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PRELIMINARY REPORT OF GEOPHYSICAL AND GEOLOGICAL SURVEYS IN THE AMUNDSEN SEA, WEST ANTARCTICA

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Abstract: Geophysical and geological surveys in the Amundsen Sea, West Antarctica were conducted during the 1986-1987 Antarctic summer season. The study area covers the continental rise and the abyssal plain. The surveys revealed the existence of the sedimentary basin in the Amundsen Sea as the westward extension of the Bellingshausen Sea Basin. The basement of the basin becomes shallow in depth and rough in topography toward the west in a manner of stepwise change along the continental rise and the abyssal plain, which are clearly observed in seismic sections. In the continental rise, the presence of thick sediments which exceeded about 2.0 s in two-way time was recognized. Characteristic sedimentary facies patterns in the continental rise such as dunes, channels, buried channels and migrating waves were observed in the upper parts of the sediment columns. In the abyssal plain, the acoustic basement showed remarkably complex relief and distorted reflections were observed in the sediments deposited on structural lows of the basement. The sediments were generally thin, about 0.5 s in two-way time.

From the viewpoint of depth, location, configuration, reflection pattern of the acoustic basement and thickness of total sediments, the study area can be divided into thrre parts, *i.e.*, eastern part, central part and western part. The boundaries between them may be assumed to correspond to fracture zones which extend from the Pacific-Antarctic Ridges.

1. Introduction

Since 1980, marine geophysical and geological surveys of the Antarctic Ocean have been continuously conducted by the Technology Research Center of the Japan National Oil Corporation (TRC, JNOC) to know the general features of the Antarctic continental margin and adjacent deep sea areas (Fig. 1). The results of the previous cruises have already been published (KIMURA, 1982; OKUDA *et al.*, 1983; SATO *et al.*, 1984; TSUMURAYA *et al.*, 1985; MIZUKOSHI *et al.*, 1986; SAKI *et al.*, 1987).

Almost through January 1987, the TH-86 cruise was conducted employing the Geological Research Vessel HAKUREI-MARU in the Amundsen Sea, West Antarctica. The study area covers the continental rise and the abyssal plain of the Amundsen Sea

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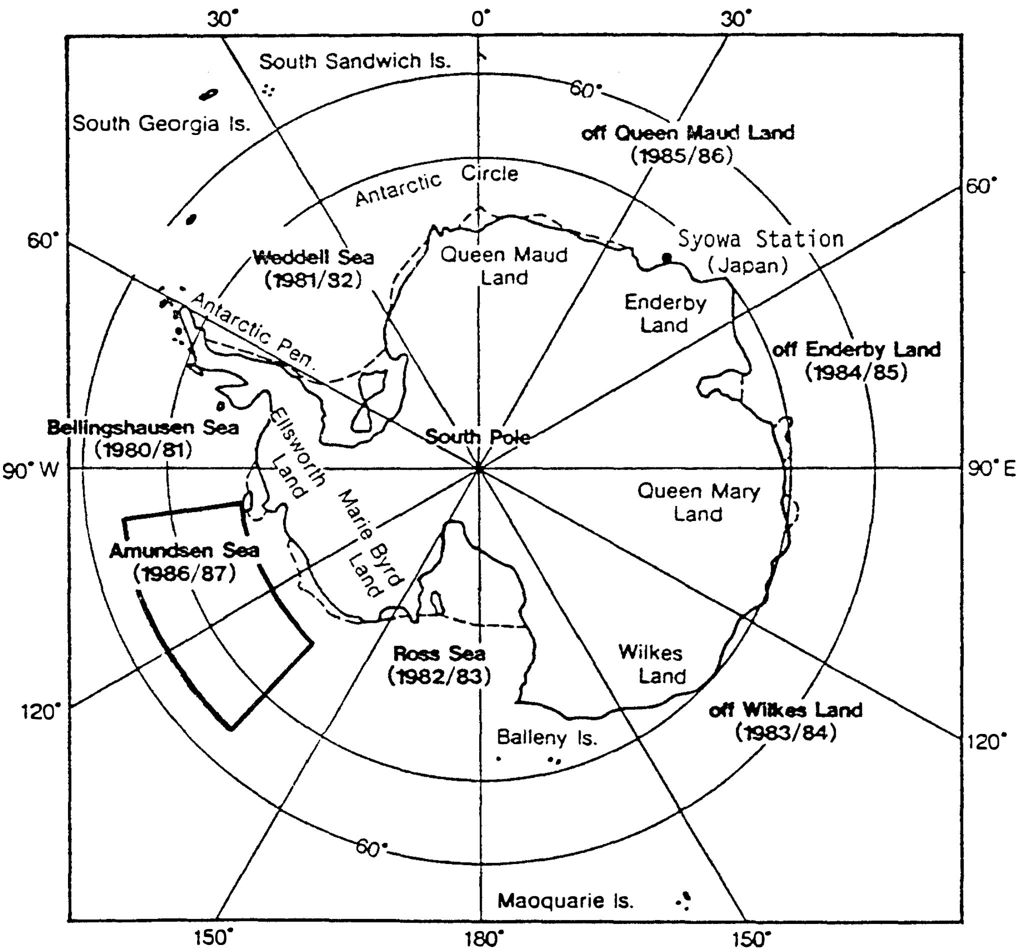

