Polar Geosci., **14**, 244–262, 2001

Preliminary results of the TH99 geological and geophysical survey in the Cooperation Sea and Prydz Bay area

Masato Joshima[1], Takemi Ishihara[2], Takeshi Nakajima[2], Kazuhiro Sugiyama[2], Kunihiko Tsuchida[1], Ayato Kato[1], Fumitoshi Murakami[2] and Belinda Brown[3]

[1]*Technology Research Center, Japan National Oil Corporation, 2-2, Uchisaiwai-cho 2-chome, Chiyoda-ku, Tokyo 100-0011*
[2]*Geological Survey of Japan, 1-3, Higashi 1-chome, Tsukuba 305-8567*
(Now: Institute for Marine Resources and Environment, National Institute of Advanced Industrial Science and Technology (AIST), Higashi 1-1-1 AIST no.7, Tsukuba 305-8567)
[3]*School of Geosciences, Division of Geology and Geophysics, Building F05, The University of Sydney, NSW 2006, Australia*

Abstract: Geophysical and geological surveys were carried out in the 1999–2000 austral summer season for the TH99 cruise aboard the R/V *Hakurei-maru*. The survey includes the abyssal basin and the continental rise area of the Cooperation Sea (CS) and Prydz Bay (PB), offshore of Mac Robertson Land and Princess Elizabeth Land, Antarctica.

In the northern abyssal plain of the CS, a mantle-like sequence (G) appears at a depth of 10 s two-way travel time (TWT), or approximately 13 km. The sequence disappears south of 64°S, in the southern part of the CS. These observations suggest that the southern part of the CS and PB is underlain by intermediate type crust that is characteristic of oceanic and continental material. The deep structure of most of the PB continental shelf is not clear due to strong seafloor multiples.

More than 7 km of thick sedimentary sequences in the northwest area of PB are confirmed by the MCS survey. Very thick sedimentary sequences, interpreted as pre-rift, rift and drift sediment can be observed under thick pelagic sediment.

Geological samples, which were recovered in the CS and PB, offer important evidence on the recent history of drift sediments caused by iceberg floes. Two cores reached 0.78 Ma (Bruhnes-Matsuyama (B-M) boundary) in magneto-stratigraphic measurements, and they gave distinct age determinations for recent sediments.

key words: Cooperation Sea, Prydz Bay, Amery Ice Shelf, marine geological and geophysical surveys, sedimentary sequences, drift sediment, deep crustal structure

1. Introduction

The Technology Research Center (TRC), Japan National Oil Corporation (JNOC), has been conducting marine geophysical and geological surveys of the Antarctic continental margins with the R/V *Hakurei-maru* since 1980. Some of the results of previous cruises have been published (Kimura, 1982; Okuda *et al.*, 1983; Sato *et al.*, 1984; Tsumuraya *et al.*, 1985; Mizukoshi *et al.*, 1986; Saki *et al.*, 1987; Yamaguchi *et* *al.*, 1988; Shimizu *et al.*, 1989; Ishihara *et al.*, 1996; Tanahashi *et al.*, 1997, 1998, 1999; Murakami *et al.*, 2000). This paper reports the preliminary TH99 survey results from the Cooperation Sea (CS) and Prydz Bay (PB), in the southwestern area of Kerguelen Plateau.

The TH99 survey cruise was planned to survey the northwestern part of the Prydz Bay continental shelf, following surveys of the northern (TH84 cruise, Mizukoshi *et al.*, 1986) and the southern (TH89 cruise) parts of Prydz Bay (unpublished report, 1990).

The TH99 survey area in the CS and PB lies in the junction between the southern Kerguelen Plateau and eastern Enderby Land (Fig. 1). Topographic features are shown in Fig. 2 using ETOPO5 data. A number of cruises were performed by JNOC, Australia and Russia before the TH99 cruise, they are also plotted in Fig. 2. There are several ODP drill sites in the survey area, including 738–744 (Barron *et al.*, 1989), and 1165–1167 (Leg.188, 2000). Drill holes 739–743 are located in Prydz Bay. ODP sites 738 and 744, located at the southern foot of Kerguelen Plateau, reached an Oligocene or older marine hemipelagic sequence at 300 m below the sea floor. Slow seafloor spreading between Antarctica and India was suggested to have started in the early Cretaceous (*c.* 130 Ma, Powell *et al.*, 1988).

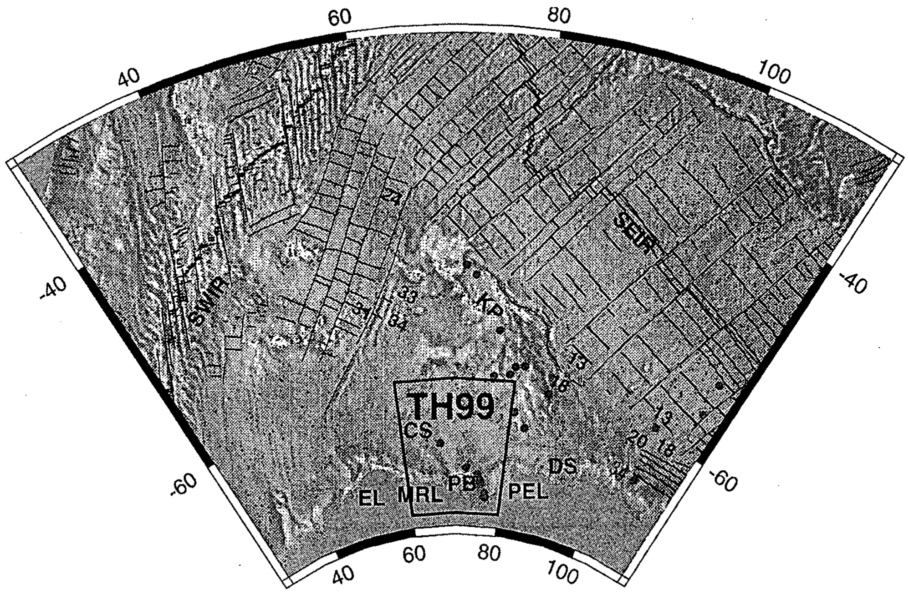

Fig. 1. Tectonic setting and topography of the TH99 survey area. Magnetic lineations and fracture zones are drawn by GMT (Wessel and Smith, 1991) using boundary files in NOAA NGDC Global Relief CD-ROM. Topographic shades are drawn using the satellite altimetry by Smith and Sandwell (1992). The box of thick solid lines shows the TH99 survey area. Gray solid circles indicate the locations of ODP and DSDP drilling sites. SWIR: Southwest Indian Ridge, SEIR: Southeast Indian Ridge, KP: Kerguelen Plateau, CS: Cooperation Sea, PB: Prydz Bay, DS: Davis Sea, EL: Enderby Land, MRL: Mac Robertson Land, PEL: Princess Elizabeth Land. Numerals indicate magnetic anomaly lineations.

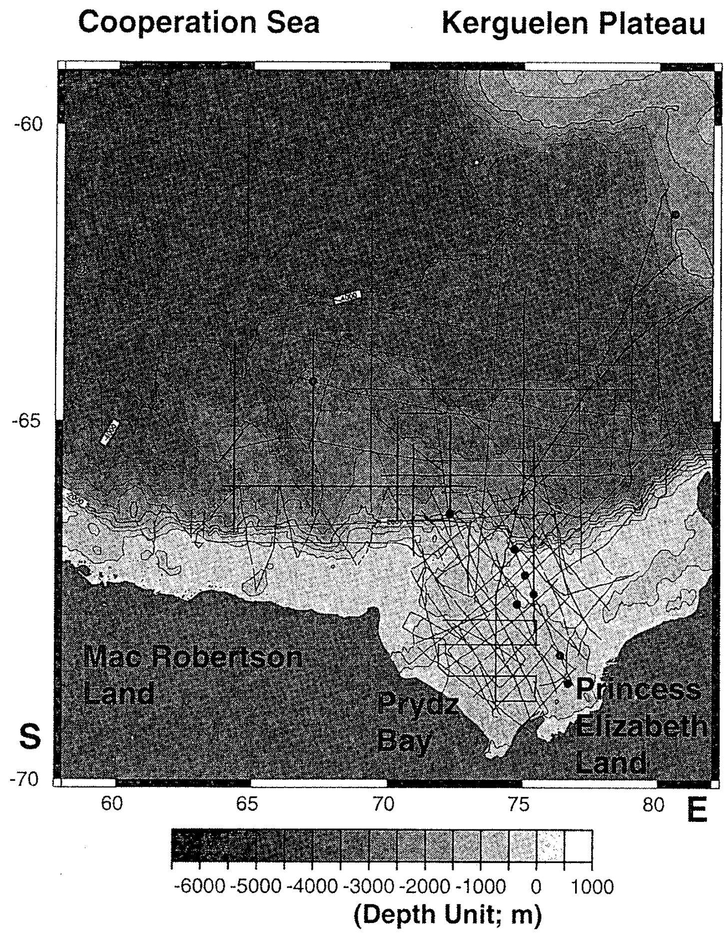

Fig. 2. Topographic map of TH99 survey area: contours are drawn by GMT using ETOPO5 data file in NOAA NGDC Global Relief CD-ROM. JNOC's survey lines including former cruises (thick bold lines), survey lines of foreign cruises (thin bold lines) and ODP sites (solid circles) are also plotted.

