic basement cannot be identified in the continental shelf and slope because of sea bottom multiple reflections.

slope where it is expected to appear clearly as one of typical paired anomalies caused by the edge effect, implying that the continent-ocean boundary may exist in the inner part of the continental shelf. The thickness of sediments in the center of the Cooperation Sea is approximately 6 km, and they seem to become thicker toward the center of Prydz Bay, where the Lambert graben extends.

6. Summary

Preliminary results of the TH-84 survey off the Amery Ice Shelf, East Antarctica, which was carried out during December 1984–February 1985 by employing R.V. HAKUREI-MARU, are summarized as follows:

(1) On the continental shelf, an upper series of seismic sequences progrades seaward and is eroded at the sea bottom. Sonobuoy seismic refraction survey suggests that the crystalline basement exists at the depth of more than 3.5 km from the sea bottom.

(2) In the continental rise and the abyssal plain, at least 6 km thick sediments exist, and they seem to become thicker toward the continent, especially toward the center of Prydz Bay.

(3) In the southwestern margin of the Kerguelen Plateau, the acoustic basement rises toward the Plateau with some normal faults, and is thinly covered by an acoustic

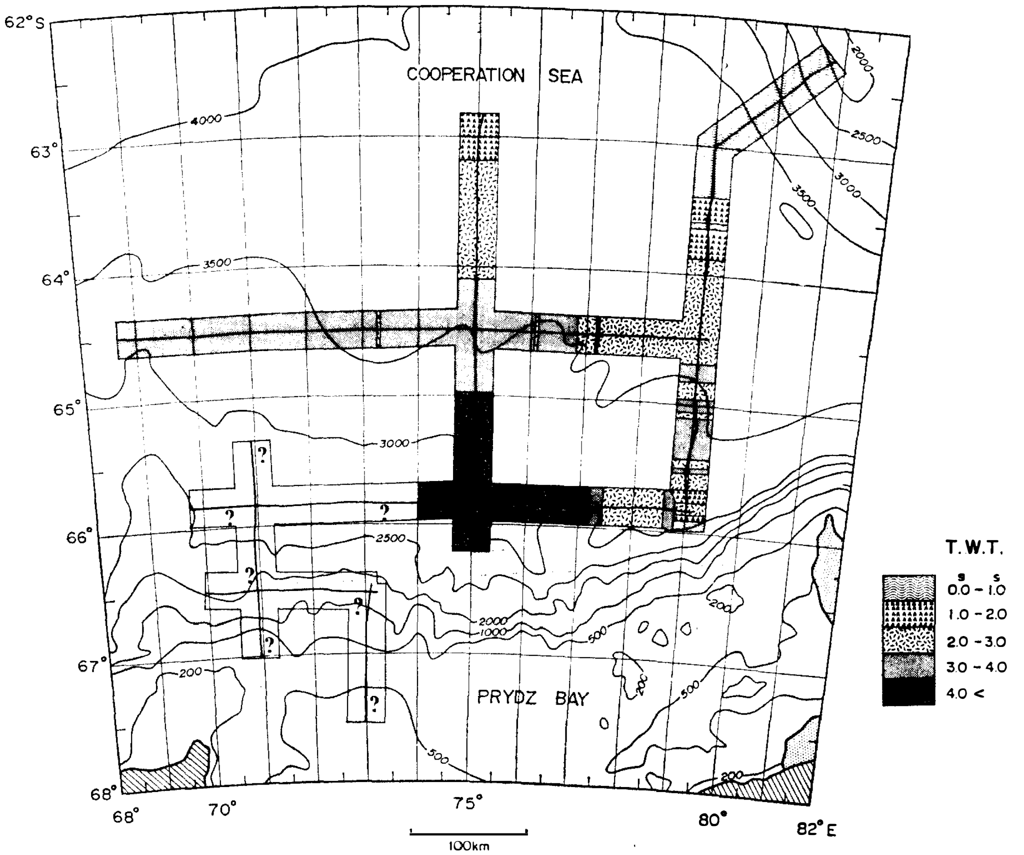

Fig. 13. Schematic isochron map of total sediments in seconds off Amery Ice Shelf.

transparent layer which may consist of relatively old pelagic sediments. The acoustic basement in which the stratification is identified consists of highly consolidated sedimentary layers, having been subjected to a complex tectonic movement which is presumably related to the origin of the Kerguelen Plateau.

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References

AKIBA, F. (1982): Late Quaternary diatom biostratigraphy of the Bellingshausen Sea, Antarctic Ocean. Sekiyu Kôdan Sekiyu Kaihatsu Gijutsu Sentâ Kenkyû Hôkoku (Rep. Tech. Res. Center), **16**, 31–74.

FEDOROV, L. V., GRIKUROV, G. E., KURININ, R. G. and MASOLOV, V. N. (1982): Crustal structure of the Lambert Glacier area from geophysical data. Antarctic Geoscience, ed. by C. CRADDOCK. Madison, Univ. Wisconsin Press, 931–936.

HOUTZ, R. E., HAYES, D. E. and MARKL, R. G. (1977): Kerguelen Plateau bathymetry, sediment distribution and crustal structure. Mar. Geol., **25**, 95–130.

KIMURA, K. (1982): Geological and geophysical survey in the Bellingshausen Basin, off Antarctica. Nankyoku Shiryô (Antarct. Rec.), **75**, 12–24.

KURININ, R. G. and GRIKUROV, G. E. (1982): Crustal structure of part of East Antarctica from geophysical data. Antarctic Geoscience, ed. by C. CRADDOCK. Madison, Univ. Wisconsin Press, 895–901.

OKUDA, Y., YAMAZAKI, T., SATO, S., SAKI, T. and OIKAWA, N. (1983): Framework of the Weddell Basin inferred from the new geophysical and geological data. Mem. Natl Inst. Polar Res., Spec. Issue, **28**, 93–114.

SATO, S., ASAKURA, N., SAKI, T., OIKAWA, N. and KANEDA, Y. (1984): Preliminary results of geological and geophysical surveys in the Ross Sea and in the Dumont d'Urville Sea, off Antarctica. Mem. Natl Inst. Polar Res., Spec. Issue, **33**, 66–92.

STAGG, H. M. J. (1985): The structure and origin of Prydz Bay and MacRobertson Shelf, East Antarctica. Geophyscis of the Polar Regions, ed. by E. S. HUSEBYE *et al.* Amsterdam, Elsevier, 315–340 (reprinted from Tectonophysics, **114**).

STAGG, H. M. J., RAMSEY, D. C. and WHITWORTH, R. (1983): Preliminary report of a marine geophysical survey between Davis and Mawson Stations, 1982. Antarctic Earth Science, ed. by R. L. OLIVER *et al.* Canbera, Aust. Acad. Sci., 527–532.

TSUMURAYA, Y., TANAHASHI, M., SAKI, T., MACHIHARA, T. and ASAKURA, N. (1985): Preliminary report of the marine geophysical and geological surveys off Wilkes Land, Antarctica in 1983–1984. Mem. Natl Inst. Polar Res., Spec. Issue, **37**, 48–62.

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