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PRELIMINARY REPORT OF THE TH96 GEOLOGICAL AND GEOPHYSICAL SURVEY RESULTS IN BRANSFIELD STRAIT AND ITS VICINITY

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Abstract: Geophysical and geological surveys of the JNOC TH96 cruise on the R/V HAKUREI-MARU, in the Pacific margin of the northern Antarctic Peninsula, were carried out in the 1996–97 austral summer season. The early and later halves of the cruise were devoted to a continental margin survey of the western and northern margins of the northern Antarctic Peninsula, respectively. The seismic data are interpreted together with the data which were aquired in this area during JNOC TH80, 88 and PetroBras and British Antarctic Survey cruises.

The geophysical data in the southwestern margin show typical passive continental margin character with abyssal plain-continental slope-continental shelf from sea to land. The thickness of the sedimentary sequence in the abyssal plain is about 3 s (twt). The development of the continental rise between abyssal plain and continental slope is very poor, compared with more mature passive continental margins.

The area north of the Antarctic Peninsula is interpreted as the triple junction area among the Antarctic-Scotia-(former) Phoenix plates. The seismic data in the area show distributed highly deformed sedimentary basins and volcanic features. The deformation trend is interpreted to be controlled by the regional trend of sinistral trans-tensional movement between the Antarctic and Scotia plates.

key words: Pacific Margin of northern Antarctic Peninsula, Bransfield Strait, marine geological and geophysical surveys, sedimentary sequences

1. Introduction

The Technology Research Center, Japan National Oil Corporation 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 already 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).

This paper reports the preliminary survey results in the Pacific Margin of the northern Antarctic Peninsula, which was surveyed during the TH96 cruise.

The TH96 survey cruise was planned to survey mainly the continental margin west and north of the northern Antarctic Peninsula. The geophysical survey lines were planned to complement the previous surveys of JNOC (TH80 and TH88 cruises in the Bellingshausen Sea, west of the Pacific margin of the Antarctic Peninsula and in and around of the Bransfield Strait, respectively), PetroBras (GAMBÔA and MALDONADO, 1990) and British Antarctic Survey (LARTER and BARKER, 1991b).

The tectonic setting of the TH96 survey area is shown in Fig. 1. A topographic map of the area is shown in Fig. 2. The survey area lies in the Pacific margin of the northern Antarctic Peninsula, which comprises active and passive continental margins in the north and south, respectively, bordered by the Hero Fracture Zone (LAWVER *et al.*, 1996). The South Shetland Trench-South Shetland Islands-Bransfield Basin forms an apparent island arc-trench topographic profile, in the north. The continental slope width decreases from northeast to southwest-from about 50 km in the northeast to 10 km in the southwest. The oceanic basin-continental rise-continental slope-continental shelf consists of typical passive margin profile in the south, in contrast. The tectonic difference between these continental margin structures is interpreted from the difference of the tectonics of the oceanward oceanic plate. That is, inactive spreading centers, which are interpreted as stopping at about 4 Ma (LARTER and BARKER, 1991a), are observed offshore of the South Shetland Trench; in contrast, there is no such structure in the south. This structure and the interpretation of magnetic anomaly suggest that there was subduction of the spreading ridge and successive stopping of the oceanic plate subduction in the south, from 25 to 3.5 Ma (LARTER and BARKER, 1991a). The timing of the ridge subduction differs segment by segment of the spreading ridge. The continental margin in this area was interpreted to have been converted from an active to a passive one after the subduction of the ridge (LARTER and BARKER, 1991a).

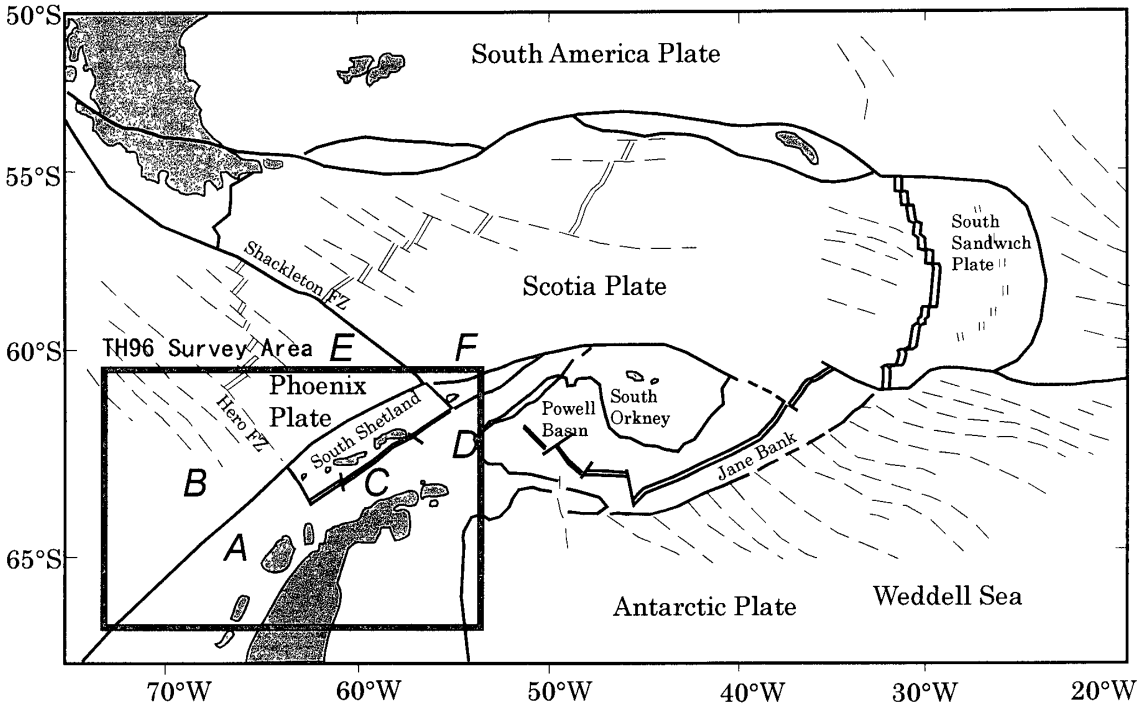

Fig. 1. Tectonic setting of the TH96 survey area of the Pacific margin of the northern Antarctic Peninsula. Modified from GALINDO-ZALDIVAR et al. (1994). A to F show the area codes for seismic stratigraphical description in this paper.

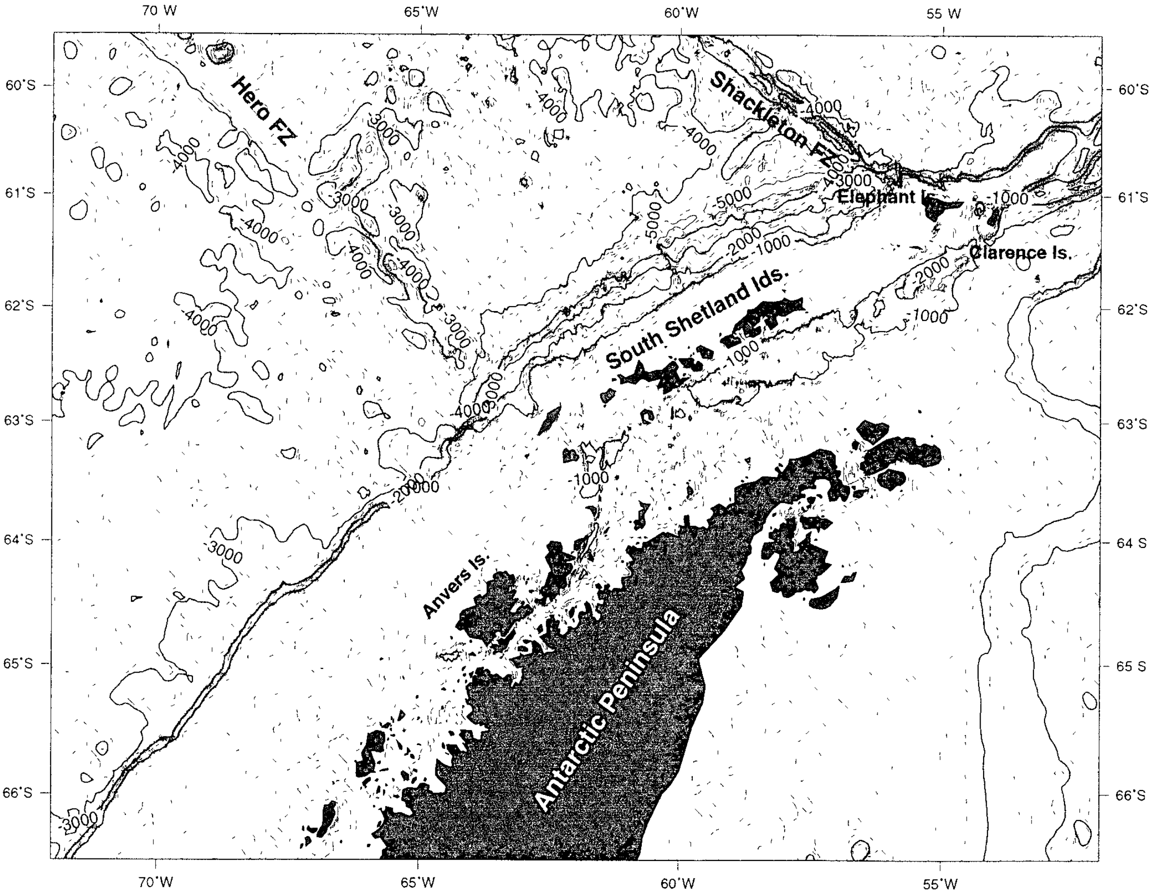

Fig. 2. Topographic map drawn by GMT (WESSEL and SMITH, 1991) using estimated topographic data file from the satellite altimetry by SANDWEL and SMITH (1992). Contour intervals are 1000 m and 200 m.

There was a triple junction between Antarctica, Scotia, and the former Phoenix plates until the stop of spreading in the northern part at about 4 Ma (LAWVER *et al.*, 1996). The boundaries of these plates are the South Scotia Ridge, Shackleton Fracture Zone, and South Shetland Island Arc system. The South Scotia Ridge is developed between the Scotia Sea and Powell Basin on the Antarctic plate. The Shackleton Fracture Zone is the structure between the Scotia Sea and the former Phoenix plate. The South Shetland Island Arc system is composed of the South Shetland trench, islands and Bransfield basin, between the former Phoenix plate and the Antarctic Peninsula on the Antarctic plate. The triple junction in this area has been transformed into a single plate boundary between the Scotia and Antarctic plates since 4 Ma. The extensional features in Bransfield Strait can be interpreted by a trench roll-back model (LAWVER *et al.*, 1996). The cooling slab under the trench sinks and pulls the fore-arc lithosphere. The extensional features in the South Scotia Ridge are interpreted through the trans-tensional tectonics caused by re-organization of the plate boundary.

