Proc. NIPR Symp. Antarct. Geosci., 3, 52–64, 1989

PRELIMINARY REPORT OF GEOPHYSICAL AND GEOLOGICAL SURVEYS OFF THE SOUTH ORKNEY ISLANDS, SCOTIA ARC REGION

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Abstract: Geophysical and geological surveys off the South Orkney Islands, West Antarctica, were conducted in Antarctic summer season from 1987 to 1988. The survey area covers the continental shelf, continental rise and the abyssal plain.

As a result of the surveys, the presence of four basins was confirmed. Two basins of them, namely, the Powell Basin lying west of the South Orkney Microcontinent, and the Jane Basin east of it, are considered northern extensions of the Weddell Basin. Other two basins are on the South Orkney Microcontinental Shelf.

Two seismic depositional sequences and the acoustic basement are identified in seismic reflection patterns. Thickness of the sediment is evaluated as approximately 2 km at a maximum. The age of these depositional sequences is estimated to range from Eocene to Quaternary, and the acoustic basement is considered to be pre-Paleogene.

1. Introduction

The South Orkney Islands is located north of the Weddell Sea, east of the Antarctic Peninsula, and south of the Scotia Sea. The South Scotia Ridge lies on the boundary between the South Orkney Islands and the Scotia Sea.

In the geological and geophysical aspects of this region, we consider three major tectonic evolutions, namely, the breaking up of the Gondwanaland (DALZIEL and ELLIOT, 1982), the eastward separation of the South Orkney block from the Antarctic Peninsula (LAWVER *et al.*, 1985; STOREY and GARRETT, 1985; BARKER *et al.*, 1984) and the transform-fault activity at the South Scotia Ridge (FORSYTH, 1975; LUDWIG and RABINOWITZ, 1982). These tectonic evolutions happened during the ages, lower Jurrasic to upper Cretaceous, Pleistocene, and Miocene, respectively.

Scientific surveys in this region were carried out by the Ocean Drilling Program LEG 113 (1986), the Antarctic Marine Geophysics Group of Birmingham University, U.K. (1970 to 1981) and so forth (HARRINGTON *et al.*, 1972).

The purpose of our survey is to investigate the geological and sedimentary features beneath the South Orkney Microcontinental Shelf and the sea-floor surrounding it. The survey was conducted by R. V. HAKUREI-MARU, in January, 1988. The contents of the survey were 24-channel seismic reflection survey, seismic refraction survey, magnetics, gravity, terrestrial heat flow measurements, dredging, gravity-coring and so on.

2. Outline of Survey

The scientific survey, TH-87 Cruise was carried out during the period from 6th to 26th January, 1988. The survey statistics in this cruise is summarized in Table 1.

The gravity and geomagnetic surveys were made for 10257 km in total line length, and the seismic reflection survey for 2265 km.

The seismic refraction surveys were performed at nine sites on seismic reflection lines. A 3.5 kHz subbottom profiler and a 12 kHz precision depth recorder were operated throughout the survey period. The bottom samplings and the terrestrial heat-flow measurements were carried out at 10 sites. Dredging was done at a station on the cliff of the continental slope.

The survey instruments and methods are summarized in Table 2.

Table 1. Summary of the TH-87 Cruise.

	Total	
Survey period	21 days	
Seismic		
Reflection survey	2265 km	
Refraction survey (Sonobuoy)	9 sites	
Gravity and magnetic	10257 km	
Heat-flow measurement	8 sites	out of 10
Gravity coring	9 sites	out of 10
Dredging	1 site	

Table 2. Summary of survey instruments.

Survey name	Instruments	Remarks
Seismic reflection	Source, H400-02 water gun 400 cu.in. × 2	Record length, 5 s
		Sampling rate, 4 ms
	Receiver, SEC ministreamer cable	Shot interval, 50 m
	(24 ch × 25 m)	CDP coverage, 600%
	Recorder, DFS-V	
Seismic refraction	Source, H400-02 water gun 400 cu.in. × 2	
(Sonobuoy)	Receiver, OKI OC-1 Sono-radio-buoy	
	OKI SZ 1038 Sonobuoy receiver	
Gravity	LaCoste & Romberg SL-2 Sea-air gravimeter	Normal gravity, IGSN 71
Magnetics	Geometrics G-866 proton magnetometer	Reference field, IGRF 1985
Navigation	Magnavox MITI-1	Geodetic datum, WGS-72
	Integrated satellite navigation system	
Bottom samplings	Gravity corer, Dredger	
Heat-flow	Nichiyu Giken NTS-11-type	
	Showa Denkou QTM-D-II-type	

3. Sea Bottom Samplings and Terrestrial Heat-Flow Measurements

3.1. *Sea bottom samplings*

Nine bottom sampling sites were chosen by referring to the observations of seismic monitoring records and 3.5 kHz subbottom profiles. These locations are shown in Fig. 1. Seven sites are located on the abyssal plain and two sites are on the continental shelf. The length of the core barrel was decided by checking the seafloor