2. Outline of survey methods

The marine geological and geophysical survey of cruise TH99 was carried out from Dec. 11, 1999 to Jan. 10, 2000 in the Cooperation Sea area and from Jan. 14 to Feb. 18, 2000 in the Cooperation Sea and Prydz Bay. Data and samples acquired during cruise TH99 are listed in Table 1. A summary of TH99 survey methods, with specifications of equipment and operating conditions, is given in Table 2.

The seismic source was towed by two cables, each equipped with eight G guns. The G gun chambers were set for four "double linear cluster mode, 250×4 cubic inches

Table 1. Summary of the TH99 cruise.

Survey period	71 (30 in survey area) days
Seismic reflection survey	2194.8 km
Magnetic and gravity survey	20240 km
Gravity coring	9 sites
Heat flow measurement	7 sites

Table 2. Summary of survey equipment and operating conditions.

Survey	Instrument (specification) and operating conditions
Multichannel Seismic reflection (MCS)	Source: 16×SSI G-guns (250 cu-in. generator × 3 + 250 cu-in. injector) × 4 air pressure is 2000 psi (13.8 × 10^6 Pa) Receiver: SYNTRAK 480-24 24 bit digital streamer cable (12.5 m × 240 ch 3000 m in total active section) Recorder: SYNTRAK 480 seismic recorder Sampling interval: 2 ms Record length: 9.5 s Shot interval and *ca* 50 m, 24 s with 4.0 knot ship speed: *ca* 25 m, 12 s with 4.0 knot CMP coverage: 3000% in CS 6000% in PB
Gravity	Lacoste & Romberg SL-2 gravimeter
Magnetics	Geometrics G-866 proton magnetometer Tierra Tecnica three component shipboard magnetometer
Bathymetry	3.5 kHz SBP system (Raytheon CESPIII with PTR and EPC)
Subbottom profiling	3.5 kHz SBP system (Raytheon CESPIII with PTR and EPC)
Bottom sampling	Gravity corer
Heat flow measurement	Nichiyu Giken GS-type, 6 channels Thermal conductivity meter: Kyoto Denshi QTM-D3

(ci.)" (65.5 liters in total), designed for deep penetration. A water gun with a total volume of 800 ci. (13.1 liters) was used in the TH84 and TH89 cruises (Mizukoshi *et al.*, 1986).

A 24 bit digital streamer cable and recording system, the SYNTRAK 480-24 digital streamer cable, which has been used in this project for three years, showed a higher S/N ratio and increased stacking effect with the increased number of channels (240), compared to the previous system which used 24 channels (TH84 and TH89 cruises).

All the reflection seismic data were obtained and processed by JAPEX/GeoScience Inc. during and after the cruise. All the reflection seismic data were processed by the "reducing multiple reflection method" to reduce extremely strong sea bottom multiples in the continental shelf area, and to increase resolution in the deeper continental shelf area. All data were processed for time migration and depth conversion. The dip moveout (DMO) process, a type of pre-stack migration process to reduce stacking noise from high angle reflectors, commonly used in former cruises, was not applied because the method is not so useful in this area. The shot intervals were not identical during the survey. The plotting scale used in this report includes a vertical exaggeration of approximately 4.

3. Geological sampling and heat flow measurements

A summary of bottom sampling and heat flow measurement results is given in Table 3. Sampling sites in the CS and PB are shown in Fig. 3. Nishimura *et al.* (1997) reported the sedimentary sequences, composed of glacial-marine, transitional glacial marine and basal tills in descending order, from the AMS ^{14}C ages of cores GC1604, GC1605 and GC1606, which were recovered from the Ross Sea during cruise TH95. They estimated that the three core sites were under the grounded ice sheet during 23530 and 37460 y.B.P. and that the ice sheet retreated before 21140 y.B.P. at the GC1604 site.

Table 3. Summary of bottom samplings and heat flow measurements.

Site	Lat. (S)	Lon. (E)	Depth (m)	Recovery	Description	T.C.	H.F.
GC2001	62°27′35″	67°35′27″	4277	1.75 m	siliceous clay	0.792	49.10
GC2002	59°51′19″	64°49′10″	4642	1.62 m	siliceous silt-clay, siliceous ooze	0.758	59.85
GC2003	62°04′45″	74°14′59″	3959	4.88 m	siliceous silt-clay	0.912	54.74
GC2004	66°47′00″	64°02′19″	534	1.04 m	silt-sand ~ sand-silt	1.713	
GC2005	63°45′34″	64°19′05″	4124	4.69 m	siliceous silt-clay	0.945	52.89
GC2006	66°00′12″	73°07′26″	2565	4.91 m	siliceous clay, clay, sand-silt	1.029	56.62
GC2007	66°29′03″	70°37′05″	2081	1.62 m	siliceous ooze, soft clay, silt-sand ~ sand-silt	1.299	
GC2008	67°51′04″	75°24′17″	454	3.05 m	siliceous ooze, sand-silt	1.208	
GC2008H	67°51′04″	75°24′17″	454			1.208	102.84
GC2009	65°08′46″	75°07′21″	3122	4.97 m	silty clay	0.956	56.40

Recovery: recovered core length, T.C.: Thermal conductivity (W/mK), H.F.: Heat flow (mW/m^2)
No HF values, GC2004, 2007 and 2008, indicate that no or less than 2 temperature data were obtained due to too short penetration. GC2008H indicates that a probe type HF measurement was done just after the gravity core sampling at station GC2008.

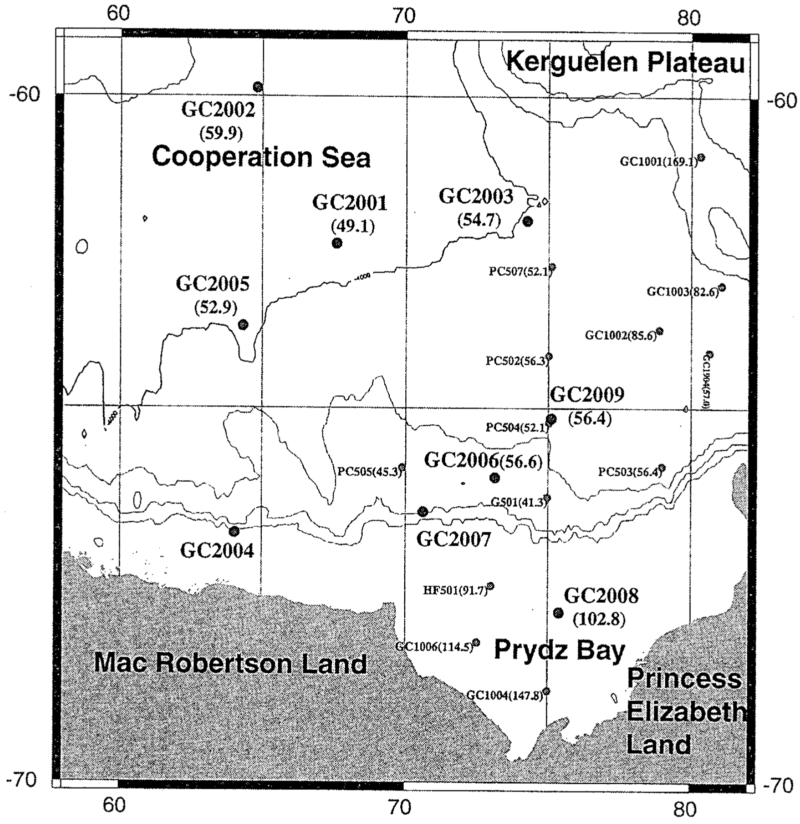

Fig. 3. Sampling sites of the TH99 cruise. GC: gravity core, PC: piston core (Small values indicate tentatively determined heat flow values (mW/m^2). Smaller solid circles and values are former cruise results).

A similar explanation might be expected for some of the gravity cores recovered at sites near the continental shelf, for example, GC2004, 2007 and 2008.

In cruise TH99, remanent magnetization measurements of sedimentary cores revealed that the ages of cores are older than 0.78 Ma in GC2003 and GC2005 (Oda, personal communication and Bergguren *et al.*, 1995); on the other hand, AMS ^{14}C ages indicate about 20 to 40 kyr for the parts lower than 1 m. Such values continue to the bottom of the measurements. The application of AMS ^{14}C age may need to be reconsidered for the geological time scale, particularly for sedimentary cores in the deeper abyssal plain area. Also, a number of gravity cores have reached the B/M (Brunhes-Matsuyama) boundary around Antarctica; the results add new restrictions for the ages of sediments. Cruises TH92, TH94 and TH95 also had two or more cores, which have reached the B/M boundary. Reinvestigation is necessary about the relationship between AMS ^{14}C age and the results of paleo-magnetic measurements for these cores.