2. Outline of Survey Methods

The marine geological and geophysical survey of the TH96 cruise was carried out from January 6 to January 31, 1997. The data and samples which were acquired during the TH96 cruise are listed in Table 1. A summary of TH96 survey methods with specifications of equipment and operating conditions is given in Table 2.

The seismic source was towed by two cables equipped with two GI (Generator-Injector) guns each. The GI gun chambers were set for "true GI mode, 45 + 105 cubic inches" (9.8 *l*), in all area targeting finer resolution over the shallow shelf. A 24 bit,

Table 1. Summary of the TH96 cruise.

Survey period	38 days
Seismic reflection survey	2474 km
Seismic refraction survey	5 sites
Magnetic and gravity survey	17342 km
Gravity coring	10 sites
Heat flow measurement	9 sites

Table 2. Summary of survey equipment and operating conditions.

Survey	Instrument (specification) and operating conditions	
Multichannel seismic reflection (MCS)	Source:	4 × SSI GI-guns (45 cu-in. generator + 105 cu-in. injector) air pressure is 2000 psi (13.8×10^6 Pa)
	Receiver:	Alliant Technology 24 bit digital streamer cable (12.5 m × 8 ch/100 m/section × 24 sections = 192 ch 2400 m in total)
	Recorder:	Alliant Technology AESOP seismic recorder
	Sampling interval:	4 ms
	Record length:	10 s
	Shot interval and ship speed:	*ca* 50 m, 24 s with 4.4 knot
	CMP coverage:	2400%
Seismic refraction	Source:	4 × GI guns (concurrent with MCS)
	Receiver:	DTC6030 digital Ocean Bottom Seismometer (3 geophones with a hydrophone)
Gravity	Lacoste & Romberg SL-2 gravimeter	
Magnetics	Geometrics G-811G proton gradiometer during MCS Geometrics G-866 proton magnetometer during other than MCS Tera Teknika three component shipboard magnetometer	
Bathymetry	12 kHz PDR system (Raytheon CESPIII with PTR and LSR1811)	
Subbottom profiling	3.5 kHz SBP system (Raytheon CESPIII with PTR and EPC)	
Bottom sampling	Gravity corer	
Heat flow measurement	Nichiyu Giken GS-type, 5 channels Thermal conductivity meter: Kyoto Denshi QTM-D3	

192 channel digital streamer cable and recording system were used.

All the reflection and refraction seismic data were thoroughly processed by JAPEX/GeoScience Inc. after the cruise. All the reflection seismic data were processed by the "reducing multiple reflection method" to reduce extremely strong sea bottom multiple reflections in the continental shelf area. A conventionally filtered CMP (Common Mid-Point) stack result was used as the standard data set for the interpretation. In addition, all of the profiling data were used for time migration and further depth conversion processing. The plotting scales are unified in this report with a vertical exaggeration of 8.33.

3. Geological Sampling and Heat Flow Measurements

A summary of sampling sites and samples and heat flow measurement results is given in Table 3. Sampling sites are shown in Fig. 3. Although we attempted to recover pre-Quaternary strata in the thin post glacial sediment cover area in most of the gravity cores, deep penetration was usually prevented by the coarse surficial sediment. GC1707 was targeted to sample recent sediments at a site close to the thermogenic hydrocarbon as reported by WHITICAR *et al.* (1985).

GC1702, 1705 and GC1707 yield mostly latest Pleistocene radiolarian fauna and the sampled sediments are interpreted to be deposited at the age. Although radiolarian fauna from GC1710 have been correlated with the *Helotholus vema* Zone and interpreted to have been deposited in the early Pliocene, it may have been during the Pleistocene because only one young species, *Prunopyle antarctica*, which shows a younger zone has been identified. Although radiolarian fauna from GC1703, 1704, and GC1709 could not be correlated precisely they seem to have been deposited post-Miocene. Most cores, *i.e.*, GC1702, GC1703, GC1704, GC1705, GC1709 and GC

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

Site	Lat. (S)	Lon. (W)	Depth (m)	Recovery	Description	T.C.	H.F.
GC1701	64°35′55″	64°40′59″	310	0.00 m	hit by gravel ?		
GC1702	64°22′13″	65°11′58″	522	3.16 m	diatomaceous clay~silty clay	2.270	77.49
GC1703	63°52′16″	65°39′14″	451	1.59 m	silt sand~silt, silty clay with gravel	3.343	117.91
GC1704	64°01′25″	65°17′58″	470	0.76 m	diatomaceous sandy silt with gravel	3.335	
GC1705	63°12′16″	63°36′33″	368	1.33 m	grayish sandy silt, silty clay with gravel	2 875	
GC1706	63°24′02″	63°13′02″	190	0.00 m	hit by gravel		
GC1707	62°33′37″	57°50′29″	1564	3.50 m	grayish diatomaceous clay, volcanic ash	1.969	152.80
GC1708	61°09′48″	55°55′04″	120	0.00 m	possible stopper trouble		
GC1709	61°34′52″	56°01′00″	591	0.39 m	gray-olive black fine~medium sand with gravel		
GC1710	61°15′16″	56°58′44″	1584	2.75 m	dark brown fine sand, yellowish~dark gray silty sand	3.270	

Recovery: recovered core length,
T.C.: Thermal conductivity (10^{-3} cal/cm s °C), H.F.: Heat flow (mW/m^2).

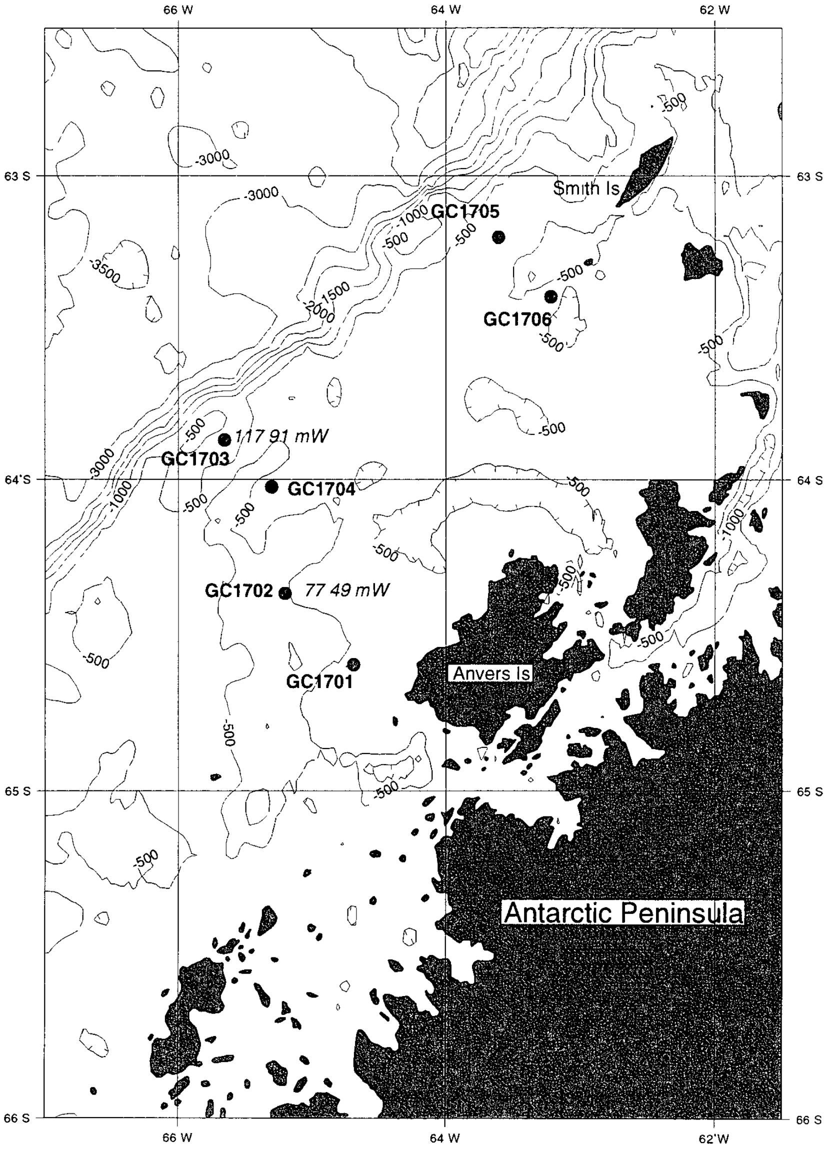

Fig. 3a. Gravity coring sites of the TH96 in the southwestern part of the Pacific margin of the northern Antarctic Peninsula. Values at GC1703 and GC1702 are the observed heat flows.

1710, yield reworked late Cretaceous radiolarian species.

Planktonic foraminifera analysis shows that the most common fauna of the TH96 gravity core samples are *Neogloboquadrina pachyderma*, interpreted to be deposited during the Plio-Pleistocene. *Globorotalia inflata*, which suggests the development of a temperate water mass, was identified from −262~−264 cm of GC1702. These fauna were reported from GC401, GC1101, and GC1201 from the Dumont d'Urville Sea (*c.f.* Sato *et al.*, 1984). Four benthonic foraminifer fauna, *i.e.*, 1) calcareous *Angulogerina* spp.-*Globocassidulina* spp. fauna, 2) calcareous *Bulimina aculeata*-*Fursenkoina davisi* fauna, 3) mixture of calcareous and arenaceous *Miliammina earlandi*-*Angulogerina earlandi* fauna, and 4) arenaceous *Miliammina earlandi* fauna, were detected from TH 96 cores. Reworked late Cretaceous planktonic foraminiferal fauna were recovered