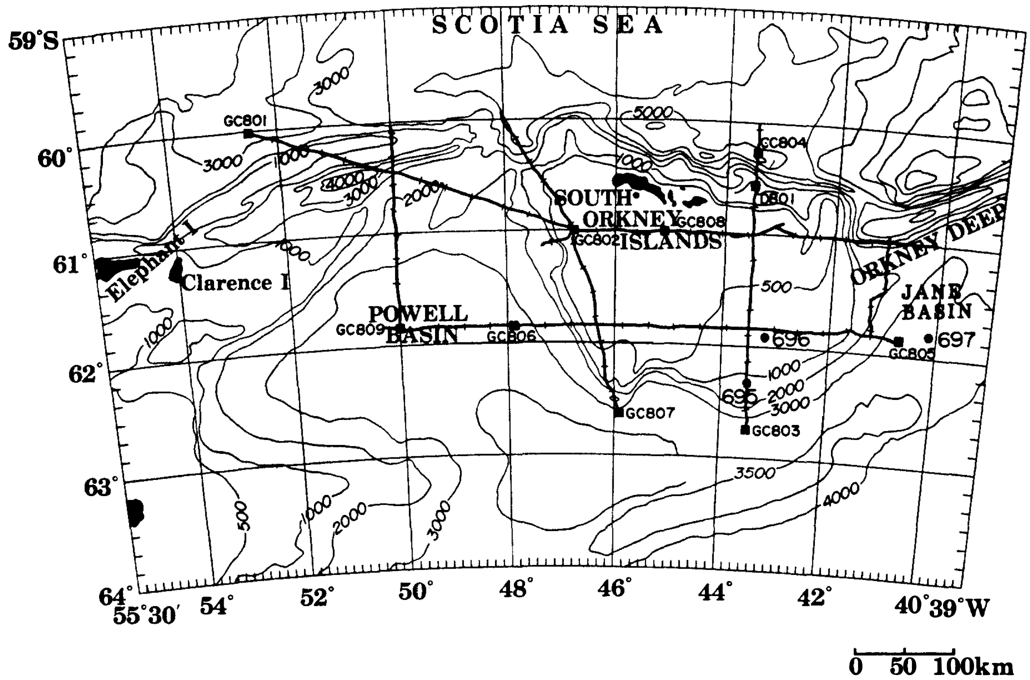

Fig. 1. Lines of geophysical survey and sampling sites. GC: Gravity core, D: Dredge, ODP: Ocean Drilling Program. Topography is derived from GEBCO and partly modified (depth in meters).

Table 3. Summary of bottom samples of sediments.

Site	Lat. (S)	Long. (W)	Depth (m)	Description	Fossils	*Recovery
GC801	60°01′02″	52°30′54″	3328	sili. clay & ooze	Diatom, Radiolaria	6.66/7.45
GC702	61°00′37″	46°45′14″	323	sili. clay & sili. sand	Diatom, Radiolaria	0.49/3.45
GC803	62°44′56″	43°30′25″	3410	silt. clay & sand	Foraminifera	3.16/5.45
GC804	60°17′50″	43°30′50″	5494	ooze	Diatom, abundant	5.30/7.45
D801	60°34′23″ | 60°33′58″	43°29′29″ | 43°29′00″	1315 | 975	sili. & cal. clay; igne. rock, sedi. rock and meta. rock, tuff	Diatom	
GC805	61°50′20″	40°43′30″	3559	clay	Diatom, Radiolaria	5.36/5.45
GC806	61°51′20″	47°53′23″	3115	clay & ooze	Diatom, Radiolaria	5.38/5.45
GC807	62°36′16″	45°54′22″	3245	clay	Radiolaria, Foraminifera	5.29/5.45
GC808	60°59′50″	45°06′21″	376	ooze	Diatom, abundant	5.45/5.45
GC809	61°51′04″	49°59′09″	3315	clay	Radiolaria, poor	5.95/7.45

GC: Gravity Core, D: Dredge. * Recovery length (m)/Core barrel length (m).

condition and thickness of the sediments. By the dredge carried out on the cliff of the continental slope, basement rocks were collected successfully. The results of bottom samplings are listed in Table 3.

3.1.1. Foraminiferal fossils

The gravity core GC-803 contains only one species of planktonic foraminifera, *Globigerina pachyderma*, a cold-water form which repesents a typical Antarctic planktonic fauna. Its age ranges from Holocene to Pliocene. GC-801 and GC-803 contain the same planktonic foraminifera, but its quantity is very poor.

Seven benthonic foraminiferal assemblages are recognized in GC-801, 803, 806, 807 and 809 data. These assemblages are as follows:

Trochammina antarctica
Cyclammina pusilla
Cyclammina cancellata
Martinottiella sp.
Cyclammina pusilla–Martinottiella sp.
Martinottiella sp.–*Miliammina earlandi*
Miliammina earlandi

3.1.2. Diatom fossils

The diatom analyses were conducted for nine gravity-cores and one dredge sample. Diatom fossils are generally abundant, and almost all of them belong to *Nitzschia kerugernsis* Zone whose age is upper Pleistocene, and the lowest sample of GC-801 may belong to *Rouxia isopolica* Zone whose age is also upper Pleistocene. *Denticulopsis lauta* Zone which is correlated with the middle to high latitude zones of the North Pacific, is found in one sample of GC-801, and its age seems to be lower middle Miocene. Two samples of GC-802 and GC-808, which are located on the inner continental shelf, are characterized by predominant resting spores. *Nitzschia curta* which is an ice alga, is more adundant at GC-808 than other sites.

Some dredged samples contain *Thalassiosira fraga* Zone whose age is presumed to be lower Miocene (ABBOTT, 1974; AKIBA, 1982, 1986).

3.1.3. Radiolarian fossils

Radiolarian assemblages are grouped into three zones, namely, *Helotholus vema–Eucyrtidium calvertense*, *Stylaractus universus* and *Antarctissa denticulata* zones. They range in age from late Pleistocene to Recent (CHEN, 1975).

GC-808 contains different assemblages from other samples, such as *Rhizoplegma boreale* and *Pseudocubus*(?) sp. *R. boreale* was found in the shallow water off Queen Maud Land (SAKI *et al.*, 1987) and the glacial sediments of the Iceland-Faeroe Ridge in the Norwegian sea (BJORKLUND, 1979). Therefore, it is inferred to have been deposited under a special sedimentary environment.