Heat flow measurement results in the survey area are plotted on a map with previous cruise results (Fig. 3). A bottom simulating reflector (BSR) can be observed in 30SMG (Fig. 11), caused by gas-hydrate 600 m beneath the sea floor (2500 to 3000 m). A phase diagram of methane-hydrate indicates T=23 to 24°C at depths between 3100 and 3600 m (Kvenvolden, 1998). Based on rough estimates of the thermal gradient (0.04°C/m) and thermal conductivity (1.2 W/mK), the estimated heat flow value is approximately 50 mW/m^2 (Hamilton, 1978; Horai, 1982). Compared with measured and tentatively calculated values (for example, 56.62 mW/m^2 at the end of 30SMG, GC2006 in Table 3) this estimate seems low. The tentative values are commonly a little higher than true values due to the effect of cooling time correction, and the above values should be a reasonable estimation. A heat flow measurement, GC2008H, was done using probe type instrument at the same gravity core site, GC2008. Heat flow values in PB are higher than those obtained from other sites (Fig. 3). Heat flow values on the continental shelf are commonly measured higher than those of deeper basins around Antarctica, for example in the Ross Sea. Heat flow measurements in shallow water involve many problems, such as the effect of fluctuation in bottom water temperature. Measurement of the higher heat flow value in PB remains for future work.

4. Gravity and magnetic surveys

Gravity anomaly data obtained in the CS and PB during cruise TH99 are plotted in Fig. 4 as profiles along the ship's track. Figure 5 shows the compiled gravity map of TH99 and previous cruises and satellite altimetry data over the TH99 survey area (Sandwell and Smith, 1992). The figure shows a broad gravity high zone (brighter area in Fig. 5) over the edge of the continental shelf in PB and narrow gravity low zones (darker area) just outside of the continental shelf. The seismic data obtained over the narrow gravity low area show thick deformed sedimentary sequences under less deformed well stratified pelagic sedimentary sequences (Fig. 10-1). These observations may suggest that there is a fragment of continental crust that was deformed with continental rifting and filled by syn-rift sediments.

Magnetic anomaly data which were obtained during cruise TH99 in the CS and PB are plotted in Fig. 6. In the CS, distinct E-W or ENE-WSW trending anomaly lineations including three positive anomalies can be observed along the N-S survey lines between 64°E–67°E. Ishihara *et al.* (2000) interpreted these to represent the oceanic crust

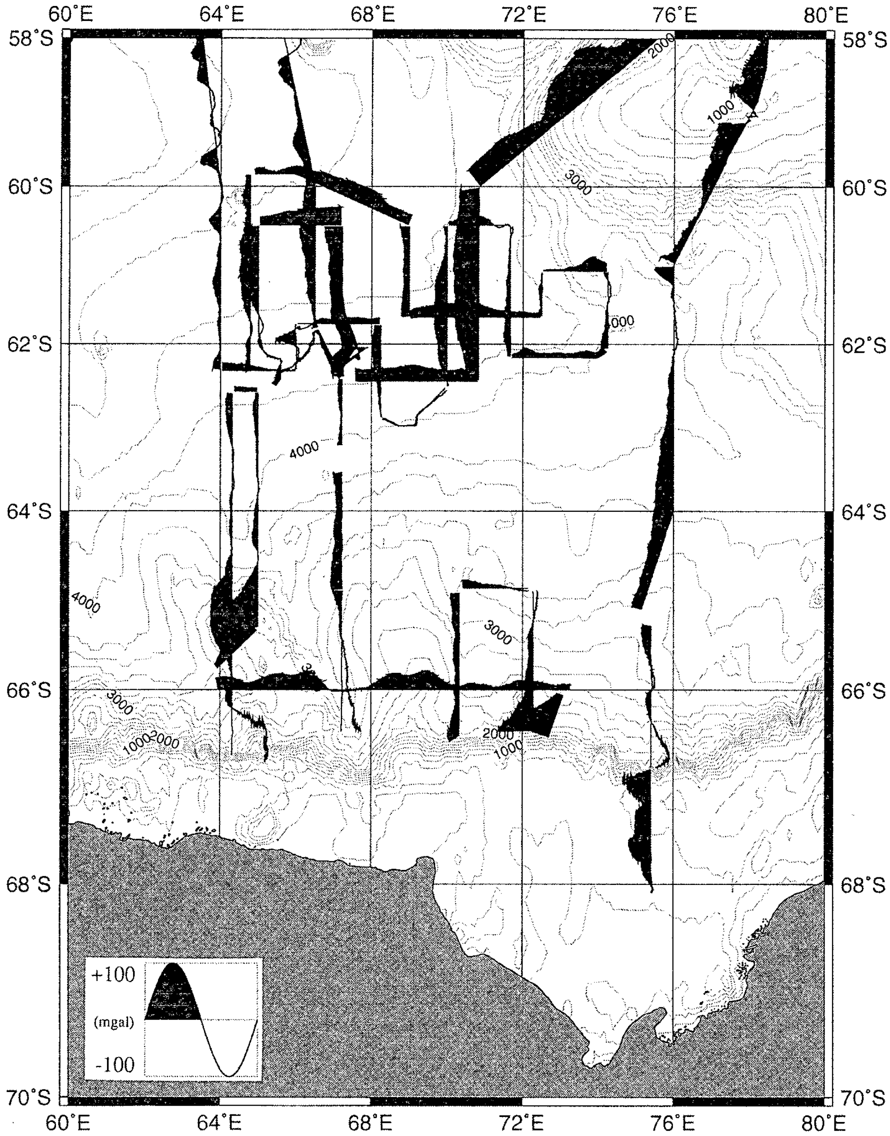

Fig. 4. Free-air gravity anomaly profiles along ship's track from cruise TH99.

produced along the E-W or ENE-WSW spreading system between India and Antarctica, and tentatively correlated the three positive anomalies with M10N, M4 and M2 (Fig. 6). Total magnetic intensity anomaly profiles of cruise TH99 resemble those reported in TH98 survey results (Murakami *et al.* 2000); this may indicate concurrent spreading between the CS (TH99 survey area) and the northern area of the Davis Sea (TH98 survey area). Strong positive anomalies extending along 64°S latitude may represent the continent ocean boundary (COB). In contrast, no distinct magnetic anomalies are observed south of this line. There are several local magnetic anomalies which are correlated with basement highs on the seismic profiles in the PB area (Ishihara *et al.*, 1999). They are interpreted as volcanic intrusions within the Lambert Rift and its vicinity.

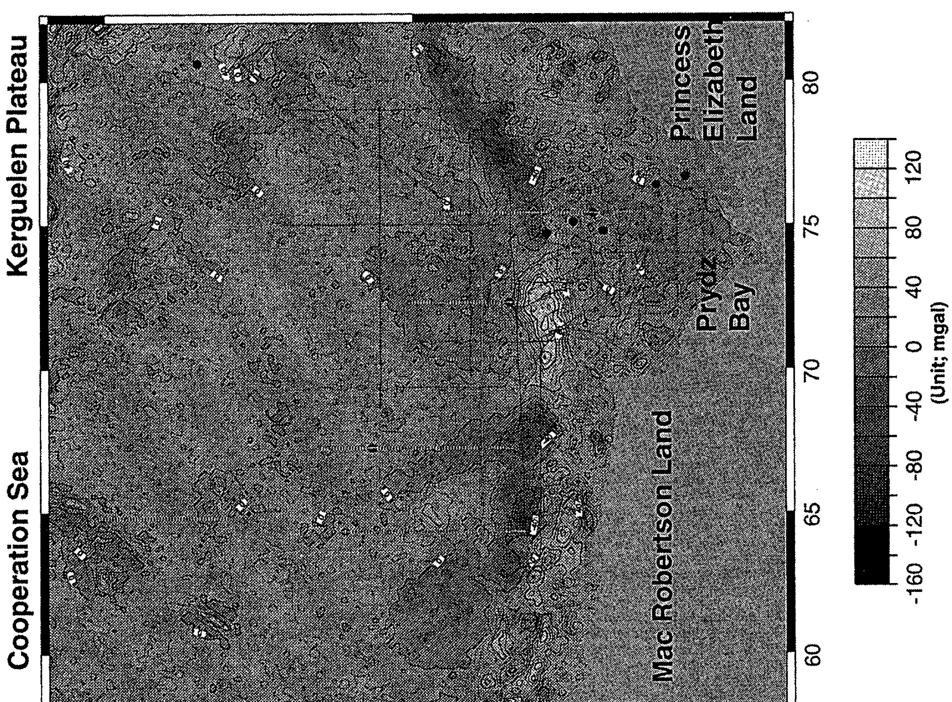

Fig. 5. Free-air gravity anomaly contours drawn using the data from satellite altimetry by Sandwell and Smith (1992).