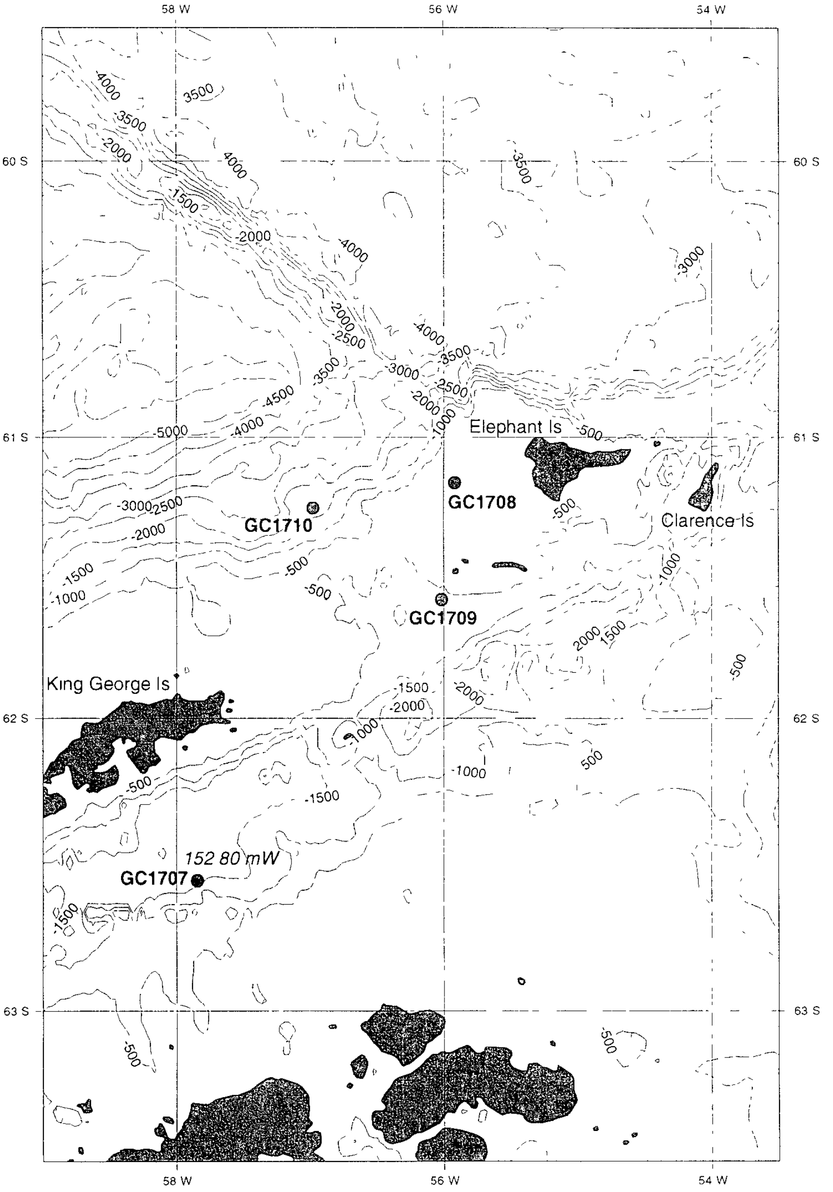

Fig. 3b. Gravity coring sites of TH96 north of the Antarctic Peninsula. The value at GC 1707 is the observed heat flow.

from GC1702 and GC1703.

Diatom fauna from TH96 gravity core samples consist of *Nitzschia curta, Nitzschia kerguelensis* and *Thalassiosira antarctica* and lack *Hemidiscus karstenii*, which indicates the base of the *N. kerguelensis* zone. Thus, the diatom fauna of all TH96 samples are correlated to the *N. kerguelensis* zone which is younger than 195 ky. There are reworked fauna including some species which had been believed to be extinct by the Pliocene or before from lower part of GC1710.

The paleontological analyses above suggest that all samples of TH96 cruise are from the Pleistocene, possibly younger than 195 ky. The frequent appearance of late Cretaceous reworked fauna suggests that extensive erosion of the late Cretaceous strata occurred during the Plio-Pleistocene age in the survey area.

4. Gravity and Magnetic Surveys

Gravity anomaly data which were obtained during the TH96 cruise are plotted in Fig. 4a and 4b. Although most of the gravity anomaly pattern is well correlated with the topography, a series of linear structures, which is parallel to the Antarctic Peninsula and continental shelf margin, is characteristic offing Anvers Island in the southwestern part of the TH96 cruise region. This gravity high and trough structure suggests the development of a subsurface sedimentary basin and basement high along the continental shelf. Another anomalous structure is the gravity low in the flat continental shelf area and the continental slope west and southwest of Elephant Island. This suggests the development of a thick sedimentary basin in the triple junction area.

Magnetic anomaly data which were obtained during the TH96 cruise are plotted in Fig. 5a and 5b. There is a narrow positive anomaly at the continental slope in the southwestern part of the survey area (Fig. 5b). Wide and high amplitude positive anomalies developed along the peninsula margin in the middle of the shelf. A broad negative anomaly, which has a small positive anomaly inside, is developed on the outer continental shelf between those parallel positive anomalies (Fig. 5b). The negative anomalies well correlated with the gravity low, suggesting the development of a

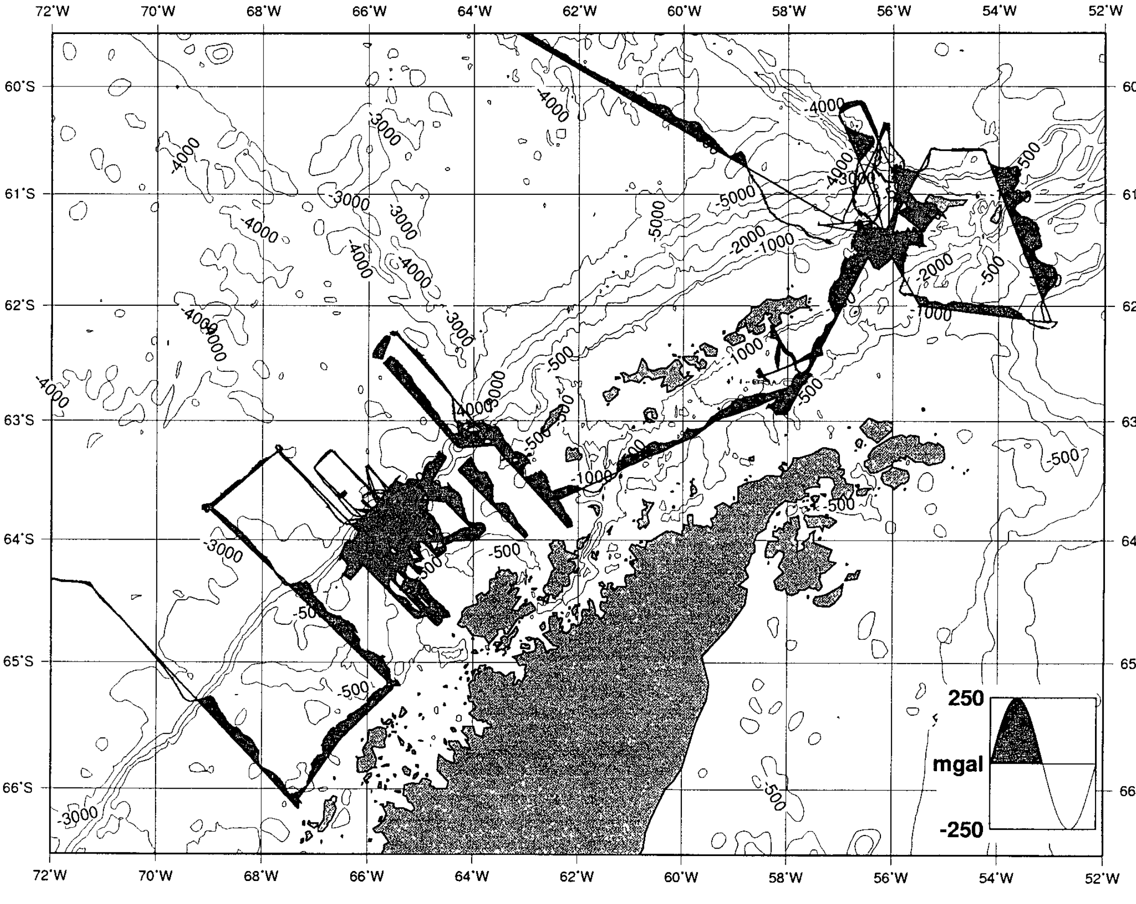

Fig. 4a. Free-air gravity anomaly profiles along the ship's track during the TH96 cruise in the Pacific margin of the northern Antarctic Peninsula.

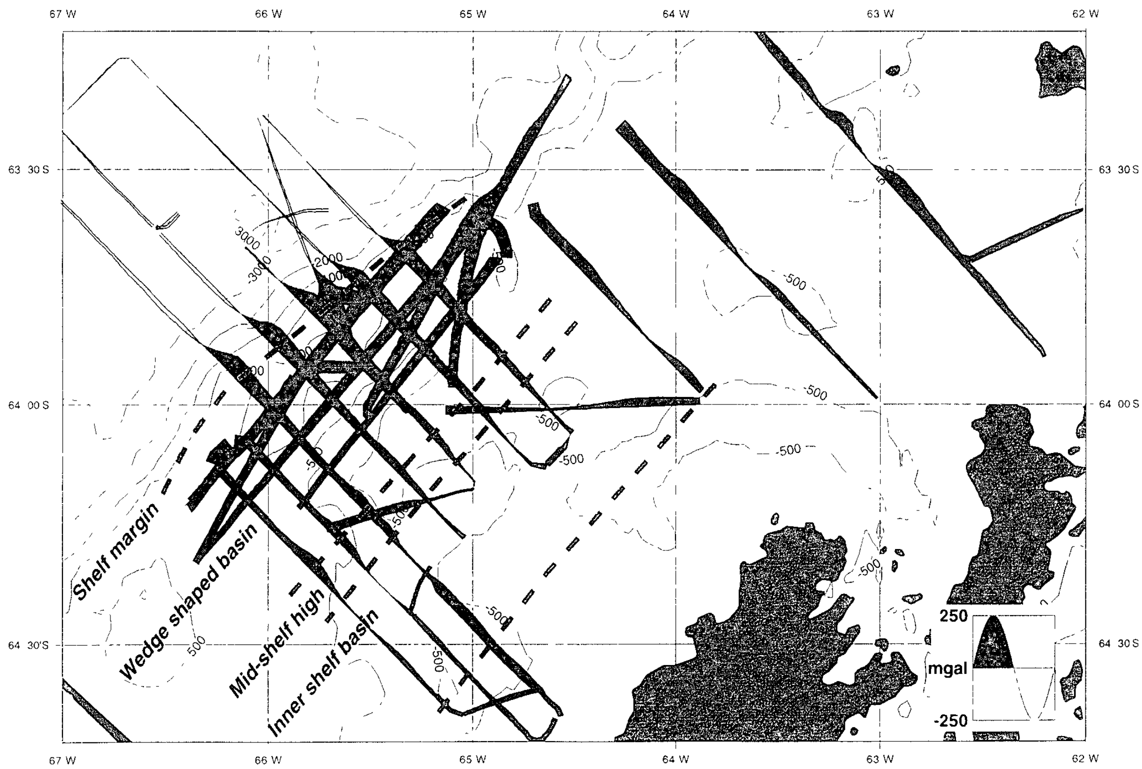

Fig. 4b. Detailed free-air gravity anomaly profiles along the ship's track during the TH96 cruise in the southwestern part of the Pacific margin of the northern Antarctic Peninsula. Gray dashed lines show structure boundaries on the continental shelf.

sedimentary basin. The magnetic anomaly around Elephant Island is highly variable; most of the characteristic anomalies can be correlated with the topographic or subsurface structure (Fig. 5a).