Fig. 1. Survey areas in the offing of Antarctica, from 1980 to 1986 by TRC, JNOC.

and a part of the Bellingshausen Sea. Some studies have been done around the Amundsen Sea (HOLLISTER *et al.*, 1976; VANNEY and JOHNSON, 1976; KIMURA, 1982) but a multichannel seismic reflection investigation was made for the first time by this cruise except for Line 18 of KIMURA (1982).

There exist about six large sedimentary basins in the offing of Antarctica (ST. JOHN, 1980). They are the Weddell Sea Basin, the Bellingshausen Sea Basin, the Ross Sea Basin, the Scott Basin, the Enderby Basin and the Queen Maud Basin. The sedimentary basin covered by the Amundsen Sea is considered to be a western part of the Bellingshausen Sea Basin and estimated to have thick sediments.

Several fracture zones, represented by the Eltanin Fracture Zone, the Udintsev Fracture Zone, *etc.*, exist in the north and west of the study area and they seem to extend roughly southeast to the study area (Fig. 2).

This paper reports the preliminary results of the TH-86 cruise and breifly describes the general features of the sedimentary basin in the Amundsen Sea.

2. Outline of Survey

The marine surveys on seismic, gravity, magnetic observations, bottom sampling and terrestrial heat flow measurement were carried out by R/V HAKUREI-MARU in the Amundsen Sea during the period from 8th to 31st January, 1987.

Data acquired during this cruise, TH-86, are summarized in Table 1. Total line length was 11232 km for the gravity and magnetic surveys (Fig. 2) and 2655 km for the seismic reflection survey (Fig. 3). The seismic refraction survey was carried out at nine sites. A 3.5 kHz subbottom profiler and a 12 kHz precision depth recorder were operated throughout the survey period. The bottom sampling and the terrestrial heat flow

Table 1. Summary of the TH-86 cruise.

	Total
Survey period	24 days
Seismic	
Reflection survey	2655 km
Refraction survey (sonobuoy)	9 sites
Gravity and magnetic	11232 km
Heat flow measurement	7 sites
Piston coring	1 site
Gravity coring	9 sites