3.2. Terrestrial heat-flow measurement

Terrestrial heat-flow data were measured at six sites, one of which is located on the continental shelf and the others are in the surrounding deep sea of the back-arc basin of the Andean Orogenic Zone, as shown in Fig. 2.

The heat-flow values in the deep sea area are significantly higher than the world's average of 69 mW/m^2. They are consistent with the values measured in the Weddell

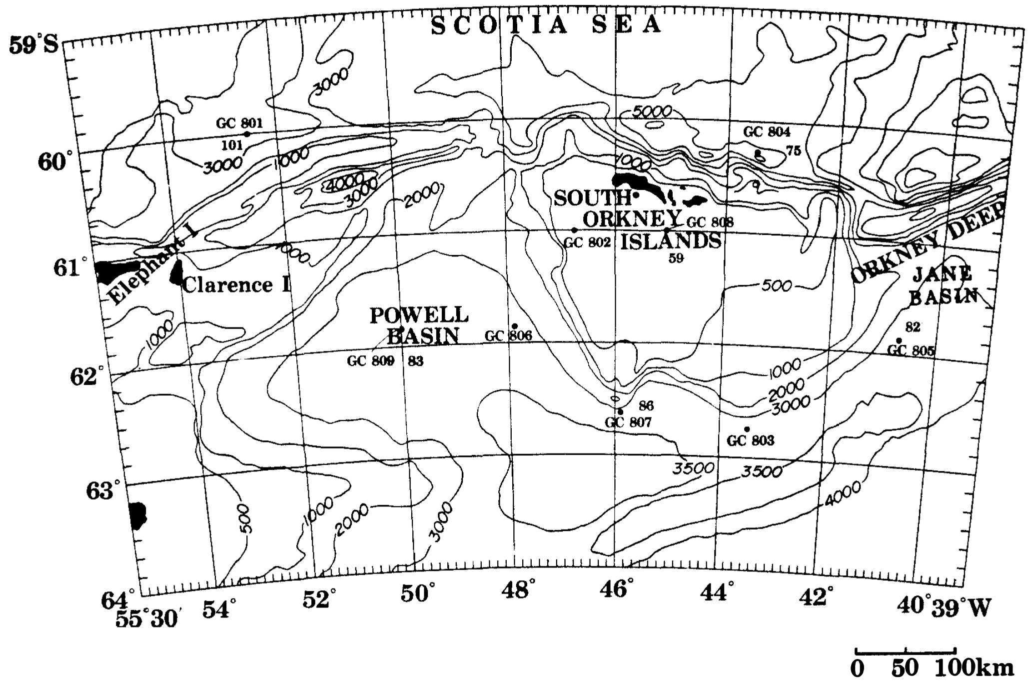

Fig. 2. Map of terrestrial heat-flow distribution and its value (unit, mW/m²).

Sea (OKUDA *et al.*, 1983), and with the universal tendency of high heat flow values in the back-arc basins. The continental shelf, on the contrary, shows a remarkably small value of 59 mW/m^2, which may correspond to a sedimentary environment also indicated by the radiolarian and diatom fossils observed at GC-808 site.

4. Gravity and Geomagnetic Survey

A free-air gravity anomaly map and a geomagnetic anomaly map of the survey area are shown in Figs. 3 and 4, respectively.

4.1. Gravity

Free-air anomalies are generally positive in the survey area except the north of the microcontinent where their value is down to -150 mgal.

Among high anomalies observed on the South Orkney Microcontinental Shelf, the significantly highest anomaly seems to correspond to parts of the acoustic basement outcropping at the crossing of lines 3 SMG and 4 SMG, and to the seamounts along the South Scotia Ridge.

The level of high anomalies seems to decrease correspondingly with thickening of sediments on the shelf as shown in the intersection areas of 4 SMG/6 SMG and 8 SMG/6 SMG.

4.2. Geomagnetics

The geomagnetic anomalies over the South Orkney Microcontinent present superposition of short and long wavelength components. Low component anomalies seem to cover the southern part of the continent from west to east. These anomalies