5. Preliminary Interpretation of Seismic Survey Results

Seismic survey lines of the TH96 cruise are shown in Figs. 6a and 6b. A refraction seismic survey using five Ocean Bottom Seismometers (OBS) was carried out over the outer continental shelf offshore of Anvers Island. The five OBSs were set as a cross pattern in the NW-SE (OBS4, 2, and 1) and NE-SW (OBS-3, 2, and 5) directions (Fig. 6b). The observations were carried out during the 12SMG and 13SMG reflection surveys. The seismic signal was detected with three component geophones and hydrophone sensors, and digitally recorded on a magneto-optical disk. An example of the OBS record is shown in Fig. 7 and the analyzed seismic structure is given in Table 4.

Although fairly extensive previous survey cruises have been carried out by many organizations in and near the TH96 survey area (ANDERSON, 1991; BANSFIELD and ANDERSON, 1995; BARKER and AUSTIN, 1994; BART and ANDERSON, 1995; BOCHU *et al.*, 1995; CAMERLENGHI *et al.*, 1994; CUNNINGHAM *et al.*, 1995; GAMBÔA and MALDONADO, 1990; GRACIA *et al.*, 1996; GRAPE TEAM, 1990; JEFFERS and ANDERSON, 1990; JIN *et al.*, 1996; KIM *et al.*, 1995; LARTER and BARKER, 1991a; LARTER and BARKER, 1991b; LAWVER *et al.*, 1996; LODOLO *et al.*, 1993), subsurface geological information is very

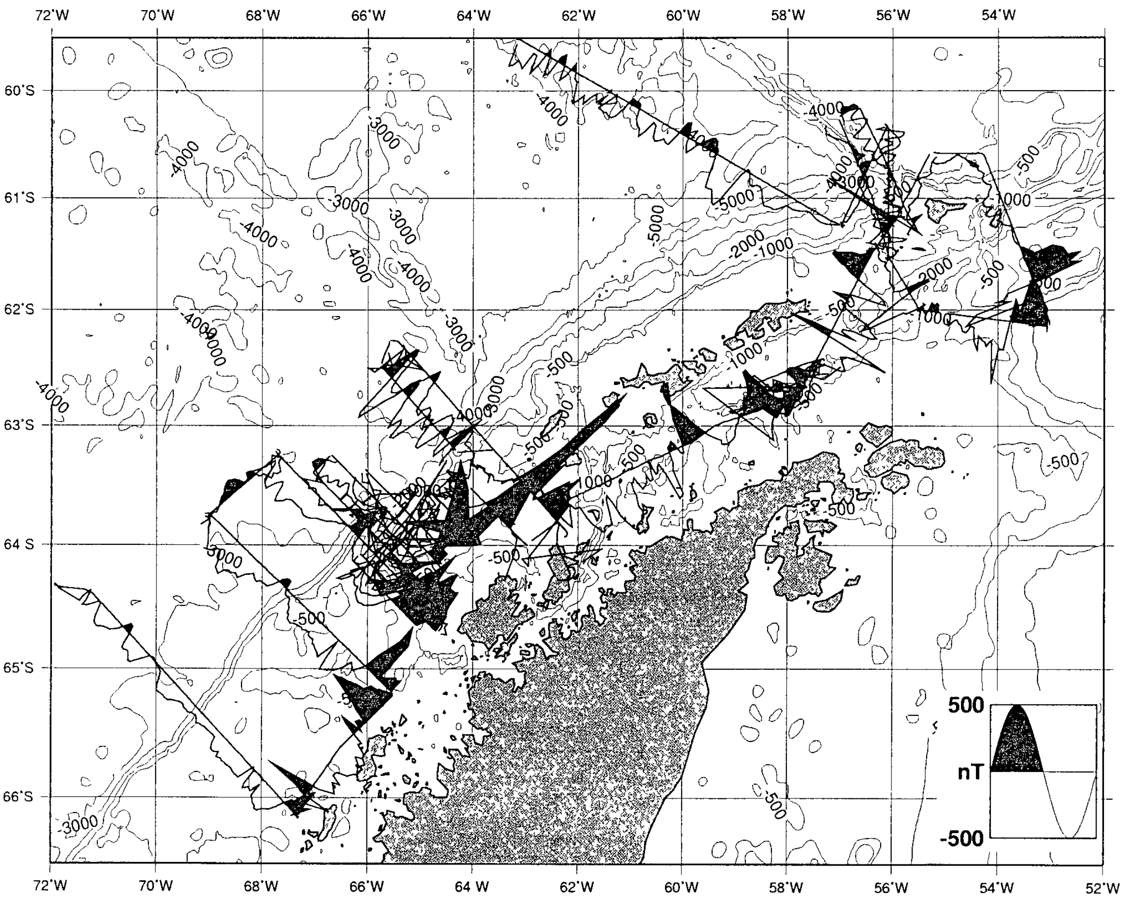

Fig. 5a. Total magnetic anomaly profiles along the ship's track during the TH96 cruise in the Pacific margin of the northern Antarctic Peninsula.

much limited and most of the authors interpret the subsurface geology by correlation to the land geology and far DSDP drilling results on the ocean floor. Thus, the seismic interpretation in this paper is highly preliminary as well. On the other hand, the cruise of the Ocean Drilling Program in the Pacific margin of the northern Antarctic Peninsula, Leg 178, has been completed recently, so that more complete interpretation with the reference to the drilling results will be possible in the near future.

Typical seismic reflection profiles of the TH96 cruise are shown in Figs. 8a–8e. The seismic sequences cannot be traced in the whole area because of the complex and variable tectonic environment. Thus, the TH96 survey area was divided into six sub-areas, *i.e.*, Western shelf area (A), Western deep ocean area (B), Bransfield Strait area (C), Powell Basin area (D), Northern deep ocean (former Phoenix plate) area (E), and Scotia Basin area (F), for convenience in interpretation. A preliminary stratigraphic correlation table of these areas in TH96 survey area is given in Table 5. The depth and layer thickness along the seismic section are given with the two way travel time (TWT) in seconds together with the interpretation of seismic data.

5.1. Western shelf area (A)

This area is the continental shelf area in the western Pacific margin of the northern

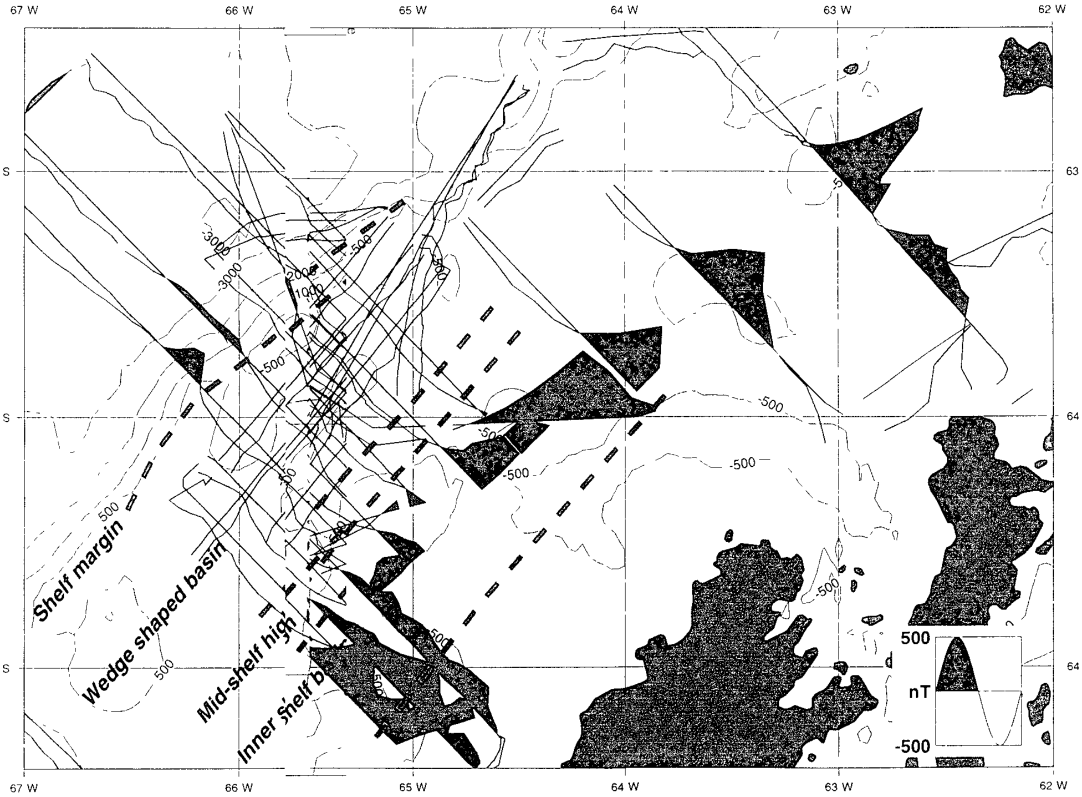

Fig. 5b. Total magnetic anomaly profiles along the ship's track during the TH96 cruise in the southwestern part of the Pacific margin of the northern Antarctic Peninsula. Gray dashed lines show structure boundaries on the continental shelf.

Antarctic Peninsula. A basement high (mid-shelf high, Barker, 1995) has developed in the middle of the shelf in NE-SW direction, parallel to the shelf edge and the peninsula coast (2SMG, Fig. 8a, 6SMG, Fig. 8b, and 22SMG, Fig. 8c). A wedge-shaped sedimentary basin is developed on the outer side of the mid-shelf high (Figs. 8a, 8b, 8c). Although the base of the basin, *i.e.*, base of the sequence A4 is not visible at the shelf margin area, the maximum depth is estimated to possibly exceed 4 s on the profile 6SMG (Fig. 8b). The wedge-shaped basin is filled by typical oceanward prograding sedimentary sequences in the upper part. The basin shape suggests that continuous subsidence occurred in the shelf margin area. If the subsidence began at about 10 Ma, the subduction age of the Antarctic-Phoenix spreading center estimated by Larter and Barker (1991b), the principal sequences A1-A3 in the wedge shaped basin are mainly composed of Late Miocene or younger formations.

The mid-shelf high, which bounds the wedge shaped shelf marginal basin, corresponds to the gravity high which is associated with the inner edge of the negative magnetic anomaly in some cases (Figs. 4b and 5b). The mid-shelf high is well continued from 2SMG (Fig. 8a) to the southwestern end of the South Shetland Islands, Smith Island, which is on the extension of the Hero Fracture Zone to the continental shelf. A Late Mesozoic to Neogene forearc accretion complex is developed on Smith Island (British Antarctic Survey, 1985), and the mid-shelf high is estimated to be composed of that accretion complex.