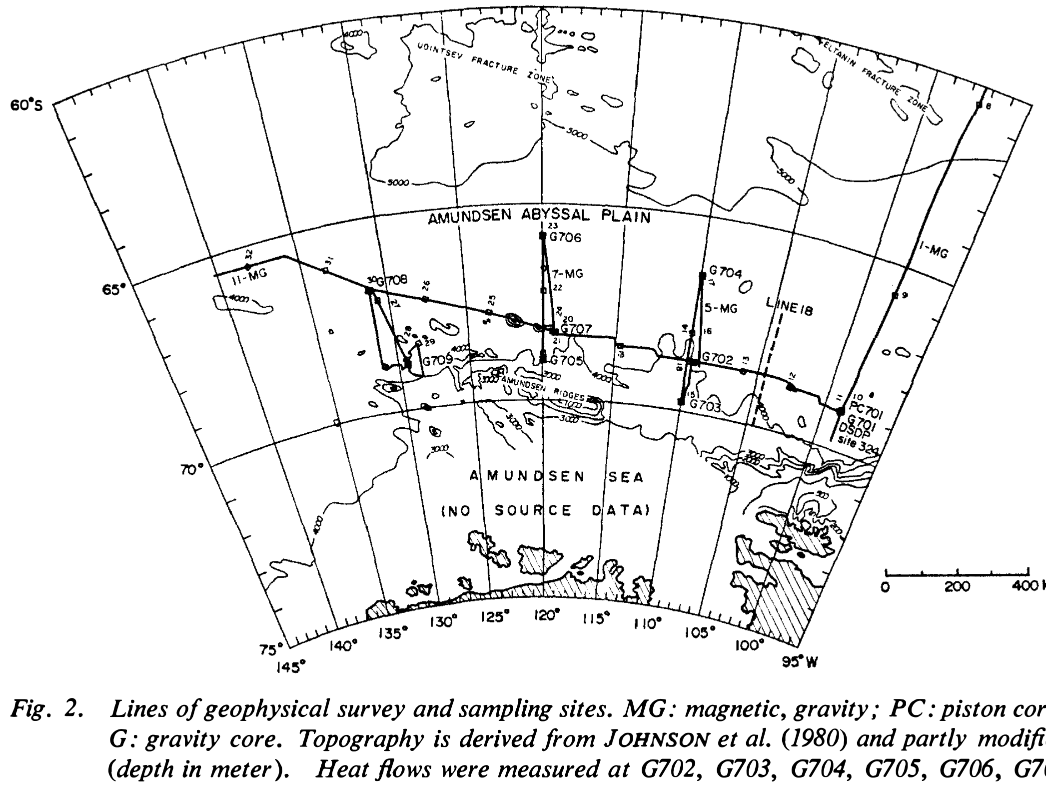

Fig. 2. Lines of geophysical survey and sampling sites. MG: magnetic, gravity; PC: piston core; G: gravity core. Topography is derived from JOHNSON *et al. (1980) and partly modified (depth in meter). Heat flows were measured at G702, G703, G704, G705, G706, G707 and G709. G701 and PC701 are approximately at DSDP site 324. Line 18 is a seismic section of* KIMURA *(1982).*

measurement were done at nine stations. The survey instruments and methods are summarized in Table 2.