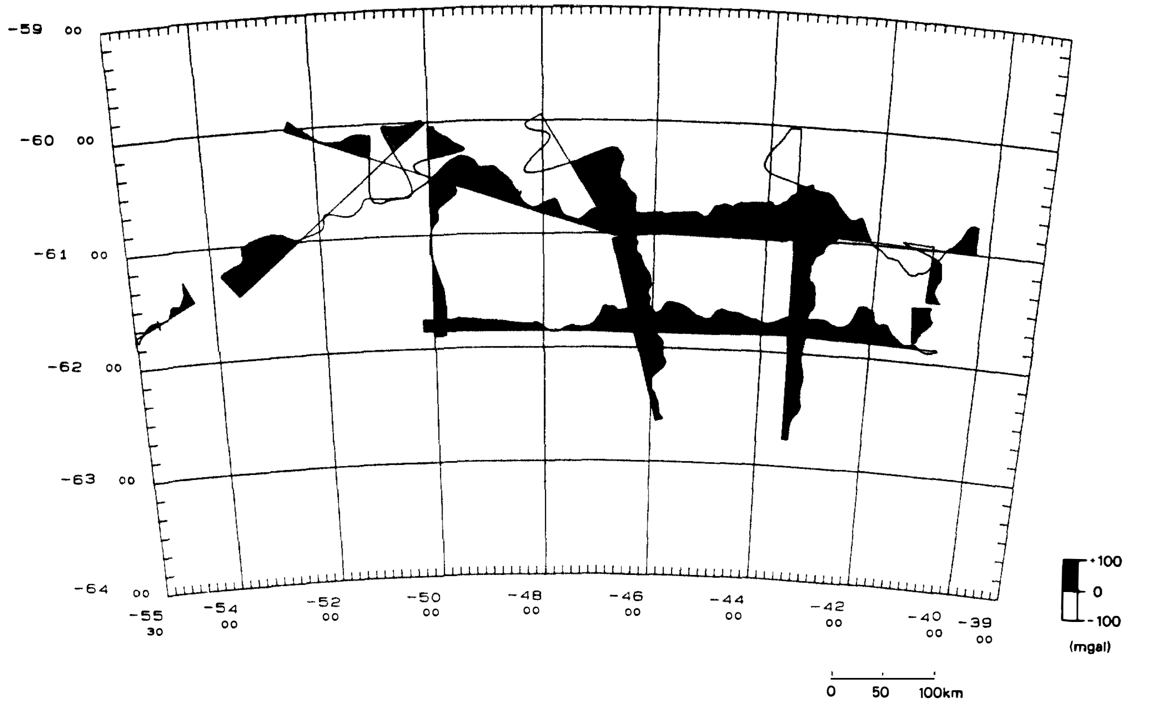

Fig. 3. Free-air gravity anomaly profile along the ship's track. Reference field, IGSN 71.

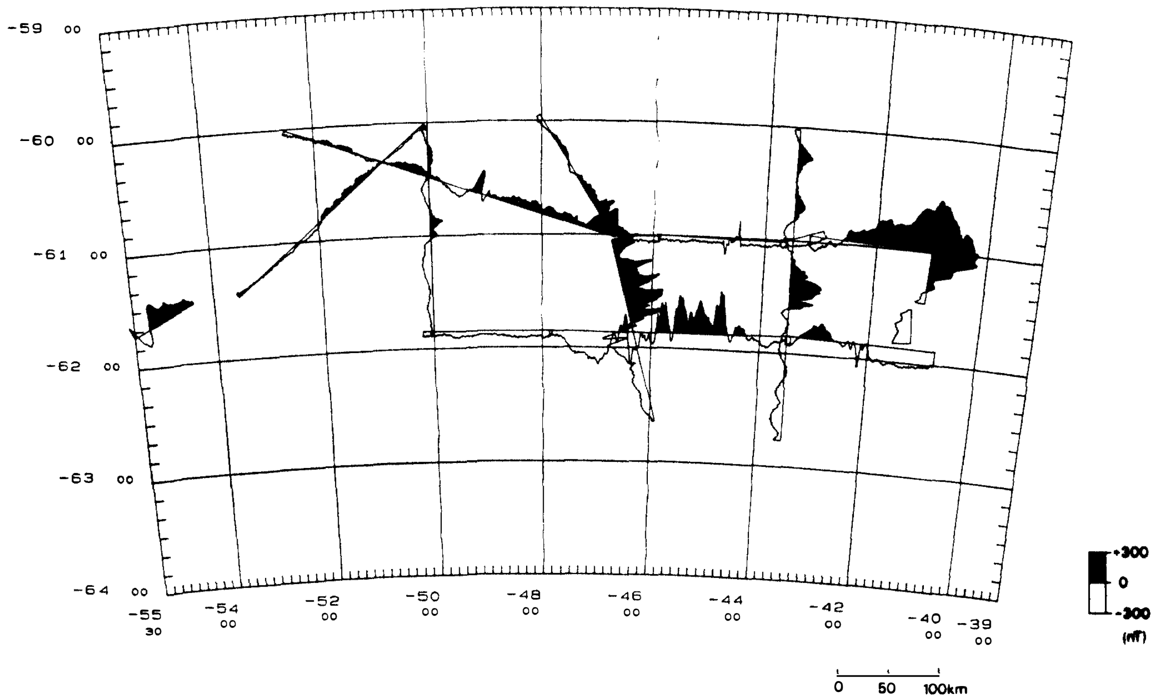

Fig. 4. Magnetic anomaly profile along the ship's track. Reference field, IGRF 1985.

are considered to be part of the anomaly which may be traced for more than 1300 km along the Antarctic Peninsula (GARRETT *et al.*, 1986/1987).

On the other hand, high component anomalies lie in the area of the crossing between 6 SMG and 8 SMG. This may indicate a volcanic intrusion or variation of its susceptibility. However, there are not any seismic characteristic indications on the reflection profiles to show the phenomenon.

5. Seismic Survey

5.1. Seismic refraction survey

Sonobuoy seismic refraction surveys were carried out at nine sites on the seismic reflection survey lines as shown in Fig. 5. The obtained data were processed and interpreted in the same way as the velocity analysis of the conventional reflection method except SB-4 whose data have a poor quality. Figure 6 illustrates the velocity structures obtained by that interpretation.

Five sonobuoy surveys, that is, SB-1, 2, 3, 5, 7, were carried out on the continental shelf, and others were done on the abyssal plain. The interpreted results show that the *P*-wave velocities of the acoustic basement range from 4.0 to 4.8 km/s, and those of sediments range from 2.2 to 3.0 km/s.

These velocities are generally consistent with those of the basement and sediments observed in the previous Antarctic Surveys (HARRINGTON *et al.*, 1972; OKUDA *et al.*, 1983).