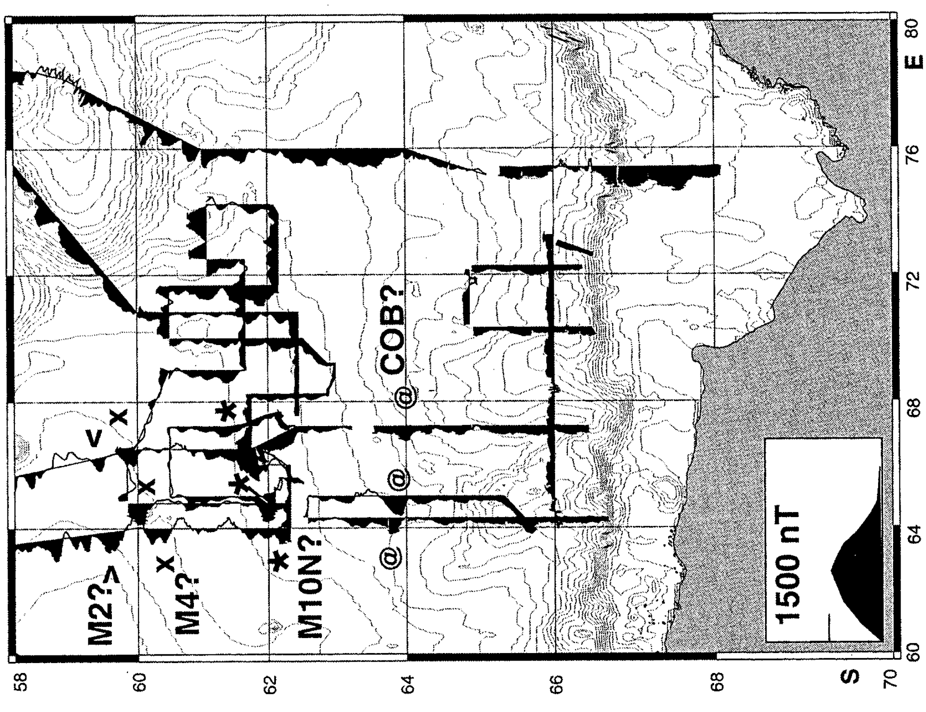

Fig. 6. Magnetic anomaly profiles along ship's track from cruise TH99. Interpolated magnetic lineations and COB lines are also plotted.

5. Preliminary interpretation of seismic survey results

Seismic survey lines from the CS and PB are shown in Fig. 7. The thickness and depth are described as two way travel time in seconds on the time section.

5.1. Cooporation Sea area (CS)

Five major unconformities, U2, U3, U4, U5 and U6 in descending order, have been recognized on MCS profiles in the CS and sequences A, B, C, D, E, F, G were defined on the seismic records, the same as those in the Davis Sea, TH98 area (Murakami *et al.*, 2000, See Table 4). Although there is very little geological age evidence for sequences older than Miocene, the five unconformities are interpreted, mainly from the regional tectonics and comparison with the Indian margin, as Late Miocene glacial erosion, Eocene glacial-onset, Early Cretaceous break-up and Jurassic rift-onset unconformities in descending order (Table 4). ODP site 744 on the SKP (Southern Kerguelen Plateau) provided stratigraphic data from the Oligocene to the Holocene, but did not reach the basement. ODP sites 740 and 741 in PB penetrate the late Paleozoic to early Mesozoic,

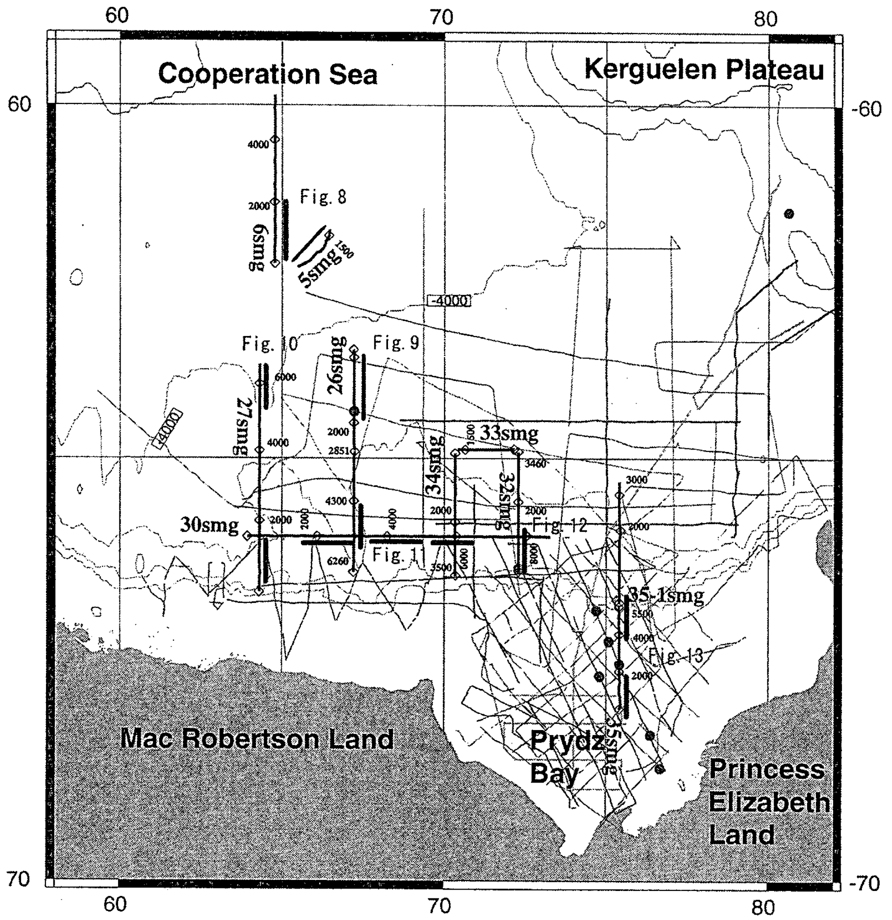

Fig. 7. Multi-channel seismic (MCS) reflection survey lines from the TH99 cruise. Thick lines indicate the TH99 cruise, medium lines: older JNOC's seismic lines, and thin lines: foreign cruises in the survey area. Accompanying dotted lines and small figure numbers with the MCS lines show the locations of seismic records used in this paper.

Table 4. Sedimentary sequences and unconformities in CS and PB area.

Type of sequence	Age	Unconformity and Sequences (CS, PB)	Davis Sea (TH98)
	Quaternary Miocene	Sequence A	Sequence A
		U2-Unconformity (glacial erosion)	U2-Unconformity
	Oligocene Eocene	Sequence B	Sequence B
		U3-Unconformity (glacial-onset)	U3-Unconformity
	Paleocene to Late Cretaceous	Sequence C	Sequence C
		U4-Unconformity (breakup?)	U4-Unconformity
		Sequence D	Sequence D
		U5-Unconformity	U5-Unconformity
	Early Cretaceous to Late Jurassic	Sequence E	Sequence E
		U6-Unconformity (rift-onset?)	U6-Unconformity
Basement	Late Jurassic and Older	Sequence F	Sequence F
Mantle?		Sequence G	

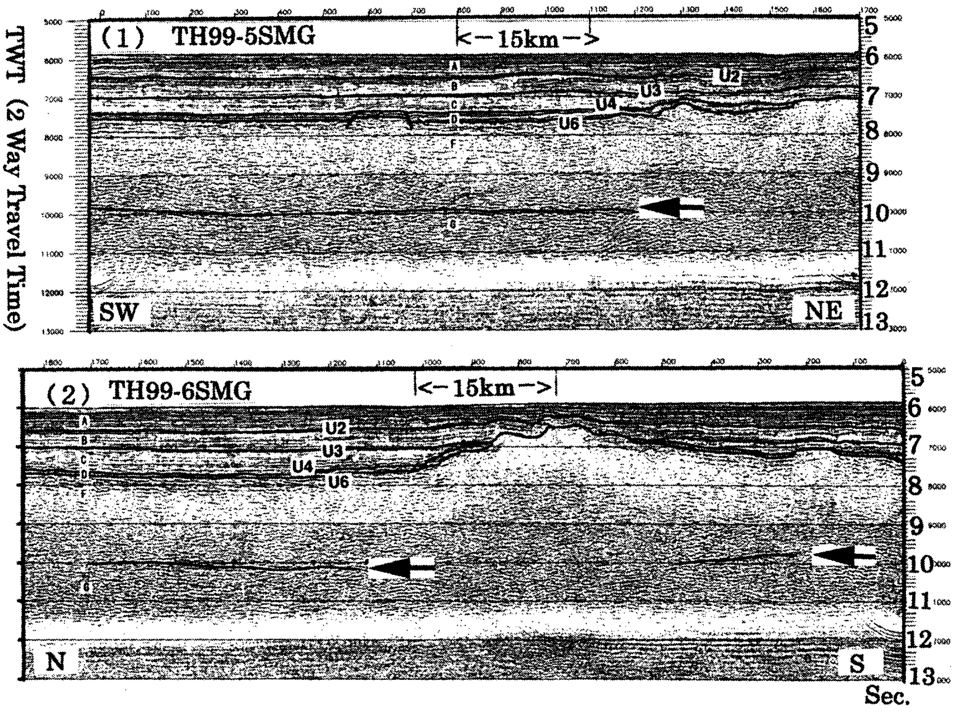

Fig. 8. Seismic profile 5SMG and part of 6SMG. The locations of seismic records in Figs. 8 to 13 are shown in Fig. 7. The deepest unconformity (top of sequence G, shown by arrow) may be caused by mantle refraction. This kind of unconformity appears in some parts of 26SMG and 27SMG. The landward side of this unconformity might represent the COB .

and Early Cretaceous and younger sediment, respectively. But they were too short to reconstruct continuous sections, and also did not reach the basement.