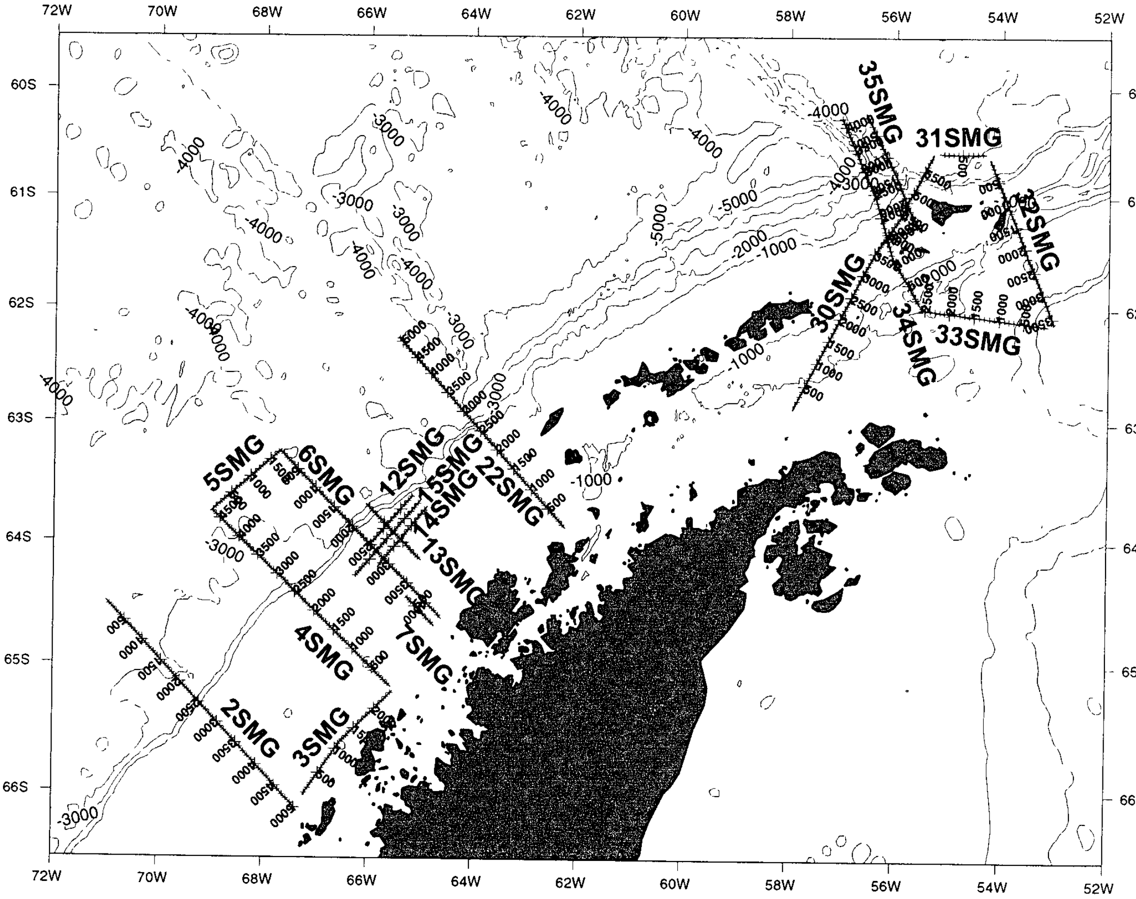

Fig. 6a. Multichannel seismic reflection survey lines during the TH96 cruise.

There is a small-scale synclinal sedimentary basin on the inner side of the mid-shelf high. The maximum thickness of the sedimentary sequence of the inner shelf basin is about 1.5 s on 6SMG (Fig. 8b). The basin corresponds to the high positive magnetic anomaly zone along the peninsula margin (Fig. 5b). The basin is not well observed on profile 2SMG (Fig. 8a).

5.2. Western deep ocean area (B)

Smooth, flat, well continued sedimentary sequences, 1.0–1.5 s in total thickness, are developed in the oceanic basin area offshore of the southwestern Pacific margin of the northern Antarctic Peninsula (Figs. 8a and 8b). There is a DSDP hole, site 325, which reaches to the Oligocene sedimentary sequence intervening 8–15 Ma hiatus, at 65.05S, 73.67W (HOLLISTER *et al.*, 1976) in the western part of the TH96 survey area. The sedimentary sequence in the basin overlies the Early to Late Miocene oceanic basement, the age of which is estimated from magnetic anomaly analysis (LARTER and BARKER, 1991a). The basement acoustic character is highly variable from very rough on 6SMG (Fig. 8b) to very smooth on 2SMG (Fig. 8a).

The thickness of sedimentary sequences on 22SMG decreases 0.5 s (Fig. 8c) because the survey line is close to the Hero Fracture Zone. There is a wider continental slope on 22SMG, 30 km, than that on 2SMG and 6SMG, only 10 km. The gentle lower

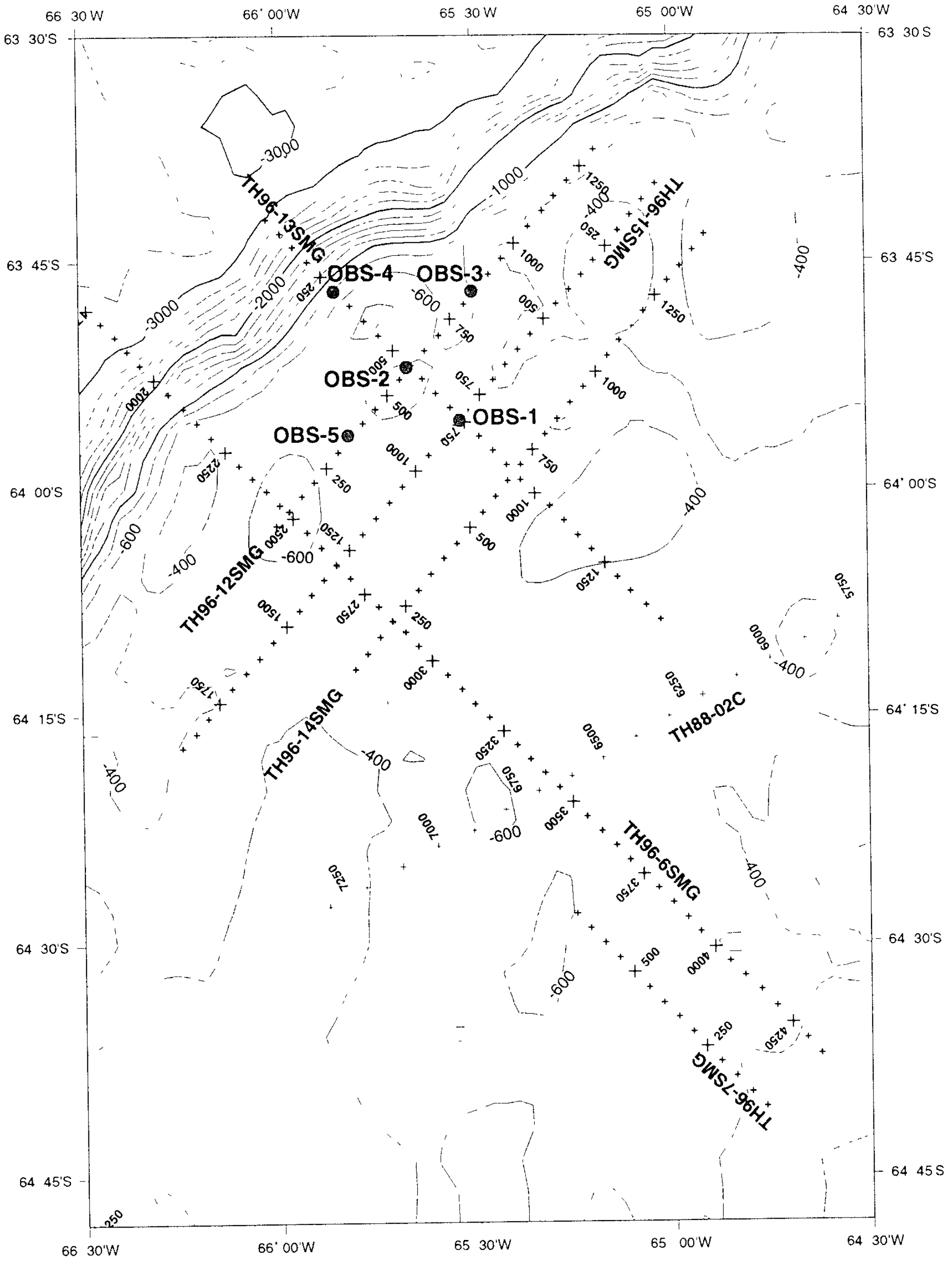

Fig. 6b. Multichannel seismic reflection survey lines in the outer shelf offshore of Anvers Island. Solid circles show OBS sites.

slope shows the active accretion complex structure including steps on the bottom and reverse fault development; even 22SMG lies west of the Hero Fracture Zone. The oceanic basement offshore of the continental slope inclines gently landward. These features suggest that some of the oceanic plate subduction has occurred recently.

There is an erosional depression in front of the continental slope from 22SMG (Fig. 8c) to 2SMG (Fig. 8a). It is interpreted to have been developed by the activity of southwest-moving bottom current along the continental slope (Nowlin and Zenk, 1988). The development of sedimentary drift, which is well developed outside of the depression southwest of the present survey area (Rebesco *et al.*, 1996), is not very well

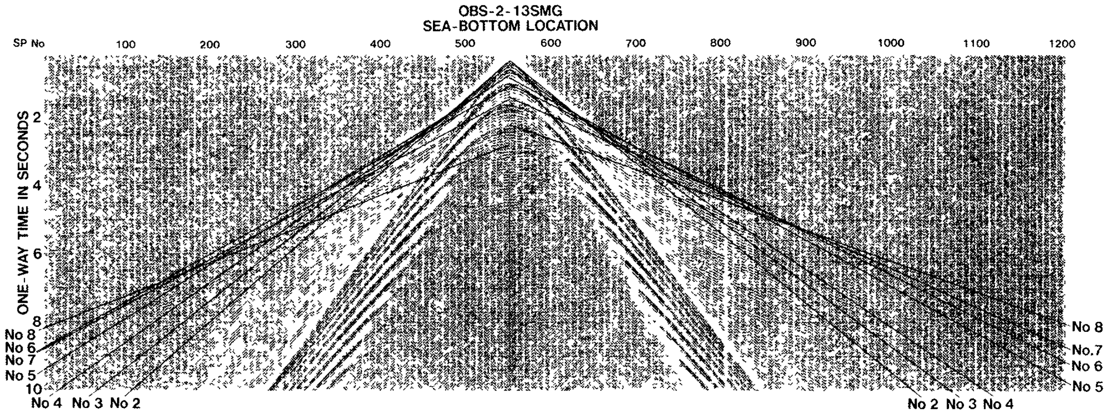

Fig. 7. A sample Ocean Bottom Seismometer (OBS) record during the TH96 cruise. OBS2 on Line 13SMG.