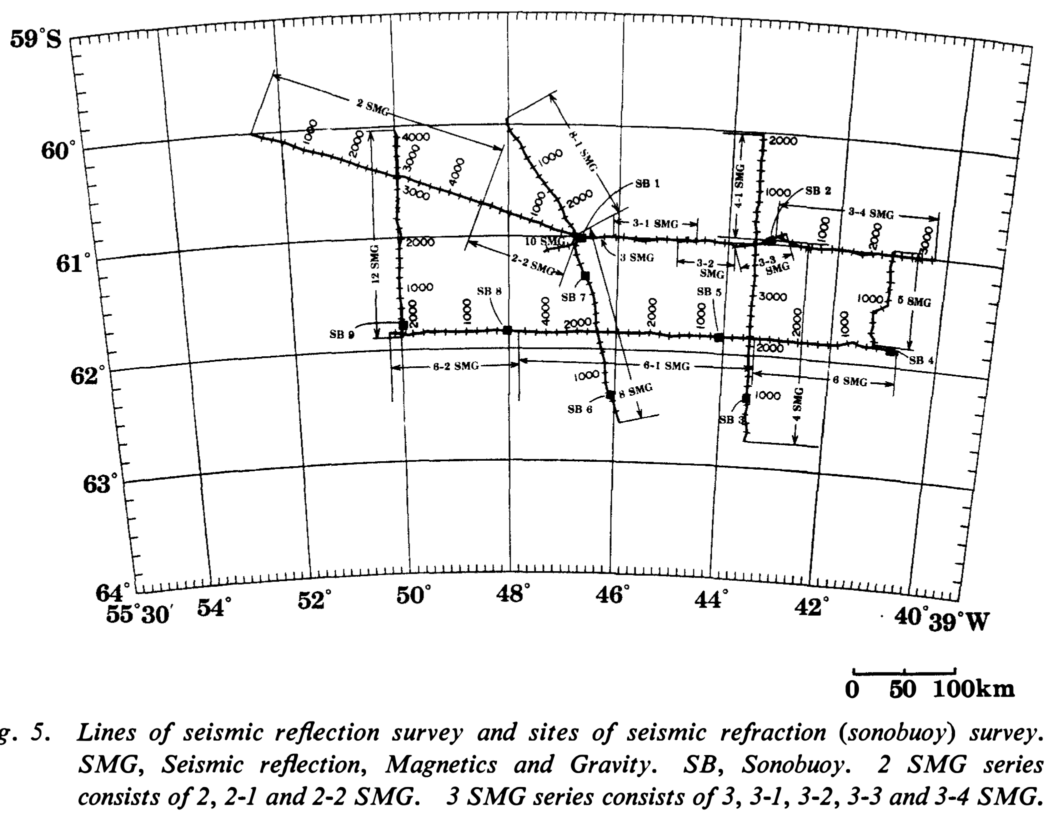

Fig. 5. Lines of seismic reflection survey and sites of seismic refraction (sonobuoy) survey. SMG, Seismic reflection, Magnetics and Gravity. SB, Sonobuoy. 2 SMG series consists of 2, 2-1 and 2-2 SMG. 3 SMG series consists of 3, 3-1, 3-2, 3-3 and 3-4 SMG. 4 SMG series consists of 4 and 4-1 SMG. 6 SMG series consists of 6, 6-1 and 6-2 SMG. 8 SMG series consists of 8 and 8-1 SMG. 5 SMG, 10 SMG and 12 SMG are one lines, respectively. Numbers along lines are s.p. (shot point) numbers.

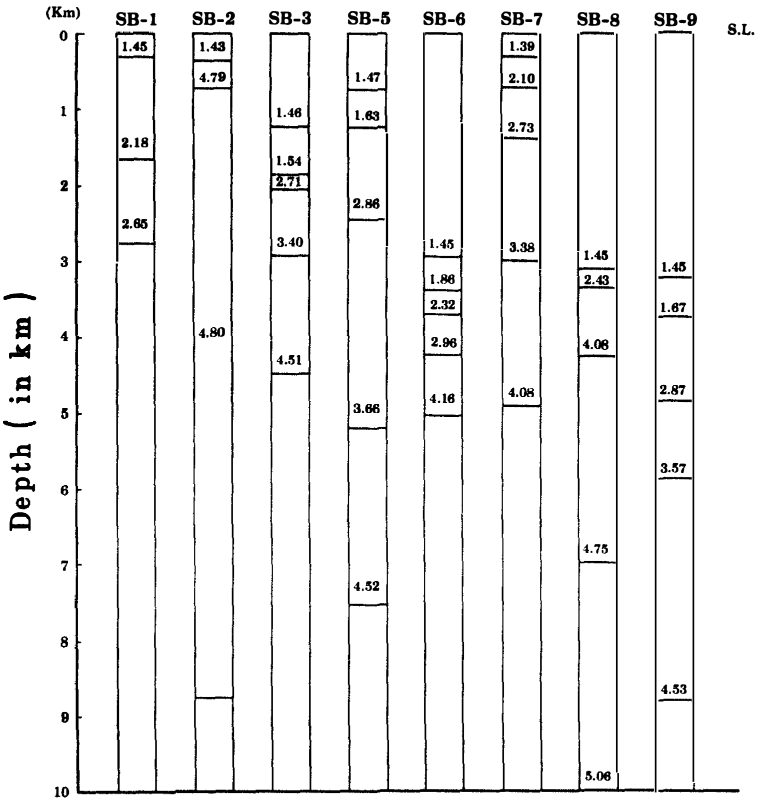

Fig. 6. Velocity structure derived from sonobuoy survey (unit, km/s).

5.2. Seismic reflection survey

Seismic reflection data were processed according to the conventional seismic data processing flow. A shot-point map of the six-fold seismic reflection survey is given in Fig. 5, including the sonobuoy survey sites. The seismic survey lines cover almost all of the South Orkney Microcontinental Shelf, and part of the Powell Basin, South Scotia Ridge, and Weddell Sea.