Four seismic profiling lines, 5 (Fig. 8-1), 6 (Fig. 8-2), 26 (Fig. 9-1,2) and 27SMG

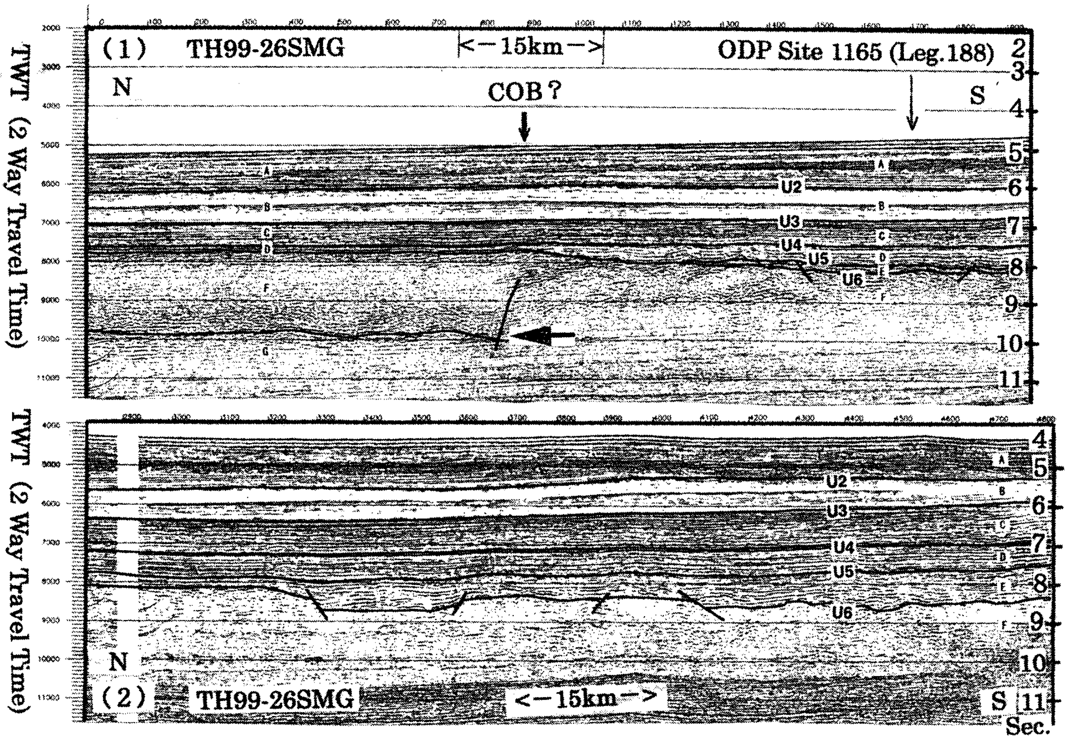

Fig. 9. Seismic profile 26SMG, located between 64°S and 66°S. A BSR (possibly indicating Opal A/CT diagenesis) can be observed around 66°S. ODP site 1165 (Leg 188) is on the line. Arrow indicates top of G.

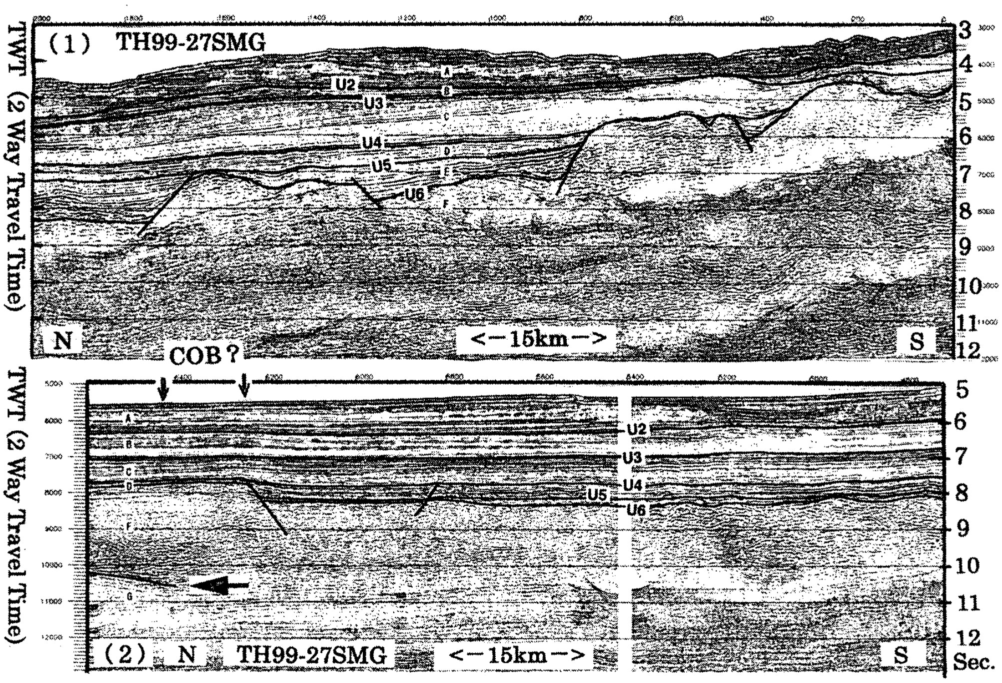

Fig. 10. Seismic profile 27SMG, located between 64°S and 67°S. Arrow is same as Fig. 8, 9.

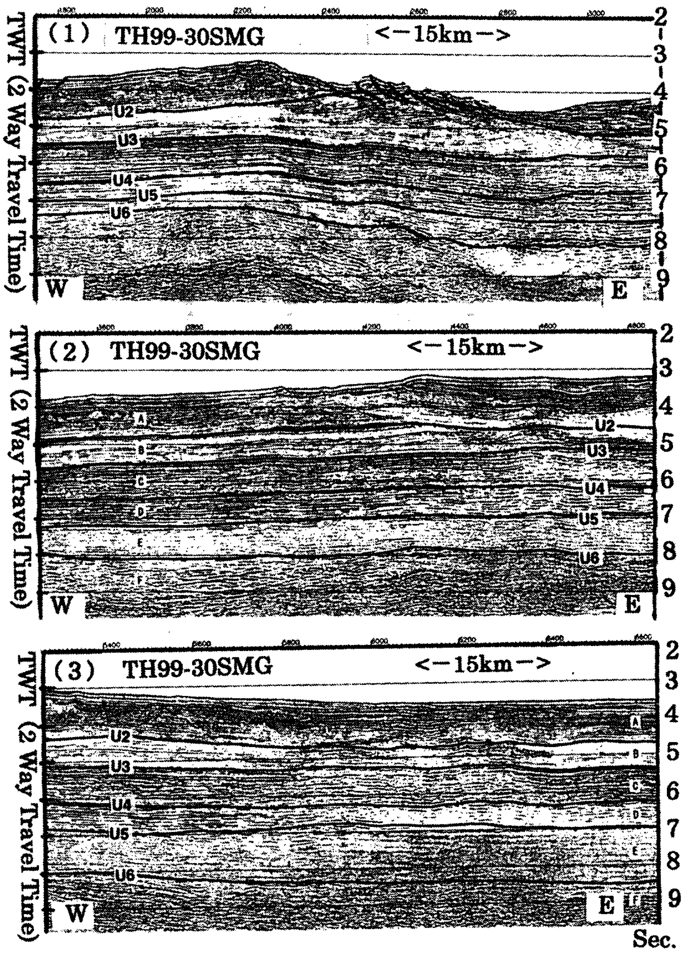

Fig. 11. Seismic profile 30SMG, located between 67°E, 68°E and 70°E. A BSR can be observed (possibly from methane hydrate).