Table 4. Velocity structure resolved from Ocean Bottom Seismometer observation during the TH96 cruise.

Site No.	OBS-1		OBS-2		OBS-2		OBS-3		OBS-4		OBS-5	
Survey line	13SMG		12SMG		13SMG		12SMG		13SMG		13SMG	
Latitude	63°55.5288′S		63°51.9990′S		<—		63°47.0010′S		63°47.0010′S		63°56.5074′S	
Longitude	65°32.0064′W		65°40.0026′W		<—		65°30.0234′W		65°50.9856′W		65°48.9930′W	
Layer	V	T	V	T	V	T	V	T	V	T	V	T
1	1491	461	1491	466	1491	466	1491	427	1491	633	1491	434
2	2152	472	2406	727	2364	500	2219	404	1988	664	2405	472
3	3012	351	2519	60	2594	205	2550	208	2115	297	2777	472
4	3420	805	3443	504	2852	253	2972	357	2413	244	2909	317
5	3930	542	3754	1029	3361	735	3305	392	2753	1202	3757	687
6	4308	1330	4328	1334	3715	1212	3502	553	3186	1095	4536	1095
7	4987	2638	5239		4091	2259	3855	1312	4518	1897	5033	1555
8	6106				5315		4127	804	6506		6157	
							4731	376				
							5911					

V: Velocity (m/s), T: Thickness (m), Layer 1 is seawater.

observed on these survey lines.

5.3. *Bransfield Strait area (C)*

Lines 30SMG (Fig. 8d) and 34SMG (Fig. 8e) cross the Bransfield Basin. The Bransfield Basin is an extensional basin located at the back-arc basin position of the general island arc morphology. But the island arc activity stopped about 4 Ma or before and it lacks important tectonic features, such as island arc volcanic activity and deep inclined seismicity, of recent island arc activity (LAWVER *et al.*, 1996). The driving force to extend the basin is interpreted by the trench roll back model after the end of the oceanic spreading activity of the Antarctic-Phoenix spreading center at 4 Ma

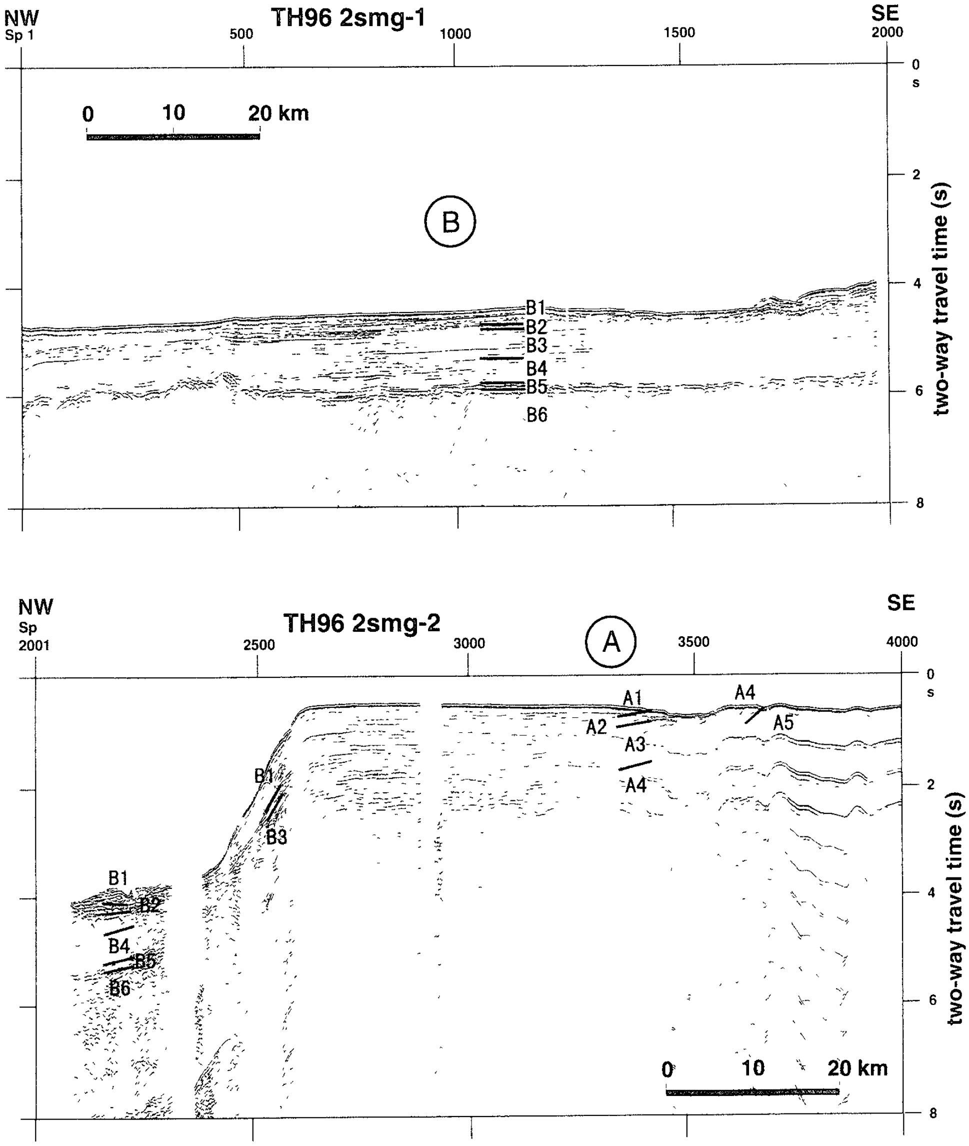

Fig. 8a(1)(2). Multichannel seismic reflection profile 2SMG in the southwestern continental shelf-deep ocean basin floor, off the Biscoe Islands. A capital letter in a circle shows the area code in this paper.

(Lawver *et al.*, 1996).

Sedimentary sequences in the basin can be seen only about 2 s deep. There is a volcanic high in the middle of the basin on the profile 30SMG (Fig. 8d). The high is a part of the linear volcanic ridge structure which is imaged clearly by multibeam bathymetric surveys (Lawver *et al.*, 1996; Gracia *et al.*, 1996). The southwestern side of the basin shows a progradational sequence pattern and a block fault pattern, and forms a passive continental margin type structure (Figs. 8d and 8e). The main part of the basin floor (30SMG SP750-1470; Fig. 8d) is covered by weakly deformed stratified sedimentary sequences, 0.7 to 0.8 s in thickness, which overlies semi-opaque deformed sedimentary sequences, 1.0 s or more in thickness. The lower sequences in the basin continue from the shelf margin area, which is a typical rifted margin. Deformation of

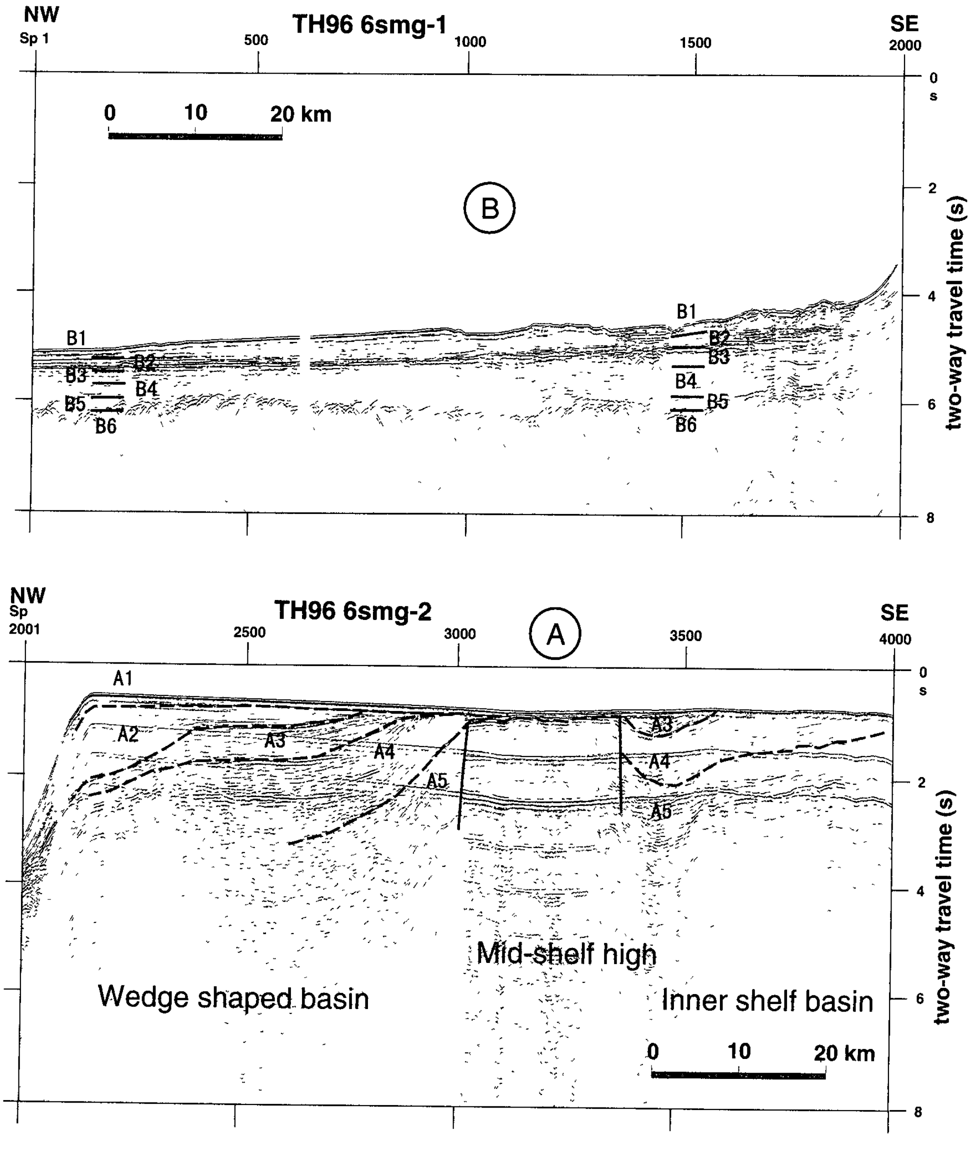

Fig. 8b(1)(2). Multichannel seismic reflection profile 6SMG in the southwestern continental shelf-deep ocean basin floor, off Anvers Island. Interpreted seismic sequence boundaries are drawn on the profile. A capital letter in a circle shows the area code in this paper.

lower sequences in the basin is interpreted as an extensional structure caused by rifting. This may suggest that the seafloor spreading has not begun or has just commenced in this part of Bransfield Basin.

The erosional feature of the upper sedimentary sequences is developed in front of the shelf slope, along the southwestern basin margin, as in front of the deep continental slope in the Pacific margin of the northern Antarctic Peninsula (Figs. 8a, 8b and 8c). In contrast, it is not observed along the northwestern margin.