Three typical seismic sequences are individually traced over the areas of the continental shelf and the deep sea area, which are named Sequence 1, 2 and 3. Sequence 1 is the younger depositional sequence, Sequence 2 is the older depositional one, and Sequence 3 corresponds to the acoustic basement.

Although there are some discontinuities due to the abrupt change of geological features between the continental shelf and the deep sea area, these three sequences can be identified from their seismic reflection patterns, respectively.

Continental shelf

The water depth at the margin of the continental shelf ranges from 300 m to 700 m, which is deeper than the world average. The significant sedimentary basins are found on the southern continental shelf as shown in Figs. 7 and 8. Three seismic sequences can be traced in this area. Sequence 1 is extensively distributed over the southern part of the continental shelf. However, Sequence 2 is restricted in the center of the basins, and its distribution is limited by the underlying structure. Sequence 3 is exposed on the continental slope and in the north of the continental shelf, but elsewhere it underlies Sequences 1 and 2, as shown in Fig. 8.

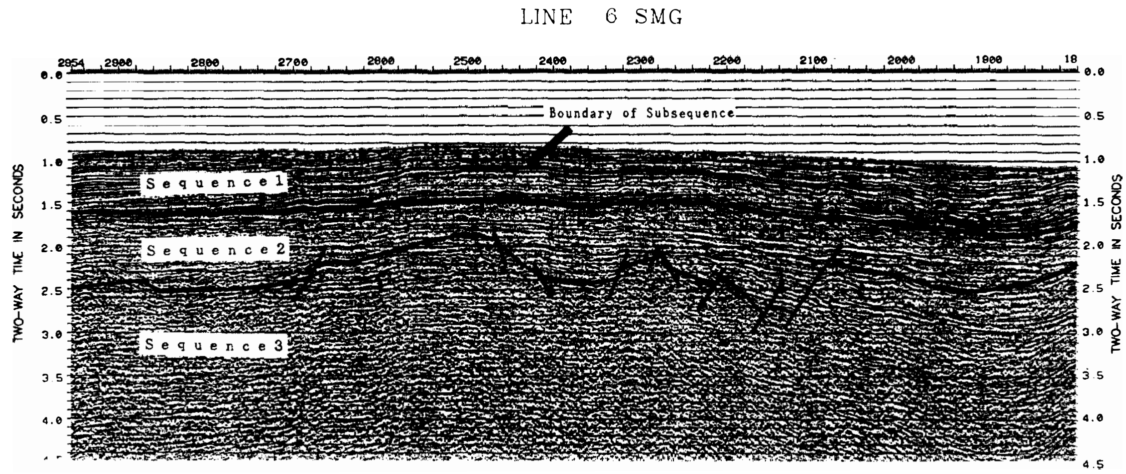

Fig. 7. Seismic section of 6 SMG (center part of the sedimentary basin on the continental shelf). Note the boundary of subsequence in Sequence 1.

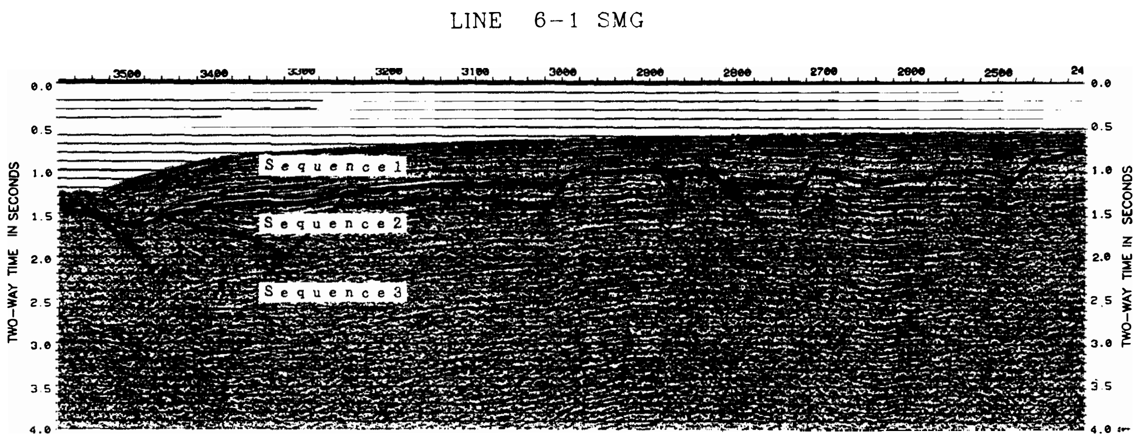

Fig. 8. Seismic section of 6-1 SMG (edge of the sedimenatry basin on the continental shelf). Note the fault system of Sequence 3, and the unconformity between Sequences 1 and 2.

Seismic reflection patterns of three sequences are summarized as follows:

Sequence 1

This sequence is characterized by a parallel-layered reflection pattern with good continuity and a medium to high amplitude. It is unconformable to both Sequences 2 and 3 shown in Fig. 8. Sequence 1 may be divided into two subsequences by the strong reflectors in some area, as shown in Fig. 7. Faults are recognized only on the continental slope.

Sequence 2

This sequence is separated by a half-graben in some area, and difficult to trace in another area, because of interference of seabed-multiples. This sequence is characterized by low amplitude reflectors or non-reflectors which have a poor continuity. The thickness of the sequence is not uniform because it is eroded by the upper sequence in the south edge of the basin, as shown in Fig. 8.