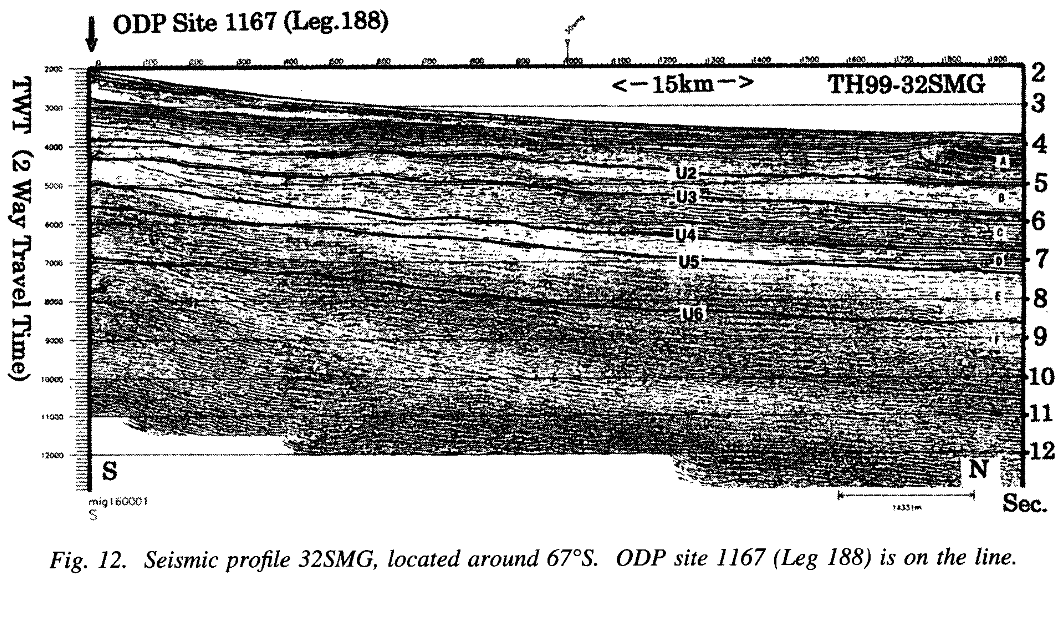

Fig. 12. Seismic profile 32SMG, located around 67°S. ODP site 1167 (Leg 188) is on the line.

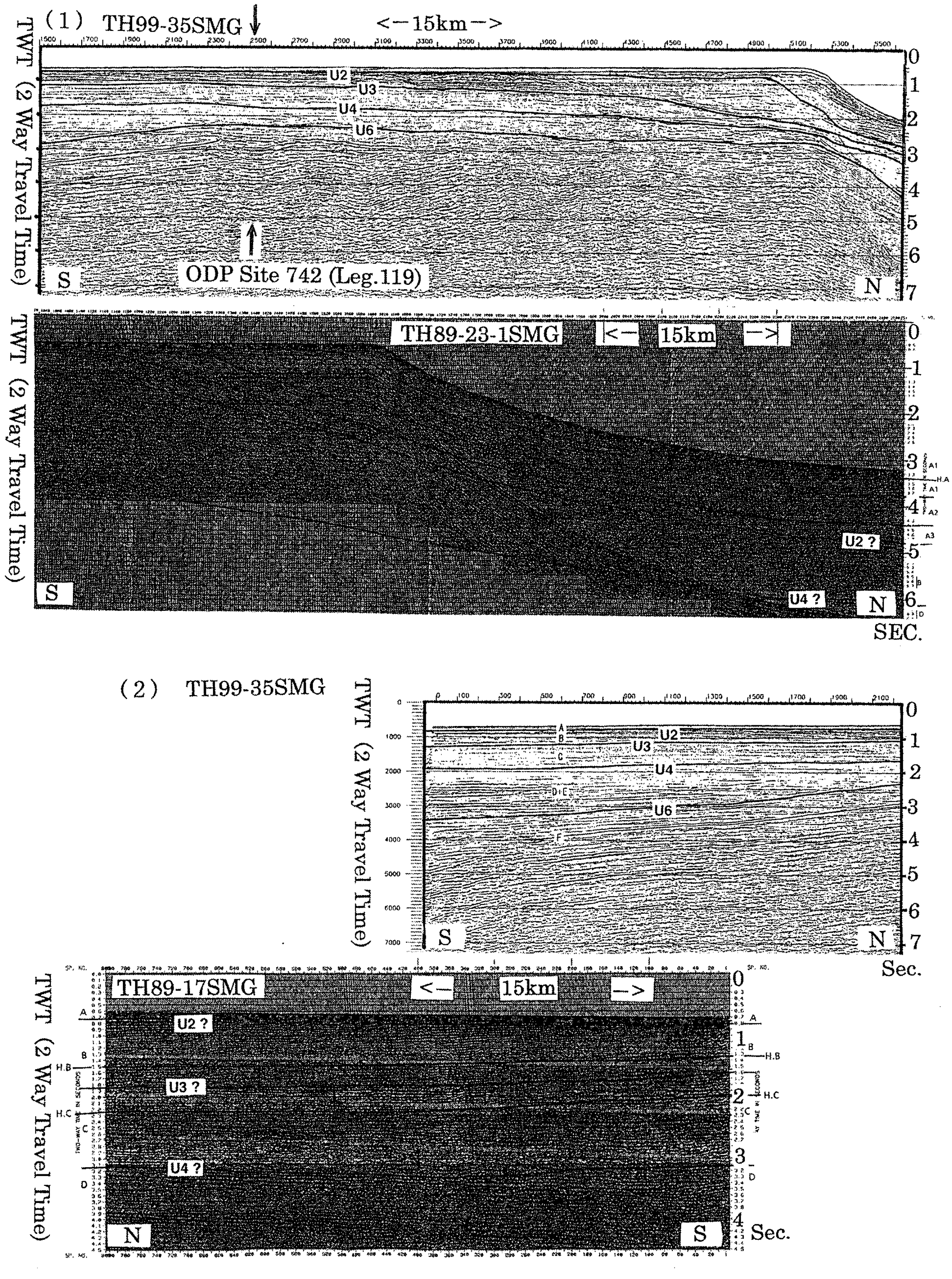

Fig. 13. Seismic profile 35SMG, located between 67°S and 68°S in comparison with profiles 17SMG (TH89) and 32-1SMG (TH89). Line 17SMG crosses the southernmost end of 35SMG (TH99). The basement in Prydz Bay in 35SMG (TH99) is inclined to the south and deeper basement is obscured by strong multiples. ODP drilling site 742 (Leg 119) is on the line.

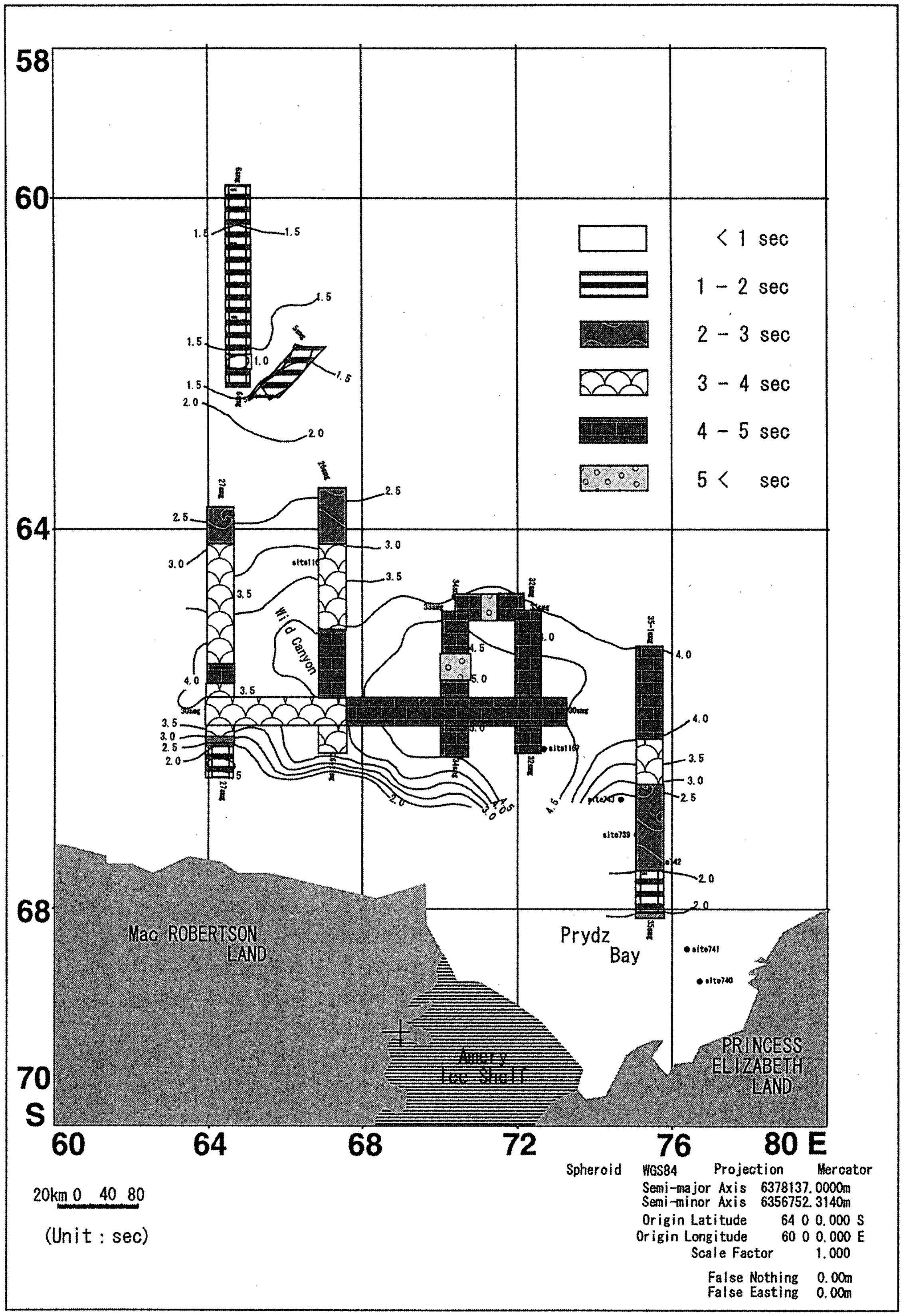

Fig. 14. Total thickness of sediments in seconds (two-way travel time) based on the multi-channel reflection seismic survey.