5.4. *Powell Basin area (D)*

There are only short survey lines which cover Powell Basin, east of the northern

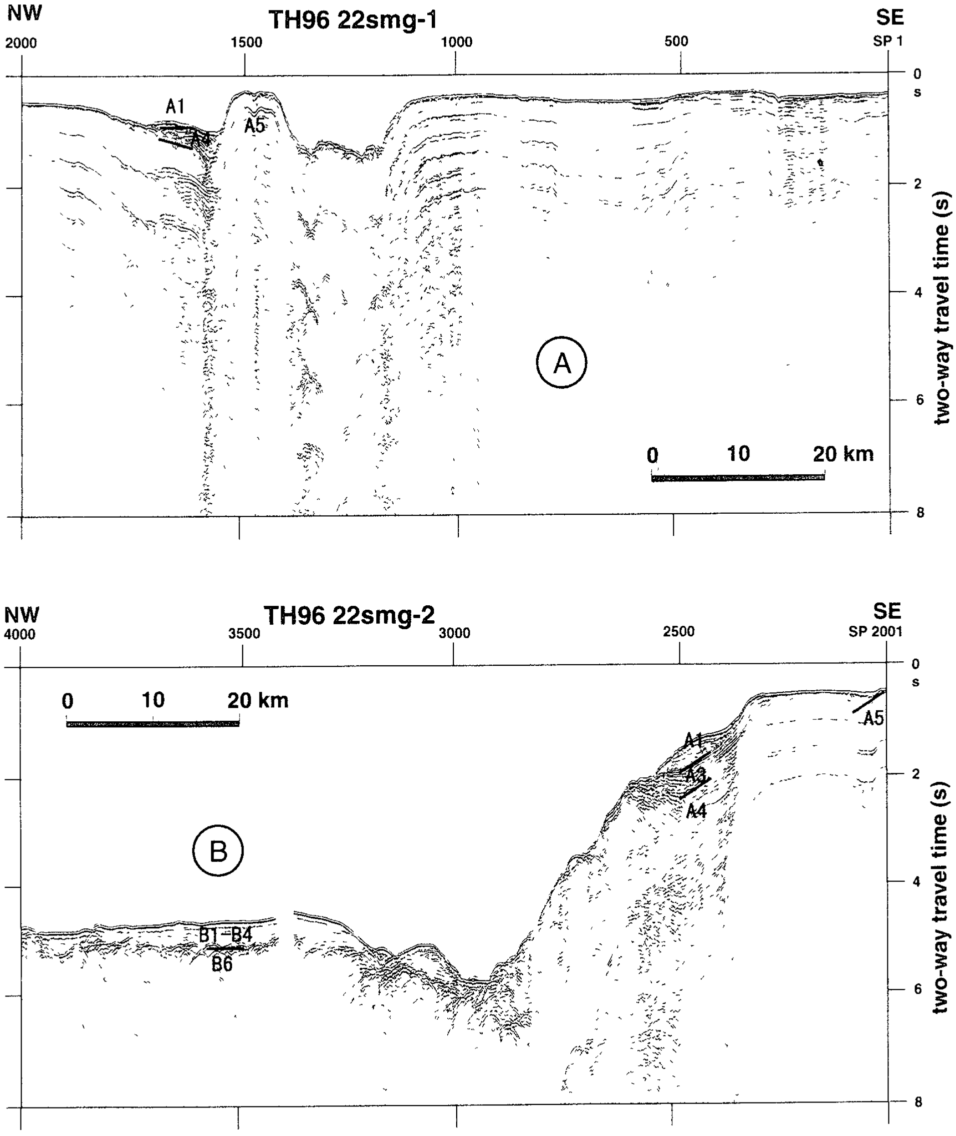

Fig. 8c(1)(2). Multichannel seismic reflection profile 22SMG in the southwestern continental shelf-deep ocean basin floor, off Brabant Island. A capital letter in a circle shows the area code in this paper.

shelf of the Antarctic Peninsula. The seismic character of the sequences resembles those in the Bransfield Strait area. The maximum sedimentary thickness in the basin is about 3 s. The basin is believed to have developed in the mainly Late Oligocene to Early Miocene age as a pull apart oceanic basin (Coren *et al.*, 1997).

5.5. *Northern shelf and deep ocean area (E)*

This area includes the former Phoenix Plate area and the continental shelf west of Bransfield Basin (30SMG and 34SMG, Figs. 8d and 8e). There is a severely deformed thick sedimentary basin area in the shelf southwest of Elephant Island. The distribution of the sedimentary sequences is not clear because it is highly variable and the survey line density is too low.

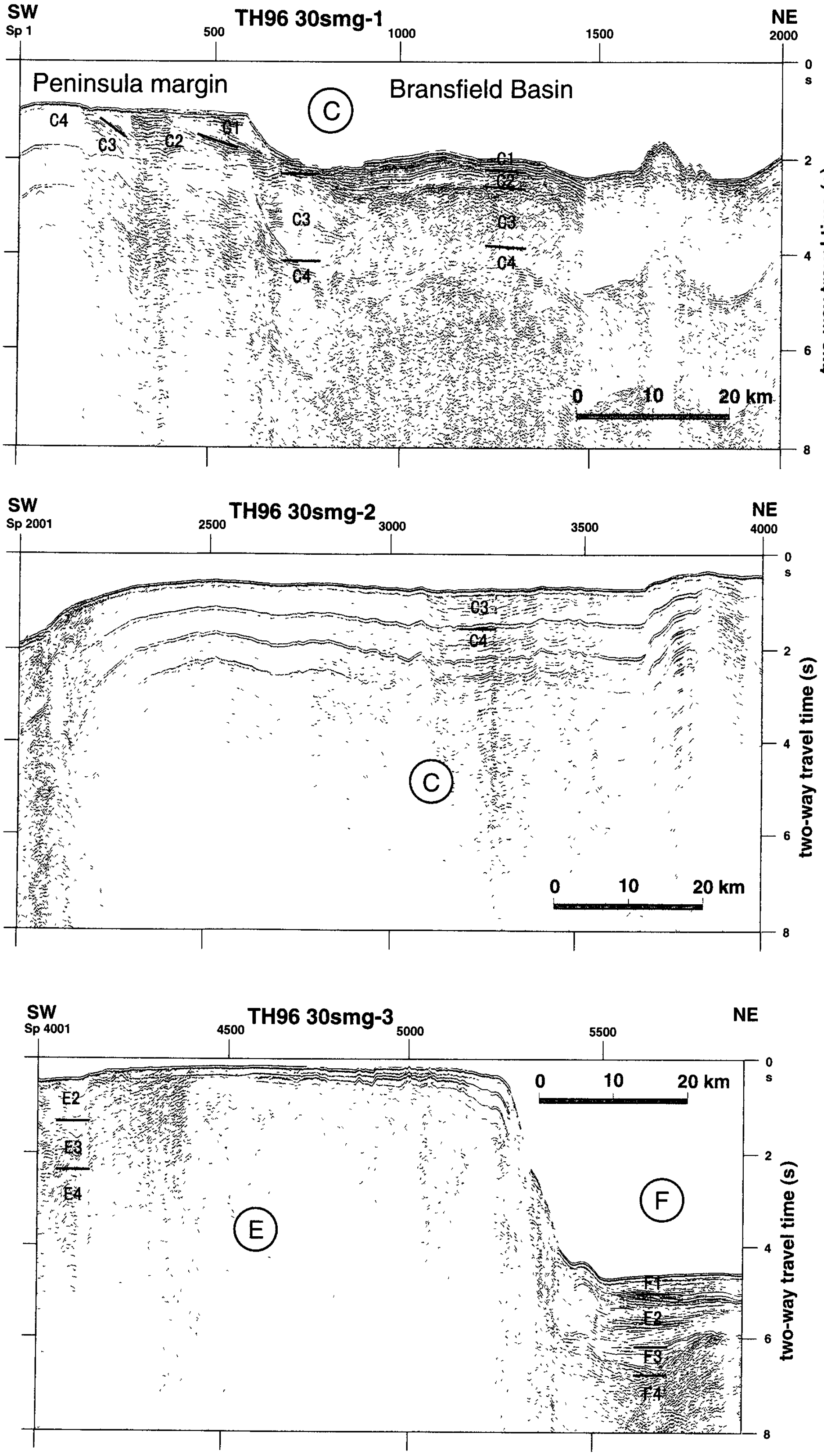

Fig. 8d(1)(2)(3). Multichannel seismic reflection profile 30SMG from the peninsular margin of the Bransfield Basin (SW) to the Scotia Sea Basin (NE), run through the continental shelf west of the Elephant Island. A capital letter in a circle shows the area code in this paper.