Sequence 3

This sequence shows the acoustic basement. Reflections from the top of the sequence are often difficult to recognize on the records available, due to interference of the seabed-multiples, as shown in Fig. 7. There are many indications of normal faults of pre-Paleogene age. This means that the basin was formed in the tension field. The *P*-wave velocity of the sequence is inferred to be 4.0–4.5 km/s, from the seismic refraction and reflection surveys.

Geological time of these sequences is difficult to define from our data alone. There are several studies in this province (LABRECQUE and BARKER, 1981; OKUDA *et al*., 1983; BARKER *et al*., 1984, 1988; DAVEY, 1985; KING and BARKER, 1988).

According to OKUDA *et al*. (1983), who defined the age of sediment in the Weddell Basin, we infer as follows:

Sequence 1: Sequence A+Sequence B+Sequence C (of OKUDA *et al*., 1983).
Geological time, Eocene to Quaternary.

Sequence 2: Sequence D+Sequence E.
Geological time, Eocene to pre-Paleogene.

Sequence 3: Acoustic Basement.
Geological time, pre-Paleogene.

Other basins

There are two sedimentary basins under the abyssal plain. One is the Powell Basin (Figs. 9 and 10), and the other is the Jane Basin which is recognized in the east end of 6 SMG, as shown in Fig. 11. Their locations are in the northern part of the Weddell Sea, and therefore they are considered to be part of the Weddell Basin.

Three seismic sequences can be defined on the reflection profiles available, as shown in Fig. 9. The seismic reflection patterns of them are the same as those of the continental shelf except for Sequence 2.

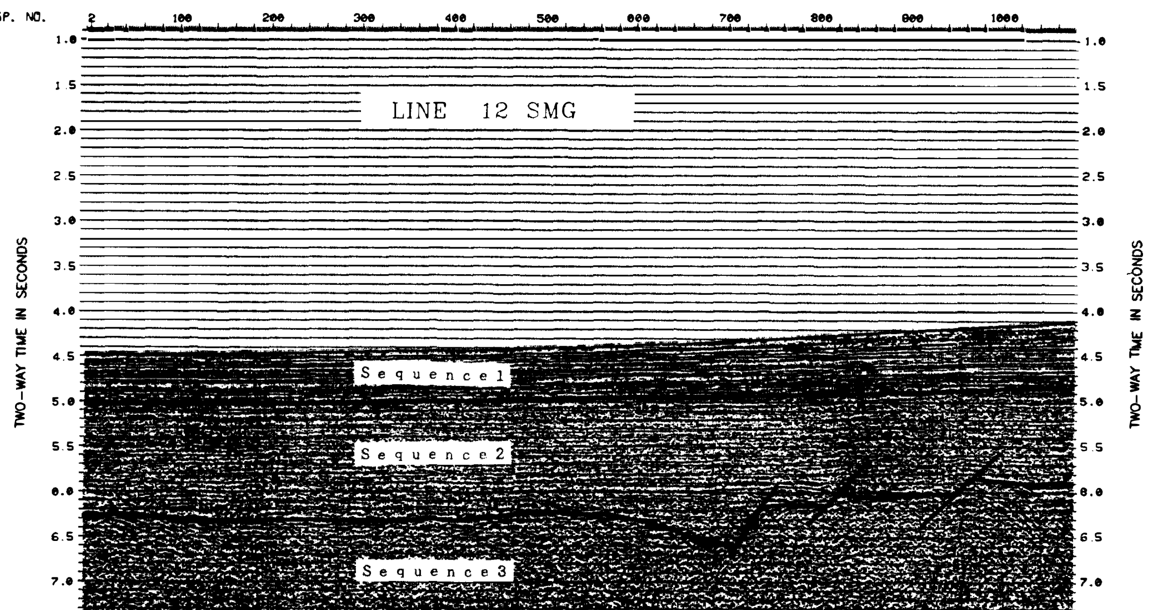

Fig. 9. Seismic section of 12 SMG (under the Powell Basin). Note the typical seismic reflection pattern of sequences.