(Fig. 10-1, 2), were carried out during cruise TH99 in the lower continental rise and the deep ocean basin in the CS. Every profile shows an upper unit (A to C) that comprises horizontally, well stratified marine sequences and a lower unit (D to F) which consists of some older sedimentary sequences and volcanic basement without regular internal structure.

The relationship between these two units is clearly shown on line 6SMG (Fig. 8-2). The upper unit consists of 1.5 s (2 km) thick sequences, which show evenly flatlying reflectors.

5.2. Prydz Bay (PB) area

PB is a north-south trending deep graben located between Mac Robertson Land in the west and Princess Elizabeth Land in the east (Fig. 2).

The sedimentary sequences (A, B and C), mainly comprised of drift sediments, form a very thick sedimentary fan in the northwestern area of PB. The sequences decrease to about 1.5 km in the northernmost part of the survey area (northern part of 6SMG, Fig. 8-2) while they increase to 7–8 km in the southern part of the basin (south of 26SMG, 32SMG, and 34SMG which resembles 32SMG, Figs. 9 and 12).

The basement is interpreted as the pre-Jurassic Group or its equivalent sedimentary units (Cooper *et al.*, 1991). The unconformity, U5, is inclined to the south and deepens to truncate an acoustic basement in PB (Fig. 13). The depth of the unconformity is about 6 sec (about 9 km below the sea floor) in the central part of the outer fan of the north PB area in lines 32 and 34SMG (Figs. 12 and 14).

A summary of seismic records is shown in Fig. 14 as a total thickness map in seconds (two-way travel time) of sediments with thickness contour lines. The shape of this thick sedimentary basin resembles the results formerly compiled by St. John (1986).

6. Discussion

The unit G under the recognized reflection U6 appears in seismic records of 5SMG (Fig. 8-1), 6SMG (Fig. 8-2), northern part of 26SMG (Fig. 9-1) and northernmost end of 27SMG (Fig. 10-2), as indicated with arrows in these figures. In these areas calculated stack velocity values from MCS records indicate higher speeds than ordinary basements. For example, velocity values include (Table 5): 7.8 km/s in the depth interval 11 km to 15 km at shot point (SP) 301 (5SMG, Fig. 8-1), 7.9 km/s at the same depth at SP2401 (6SMG, Fig. 8-2), and 8.0 km/s in the depth interval 11.6 km to 14.5 km at SP101 (26-1SMG, Fig. 9-1). The velocity becomes as low as 6.9 km/s in the depth interval 10.7 km to 14 km of SP6501 (27SMG, Fig. 10-2). Velocities for the sedimentary basin area, are lower in comparison, for example, 6.1 km/s at the depth interval of 6.9 km to 9.5 km of SP1001 (35SMG, Fig. 13-2). The unit G is thought to be mantle considering its velocity in Table 5. Furthermore, the unit G is around 5 s (TWT) under the sea bottom and appears in the deeper abyssal plain area, but disappears in the southern part of CS (south of 64°S). The southernmost end of the area in which unit G appears is thought to be the edge of the oceanic crust (COB).

From the pattern of basement in seismic profiles, the upper limit of unit F, we can recognize very clear and continuous reflectors. This may also indicate some information

Table 5. Examples of velocity analysis in TH99 MCS survey.

5SMG SP. No.= 301

	Time (m.sec)	Interval (m/sec)	Depth (m)
		1500.0	
S	5859		4394.3
		1604.7	
	6026		4528.2
A		1669.0	
	6167		4645.9
		1952.0	
	6556		5025.6
B		2479.6	
	7037		5621.9
		3032.3	
C	7210		5884.2
		3020.2	
D	7565		6420.3
		3142.1	
	7912		6965.4
		3242.4	
	8209		7446.9
F		4299.2	
	8768		8648.5
		5766.4	
	9326		10257.4
		6146.5	
	11012		15438.9
G		7776.0	
	15004		30959.7

6SMG SP. No.= 2401

	Time (m.sec)	Interval (m/sec)	Depth (m)
		1502.0	
S	6009		4512.8
		1601.4	
	6253		4708.1
A		1960.9	
	6490		4940.5
		2205.9	
	6626		5090.5
B		2327.8	
	6836		5334.9
		2498.4	
	7223		5818.4
C		2718.1	
	7470		6154.0
D		2991.2	
	7725		6535.4
		3455.2	
	8184		7328.4
F		4146.5	
	8591		8172.2
		5498.7	
	9883		11724.4
		6098.5	
	11026		15209.7
G		7868.9	
	15004		30860.9

26-1SM SP. No.= 101

	Time (m.sec)	Interval (m/sec)	Depth (m)
		1495.0	
S	5210		3894.5
		1586.9	
	5440		4077.0
		1744.9	
A	5698		4302.1
		1855.0	
	5883		4473.7
		2222.3	
	6174		4797.0
		2812.5	
B	6617		5420.0
		3506.4	
	7054		6186.1
		3563.7	
C	7379		6765.2
		4051.8	
D	7699		7413.5
		4194.7	
	8108		8271.3
F		4452.9	
	8749		9698.5
		4901.2	
	10173		13188.1
		6565.9	
	11590		17840.0
G		7960.0	
	14508		29453.6

27SMG SP. No.= 6501

	Time (m.sec)	Interval (m/sec)	Depth (m)
		1496.0	
S	5547		4149.2
		1649.6	
	5837		4388.3
A		1826.3	
	6186		4707.0
		2264.3	
	6471		5029.7
		2811.0	
B	6702		5354.4
		3161.6	
	6960		5762.2
		3391.0	
C	7266		6281.0
		3479.6	
D	7722		7074.4
		4661.4	
	8206		8202.5
		5258.2	
F	8723		9561.7
		5318.8	
	9501		11630.7
		5598.3	
	10672		14908.5
G		6885.7	
	14012		26407.5

35SMG SP. No.= 1001

	Time (m.sec)	Interval (m/sec)	Depth (m)
		1452.0	
S	626		454.5
A		2031.6	
	749		579.4
B		2231.2	
	1129		1003.3
C		2242.0	
	1563		1489.9
		2559.0	
D	2443		2615.8
E		3214.0	
	3669		4586.0
		3638.6	
	4606		6290.7
		3804.3	
F	5346		7698.3
		5077.7	
	6847		11509.1
		6145.9	
	9500		19661.6

S: Sea Bottom, A to G: Sequences from seismic record

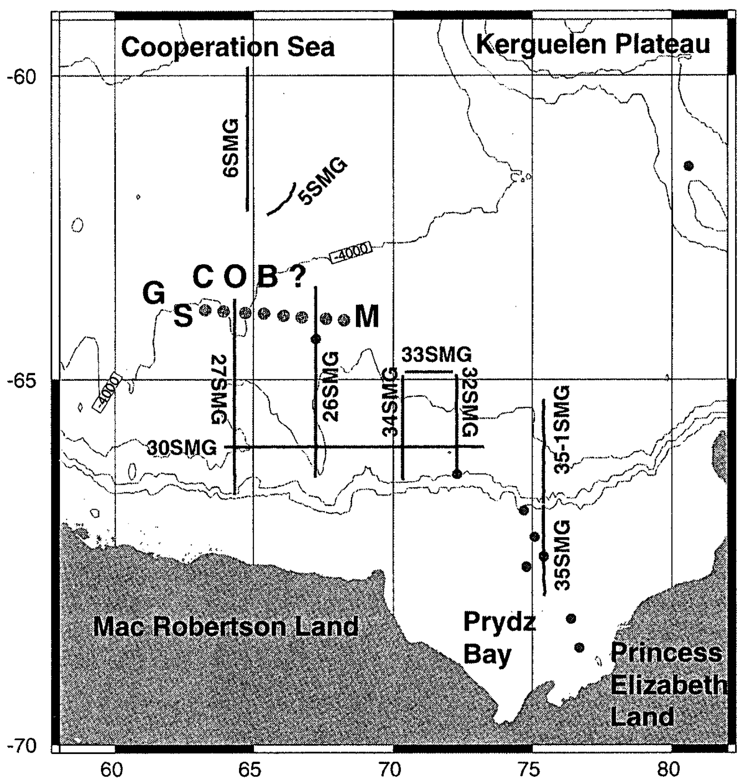

Fig. 15. The location of the continent-ocean boundary (COB) interpreted from magnetic anomaly and seismic reflection data as shown in Figs. 9 and 10. (M) indicates magnetic anomaly, (G) G sequence, and (S) clear and continuous basement reflections.

about the COB. The COB is commonly identified by a high in magnetic anomaly profiles and we can recognize it at 64°S in 26SMG, 27SMG and 28MG, 3 NS survey lines in Fig. 6. The COB, interpreted from magnetic anomalies and from seismic records, both from sequence G and the basement pattern, are plotted in Fig. 15. They coincide well with each other, with some differences by several hundred shots (about 10 km, Fig. 15).