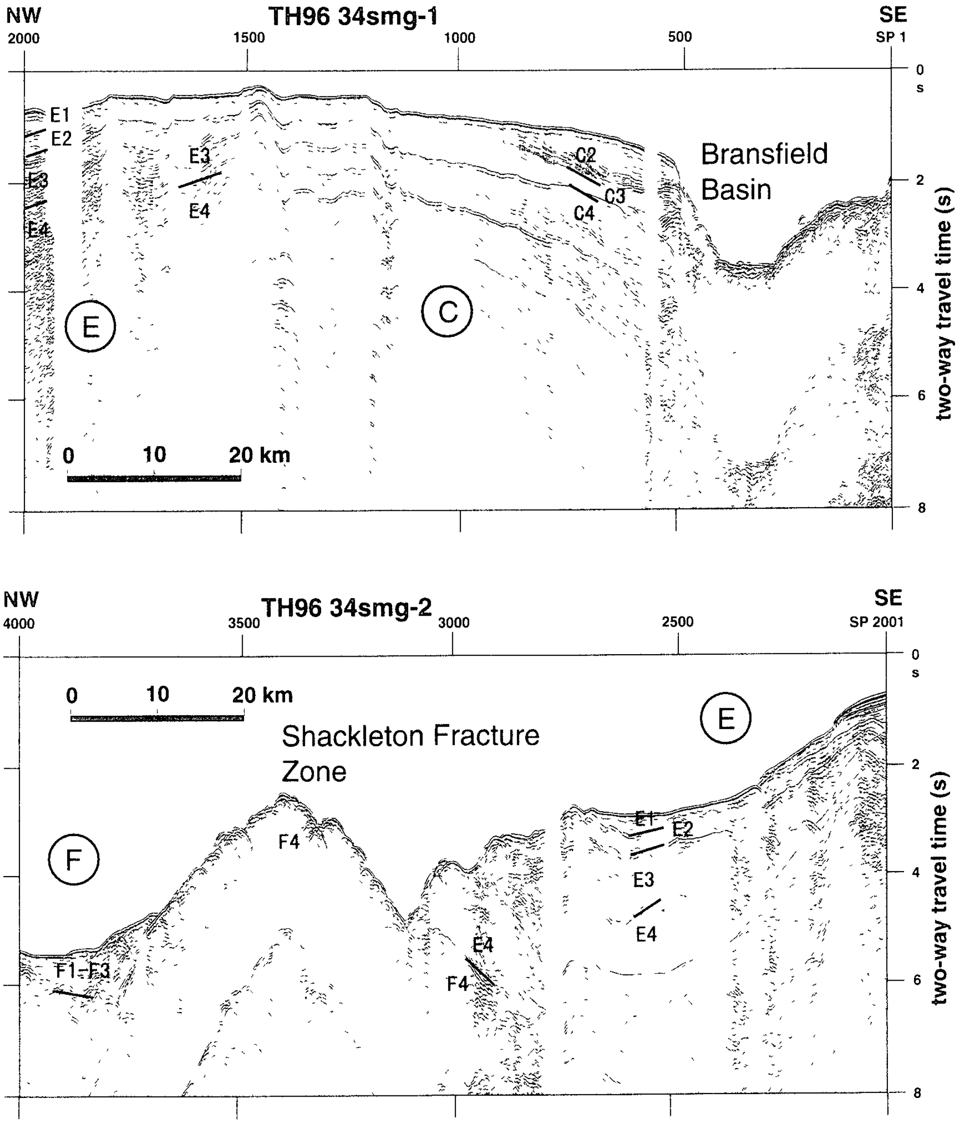

Fig. 8e(1)(2). Multichannel seismic reflection profile 34SMG from the Eastern Bransfield Basin (SE) to the Shackleton Fracture Zone (NW). A capital letter in a circle shows the area code in this paper.

Table 5. Preliminary correlation table of sedimentary sequences of offshore northern Antarctic Peninsula.

Area Age			Western Shelf	Western Deep Ocean	Bransfield Strait	Powell Basin	Northern Shelf and Deep Ocean	Scotia Basin
			A	B	C	D	E	F
Quaternary			A1	B1	C1+C2	D1+D2	E1+E2	F1+F2
Neogene	Pliocene		A2					
	Miocene	Late	A3	B2+B3				
		Middle	A4	B4+B5				F3
		Early		B6				
Paleogene	Oligocene							F4
	Eocene				C3	D3+D4	E3	
	Oligocene					D5		
Cretaceous			A5		C4		E4	

The continental slope on the profile 34SMG (Fig. 8e) shows a big slope collapse structure over the southeastern foot of the high of the Shackleton Fracture Zone. A southward dipping oceanic basement of Scotia Basin, north of Shackleton Fracture Zone, is observed at the northwestern end of profile 34SMG.

5.6. Scotia Basin area (F)

Scotia Basin (30SMG, Fig. 8d) has an Oligocene to Miocene oceanic basement (British Antarctic Survey, 1985). The boundary with the continental shelf is a steep slope. A 20 km wide 1 s deep depression is developed on the basement on the foot of the slope. Sediments filled the depression and overlie 1.5 s more. Sedimentary sequences deformed and make a small anticline in the southern part of the basement depression. The anticline appears in the youngest formation and suggests that the compressional tectonics is active across the boundary. Upper 0.5–0.75 s of the sedimentary sequences shows prominent sedimentary wave structures. Lower sequences show fairly gentle continuous character.

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References

Anderson, J.B. (1991): The Antarctic continental shelf: Results from marine geological and geophysical investigations. The Geology of Antarctica, ed. by R.J. Tingey. Oxford, Oxford Univ. Press., 285–334.

Bansfield, L.A. and Anderson, J.B. (1995): Seismic facies investigation of the Late Quaternary glacial history of Bransfield Basin, Antarctica. Geology and Seismic Stratigraphy of the Antarctic Margin, ed. by A.K. Cooper *et al.* Washington, D.C., Am. Geophys. Union, 123–140 (Antarct. Res. Ser., Vol. 68).

Barker, D.H.N. and Austin, J.A., Jr. (1994): Tectonic evolution of Bransfield Strait, Antarctica: Intracrustal diapirism, distributed extension and stratigraphic response to marginal basin rifting. Terra Antarct., **1**, 287–288.

Barker, P.F. (1995): The proximal marine sediment record of Antarctic climate since the Late Miocene. Geology and Seismic Stratigraphy of the Antarctic Margin, ed. by A.K. Cooper *et al.* Washington, D.C., Am. Geophys. Union, 25–57 (Antarct. Res. Ser., Vol. 68).

Bart, P.J. and Anderson, J.B. (1995): Seismic record of glacial events affecting the Pacific margin of the northwestern Antarctic Peninsula. Geology and Seismic Stratigraphy of the Antarctic Margin, ed. by A.K. Cooper *et al.* Washington, D.C., Am. Geophys. Union, 75–95 (Antarct. Res. Ser., Vol. 68).

Bochu, Y., Guangyu, W., Bangyan, C. and Shengyuan, C. (1995): The characteristics of geophysical field and tectonic evolution in the Bransfiled Strait. Antarct. Res., **6**, 12–23.

British Antarctic Survey (1985): Tectonic map of the Scotia Arc, 1: 3000000, BAS (Misc) 3. Cambridge; British Antarctic Survey.

Camerlenghi, A., Bohem, G., Vedova, B.D., Lodolo, E., Pellis, G. and Vesnaver, A. (1994): Seismic reflection tomography and thermal implications of a gas hydrate bottom simulating reflector on the

South Shetland margin (Antarctic Peninsula). Terra Antarct., **1**, 295–296.

Canals, M., De Batist, M., Baraza, J., Acosta, J. and GEBRA team (1994): New reflection seismic data from Bransfield Strait: Preliminary results of the GEBRA-93 survey. Terra Antarct., **1**, 291–292.

Coren, F., Ceccone, G., Lodolo, E., Zanolia, C., Zitellini, N., Bonazzi, C. and Centonze, J. (1997): Morphology, seismic structure and tectonic development of the Powell Basin, Antarctica. J. Geol. Soc., London, **154**, 849–862

Cunningham, A.P., Vanneste, L.E. and Antostrat Antarctic Peninsula Regional Working Group (1995): The ANTOSTRAT Antarctic Peninsula regional working group digital navigation compilation. Geology and Seismic Stratigraphy of the Antarctic Margin, ed. by A.K. Cooper *et al.* Washington, D.C., Am. Geophys. Union, 297–301 (Antarct. Res. Ser., Vol. 68).

Galindo-Zaldivar, J., Jabaloy, A., Maldonado, A. and Sanz De Caldeano (1994): Transtensional deformation and internal basin evolution in the South Scotia Ridge. Terra Antarct., **1**, 303–306.

Gambôa, L.A.P. and Maldonado, P.R. (1990): Geophysical investigations in the Bransfield Strait and in the Bellingshausen Sea, Antarctica. Antarctica as an Exploration Frontier—Hydrocarbon Potential, Geology, and Hazards, ed. by B. St. John. 127–141 (Am. Assoc. Pet. Geol. Stud. Geol., No. 31).

Gracia, E., Canals, M., Farran, M.L., Prieto, M.J., Sorribas, J. and Gebra Team (1996): Morphostructure and evolution of the Central and Eastern Bransfield Basins (NW Antarctic Peninsula). Mar. Geophys. Res., **18**, 429–448.

GRAPE Team (1990): Preliminary results of seismic reflection investigations and associated geophysical studies in the area of the Antarctic Peninsula. Antarct. Sci., **2**, 223–234.

Hollister, C.D., Craddock, C. *et al.* (1976): Initial Rep. Deep Sea Drill. Proj., **35**.

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.

Jeffers, J.D. and Anderson, J.B. (1990): Sequence stratigraphy of the Bransfield Basin, Antarctica: Implications for tectonic history and hydrocarbon potential. Antarctica as an Exploration Frontier—Hydrocarbon Potential, Geology, and Hazards, ed. by B. St. John. 13–29 (Am. Assoc. Pet. Geol. Stud. Geol., No. 31).

Jin, Y.K., Kim, Y., Kim, H.-S. and Nam, S.H. (1996): Preliminary results of seismic survey in the central Bransfield Strait, Antarctic Peninsula. Proc. NIPR Symp. Antarct. Geosci., **9**, 141–149.

Kim, Y., Kim, H.-S., Larter, R.D., Camerlenghi, A., Gambôa, L.A.P. and Rudowski, S. (1995): Tectonic deformation in the upper crust and sediments at the south Shetland Trench. Geology and Seismic Stratigraphy of the Antarctic Margin, ed. by A.K. Cooper *et al.* Washington, D.C., Am. Geophys. Union, 157–166 (Antarct. Res. Ser., Vol. 68).

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

Larter, R.D. and Barker, P.F. (1991a): Neogene interaction of tectonic and glacial processes at the Pacific margin of the Antarctic Peninsula. Sedimentation, Tectonics and Eustasy, ed. by D.I.M. MacDonald. 165–186 (Int. Assoc. Sedimentol. Spec. Publ., Vol. 12).

Larter, R.D. and Barker, P.F. (1991b): Effects of ridge crest-interaction on Antarctic-Phoenix spreading: Forces on a young subducting plate. J. Geophys. Res., **96**, 19583–19607.

Lawver, L.A., Sloan, B.J., Barker, D.H.N., Ghidella, M., Von Herzen, R.P., Keller, R., Klinkhammer, G.P. and Chin, C.S. (1996): Distributed, active extension in Bransfield Basin, Antarctic Peninsula: Evidence from multibeam bathymetry. GSA Today, Nov. 1996.

Lodolo, E., Camerlenghi, A. and Brancolini, G. (1993): A bottom simulating reflector on the South Shetland Margin, Antarctic Peninsula. Antarct. Sci., **5**, 207–210.

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.

Nowlin, W.D. and Zenk, W. (1988): Westward bottom currents along the margin of the South Shetland Island Arc. Deep-Sea Res., **35**, 269–301.

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.

REBESCO, M., LARTER, R.D., CAMERLENGHI, A. and BARKER, P.F. (1996): Giant sediment drifts on the continental rise west of the Antarctic Peninsula. Geo-Mar. Lett., **16**, 65–75.

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.

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. Terra Antarct., **2**, 391–393.

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.

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.

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

WHITICAR, M.J., SUESS, E. and WEHNER, H. (1985): Thermogenic hydrocarbons in surface sediments of the Bransfield Strait, Antarctic Peninsula. Nature, **314**, 87–90.

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.

YUASA, M., NIIDA, K., ISHIHARA, T., KISIMOTO, K. and MURAKAMI, F. (1995): Peridotite seamount off Wilkes Land, the Antarctic subcontinental mantle fragment emplaced at early rifting stage between Australia and Antarctica at the last break up of the Gondwanaland. Programme of VII Int. Symp. Antarctic Earth Sci., 418.

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