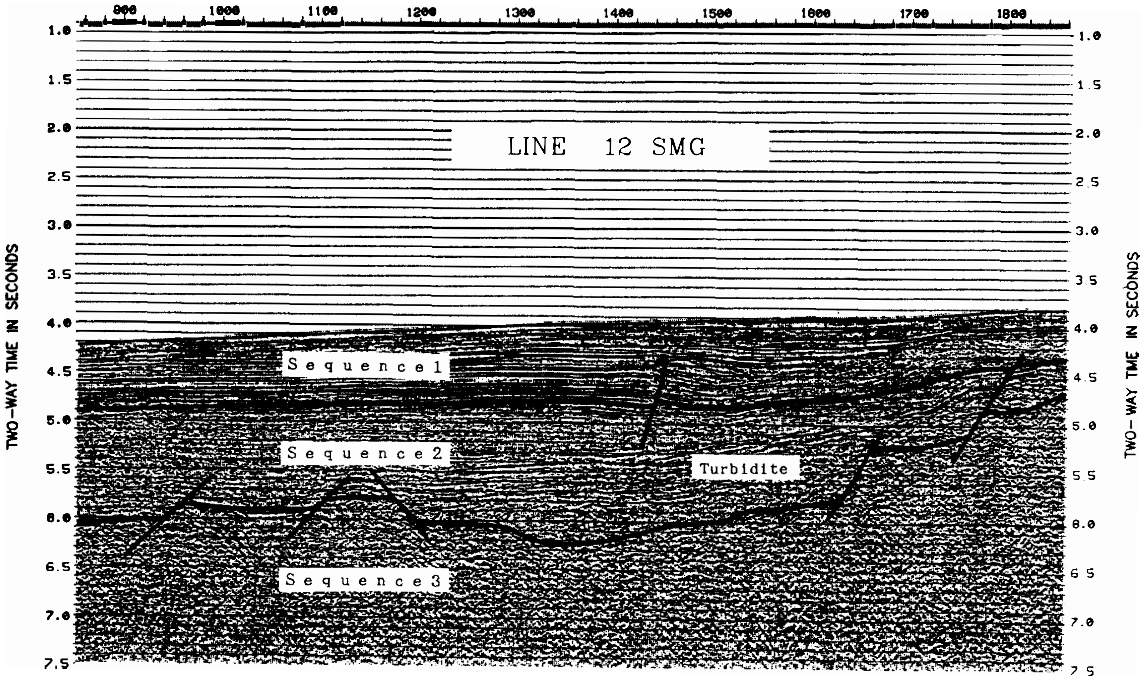

Fig. 10. Seismic section of 12 SMG (under the Powell Basin). Note the seismic reflection pattern of turbidite in Sequence 2.

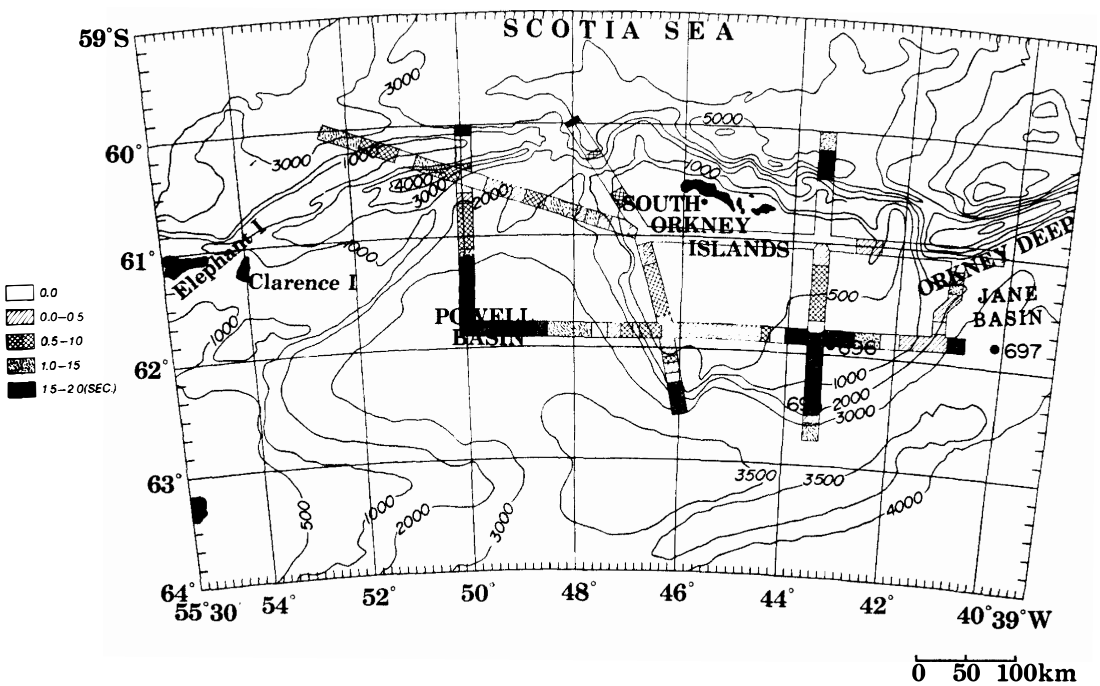

Fig. 11. Map of total thickness of sediment in two-way time (s).

Sequence 2 has a fairly good continiuty, and its frequency is medium. Seismic reflection patterns of the turbidite are recognized in this sequence in the area from the continental slope to the abyssal plain, as shown in Fig. 10. Total thickness of the sedimentary layers becomes gradually larger southward, and the seismic reflection patterns are the same as those in our previous study of OKUDA *et al.* (1983). These data support that the two basins belong to the northern part of the Weddell Basin.

Other tectonic features

The South Scotia Ridge lies in the northern part of the survey area from west to east. Its tectonic features are visible on the seismic profiles, that is, Lines 2 SMG, 4 SMG and 8 SMG across the ridge. Its feature looks like a horst-and-graben structure with a width of about 50 km.

6. General Features of Sedimentary Basins

We have confirmed the four sedimentary basins in the survey area. Two basins are on the South Orkney Microcontinental Shelf and others are under the abyssal plain in the northern part of the Weddell Sea, as shown in Fig. 11.

The first two basins are described as follows.

(1) Location, crossing 4 SMG and 6 SMG
Area, approximately 150 km × 110 km
Thickness, approximately 2 km

(2) Location, crossing 8 SMG and 6 SMG
Area, not to be defined
Thickness, 1 km to 1.5 km

These two basins are on the continental shelf and at water depth of about 700 m. In the viewpoint of the heat-flow, their data are higher than the world average, because this area is considered to be the back-arc basin of the Andean Orogenic Zone.

The last two basins exist under the abyssal plain. The thickness of sediment is 2 s in two-way time (about 2000 m) and becomes thicker southward. These basins are little influenced by the tectonic activity because there are not any faults and folds in the upper two sequences.

In the viewpoints of seismic reflection patterns and tectonic features, they are a part of the Weddell Basin, and this basin becomes younger northward. It is considered that these basins would provide a key to the developments of the Weddell Sea and the South Scotia Sea. However, our data are too scarce to make a conclusive remark on that.

Acknowledgments

The authors thank all participants of the TH-87 cruise project for their cooperation and efforts during the preparation and the execution of the survey.

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(Received April 10, 1989; Revised manuscript received May 15, 1989)