Although the basement in PB is not recognized well in seismic records because of the strong multiple reflections, the depth resolution is constrained to at least 5–6 km by many sonobuoy measurements, for example in cruise TH89. There are a number of ODP drill holes (ODP report of Leg.188, 2000, http://www-odp.tamu.edu/publications/prelim/188_prel/188toc.html) in and around PB, but they are all short and do not reach the basement, due to the fact that these drill sites are too far from ports or are often disturbed by floating icebergs. The sampling of these basements is expected to strongly clarify the tectonic history of PB and its northern vicinity.

7. Summary

TH99 cruise added new data and revealed some facts as follows:

1) In the northern abyssal plain of the CS, a mantle-like sequence (G) appears at a depth of 10 s two-way travel time (TWT), or approximately 13 km. The sequence disappears south of 64°S, in the southern part of the CS.

2) More than 7 km of thick sedimentary sequences in the northwest area of PB are confirmed by the MCS survey. Very thick sedimentary sequences, interpreted as pre-rift, rift and drift sediments, can be observed under thick pelagic sediment.

3) Geological samples, which were recovered in the CS and PB, offer important evidence on the recent history of drift sediments caused by iceberg floes. Two cores reached 0.78 Ma (the Bruhnes-Matsuyama (B-M) boundary) in magneto-stratigraphic measurements, and they gave distinct age determinations for recent sediments.

Acknowledments

The authors are grateful to Captain T. Takahashi, officers and crew as well as scientific colleagues of cruise TH99 for their cooperation and efforts during the preparation and execution of the survey. We are grateful to Drs. A. Nishimura, T. Nakajima, H. Oda and Y. Okuda of the Geological Survey of Japan and Y. Asano and T. Saki of Technology Research Center, Japan National Oil Corporation for their kind continuous support to the program.

References

Barron, J., Larsen, B. *et al.* (1989): Proc. ODP, Init. Repts., **119**, College Station, TX (Ocean Drilling Program).

Bergguren, W.A., Kent, D.V., Swisher, I.C.C. and Aubry, M.-P. (1995): A revised Cenozoic geochronology and chronogtratigraphy. Geochronology Time Scales and Global Stratigraphic Correlation, ed. by D.V.K. Bergguren *et al.* Tulsa, SEPM, 129–212.

Cooper, A.K., Davey, F.J. and Behrendt, J.C. (1991): Structural and depositional controls on Cenozoic and (?)Mesozoic strata beneath the western Ross Sea. Geological Evolution of Antarctica. ed. by M.R.A. Thompson *et al.* Cambridge, Cambridge Univ. Press, 285–291.

Hamilton, E.L. (1978): Sound velocity-density relation in sea-floor sediments and rocks. J. Acoustic Soc. Am., **63**, 366–377.

Horai, K. (1982): Thermal conductivity of sediments and rocks recovered during DSDP Leg 60. Init. Rep. DSDP, **60**, 807–834.

Ishihara, T., Tanahashi, M., Sato, M. and Okuda, Y. (1996): Preliminary report of geophysical and geological surveys of the west Wilkes Land margin. Proc. NIPR Symp. Antarct. Geosci., **9**, 91–108.

Ishihara, T., Leitchenkov, G.L., Golynsky, A.V., Alyavdin, S. and O'Brien, P.E. (1999): Compilation of shipborne magnetic and gravity data images crustal structure of Prydz Bay (East Antarctica). Ann. Geofis., **42**, 229–248.

Ishihara, T., Brown, B., Joshima, M. (2000): M-series magnetic anomalies in Enderby Basin. EOS Trans., **81**, F1130.

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

Kvenvolden, K.A. (1998): A primer on the geological occurrence of gas hydrate. J. Minerol. Geol. Soc. London, Spec. Publ., **137**, 9–30.

Mizukoshi, I., Sunouchi, H., Saki, T., Sato, S. and Tanahashi, M. (1986): Preliminary report of geological and geophysical surveys off Amery Ice Shelf, East Antarctica. Mem. Natl Inst. Polar Res., Spec. Issue, **43**, 48–61.

Murakami, F., Ishihara, T., Oda, H., Fujimoto, M., Oda, H., Sugiyama, K. and Joshima, M. (2000): Preliminary report of geological and geophysical survey results in the Princess Elizabeth Trough and its vicinity by R/V Hakurei-maru. Polar Geosci., **13**, 165–186.

Nishimura, A., Nakasone, T., Hiramatsu, C., Akiba, F., and Tanahashi, M. (1997): Latest Quaternary paleoenvironment of the Ross Sea continental shelf, Antarctica. Antarctic and Global Change: Interactions and Impacts. Symposium programme & Abstracts, Antarctic CRC, Hobart, 0381.

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.

Powell, C.McA., ROOTS, S.R. and Veevers, J.J. (1988): Pre-breakup continental extension in East Gondwanaland and the early opening of the eastern Indian Ocean. Tectonophysics, **155**, 261–283.

Saki, T., Tamura, Y., Tokuhashi, S., Kodato, T. Mizukoshi, I. and Amano, H. (1987): Preliminary report of geological and geophysical surveys off Queen Maud Land, East Antarctica. Proc. NIPR Symp. Antarct. Geosci., **1**, 23–40.

Sandwell, D.T. and Smith, W.F. (1992): Global marine gravity from ERS-1, Geosat, and Seasat reveals new tectonic fabric. EOS; Trans., **73**, 133.

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 Dumond d'Urville Sea, off Antarctica. Mem. Natl. Inst. Polar Res., Spec. Issue, **33**, 66–92.

Shimizu, S., Morishima, H. and Tamura, Y. (1989): Preliminary report of geophysical and geological surveys off the South Orkney Islands, Scotia Arc region. Proc. NIPR Symp. Antarct. Geosci., **3**, 52–64.

Smith, W.H.F. and Sandwell, D.T. (1992): Charting the remote southern oceans with satellite altimetry and shipboard bathymetry. EOS; Trans., **73**, 85.

St. John, B. (1986): Antarctica — Geology and hydrocarbon potential. Future Petroleum Provinces. Am. Assoc. Petrol. Geol. Mem., **34**, 55–100.

Tanahashi, M., Ishihara, T., Yuasa, M., Murakami, F. and Nishimura, A. (1997): Preliminary report of the TH95 geological and geophysical survey results in the Ross Sea and Dumont d'Urville Sea. Proc. NIPR Symp. Antarct. Geosci., **10**, 36–58.

Tanahashi, M., Matsuyama, T., Tokuhashi, S. and Oda, H. (1998): Preliminary report of the TH96 geological and geophysical survey results in Bransfield Strait and its vicinity. Polar Geosci., **11**, 90–111.

Tanahashi, M., Eittreim, S. and Wannesson, J. (1994): Seismic stratigraphic sequences of the Wilkes Land Margin. The Antarctic Continental Margin: Geophysical and Geological Stratigraphic Records of Cenozoic Glaciation, Paleoenvironments, and Sea-Level Change, Antarctic Offshore Acoustic Stratigraphy Project (ANTOSTRAT) Symposium, Siena, 391–393.

Tanahashi, M., Nishimura, A., Oda, H. and Murakami, F. (1999): Preliminary report of the TH97 geological and geophysical survey results, north of the Antarctic Peninsula. Polar Geosci., **12**, 192–214.

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.

Yamaguchi, K., Tamura, Y., Mizukoshi, I. and Tsuru, T. (1988): Preliminary report of geophysical and geological surveys in the Amundsen Sea, West Antarctica. Proc. NIPR Symp. Antarct. Geosci., **2**, 55–67.

Wessel, P. and Smith, W.H.F. (1991): Free software helps map and display data. EOS; Trans., **72**, 445–446.

(Received March 1, 2001; Revised manuscript accepted May 9, 2001)