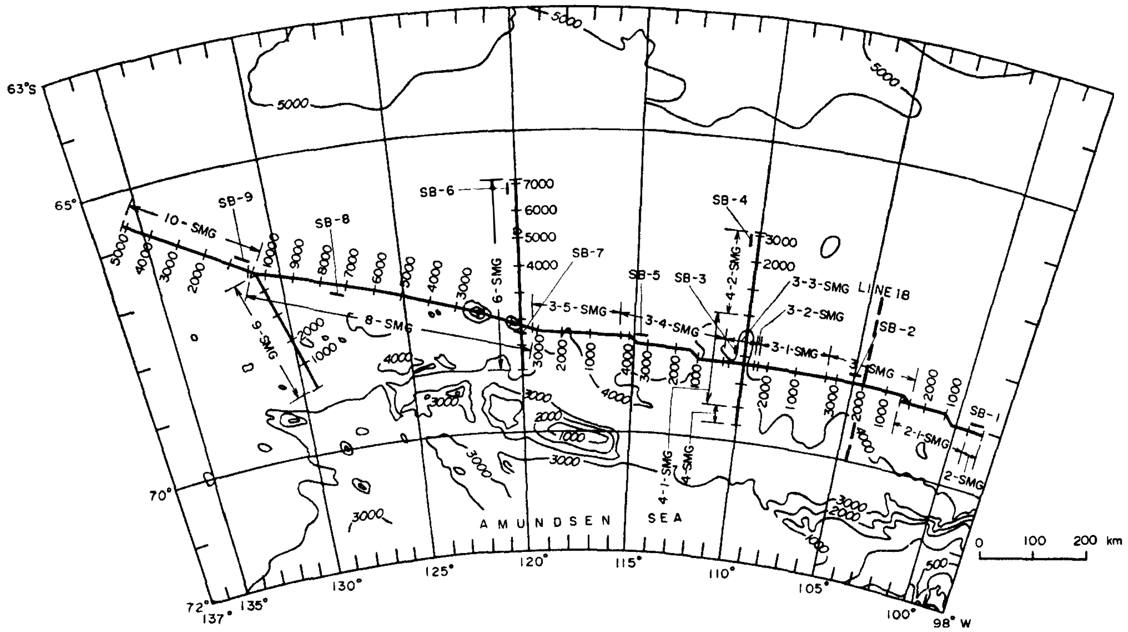

Fig. 3. Lines of seismic reflectinon survey and sites of seismic refraction (sonobuoy) survey. SMG: seismic reflection, magnetic, gravity; SB: sonobuoy. 2-SMG series consists of 2 and 2-1-SMG, 3-SMG series 3, 3-1, 3-2, 3-3, 3-4 and 3-5-SMG, 4-SMG series 4, 4-1 and 4-2-SMG, respectively. Numbers along lines are s.p. (shot point) for each line. Line 18 is a seismic section of KIMURA (1982).

Table 2. Summary of survey instruments.

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

3. Bottom Sampling and Terrestrial Heat Flow Measurement

3.1. Bottom sampling

Bottom sampling sites were selected by careful observation of seismic onboard monitor records and 3.5 kHz subbottom profiles (Fig. 2). Piston coring was chosen under conditions of muddy, silty or unconsolidated sediments, while gravity coring was selected for sandy sediments. The results of bottom samplings are listed in Table 3.

Table 3. Summary of bottom samples of sediments.

Site	Lat. (S)	Long. (W)	Depth (m)	Description	Fossils	Recovery[1]
G701	69°01′40″	98°44′14″	4445	silic. ooze (upper) clay, silty clay (lower)		1.00/3.17
PC701	69°01′37″	98°43′56″	4444	alter. silic. ooze/clay	Foraminifera, Diatom common	7.28/8.00
G702	68°44′50″	109°32′37″	3880	alter. clay/calc. clay		3.90/4.17
G703	69°45′53″	109°58′45″	3710	clay		4.95/5.17
G704	66°32′11″	109°55′37″	4524	silic. ooze (upper) clay, silt (lower)		4.90/5.17
G705	68°59′59″	119°58′48″	4085	calc. clay, marl ooze chalk ooze	Foraminifera abundant	4.71/5.17
G706	65°49′34″	119°59′19″	4814	silic. ooze	Diatom, Radiolarian abundant	4.17/5.17
G707	68°18′40″	119°12′47″	4118	alter. clay/clac. clay		5.17/5.17
G708	66°51′34″	131°09′46″	4580	silic. ooze silic. clay (lowest)	Diatom, Radiolarian abundant	4.72/5.17
G709	68°51′42″	129°22′03″	3987	silic. ooze (upper) clay (lower)		4.70/5.17

PC: Piston Core, G: Gravity Core, [1] Recovery length (m)/core length (m).

3.1.1. Foraminiferal fossils

A gravity core, G705, contains such warm-water planktonic foraminifera as *Globorotalia puncticuloides*, suggesting the core ranges in age from Late Pliocene to Early Pleistocene. Planktonic foraminiferal assemblages of other cores are monospecific as represented by a cold-water form, *Grobigerina pachyderma*, which ranges in age from Pliocene to Holocene.

Four benthonic foraminiferal assemblages are recognized, *i.e.*, *Cyclammina pusilla-Nuttallides* umbonifer, *Eilohedra weddellensis-Nuttallides* umbonifer, *Trochammina* spp. and *Cyclammina* spp. assemblages. These assemblages are frequently observed in the area dominated by Antarctic bottom water.

3.1.2. Diatom fossils

Diatom fossils are generally abundant in the upper part of cores, while they are absent in the lower part, the age of which is not clear. In the south of 67°S, only *Nitzschia keruguelensis* Zone is recognized, which ranges in age from 0.2 to 0 Ma. In the north of 67°S (G704, G706, G708), deeper than 4500 m, *Hemidiscus karstenii* Zone, *Rouxia isopolica* Zone and *Actinocyclus ingens* Zone are observed and they range in age from 0.35 to 0.2 Ma, from 0.66 to 0.35 Ma and from 1.67 to 0.66 Ma, respectively (AKIBA, 1982). Probably this indicates that the accumulation rate is lower in the north of 67°S than in the south.

3.1.3. Radiolarian fossils

Radiolarian assemblages in cores G704, G706, G708 and G709 are characterized by such age diagnostic species as *Stylatractus universus* and *Antarctissa denticulata*, which suggests that these cores range in age from Late Pleistocene to Recent. Other cores, except for G707, contain abundant *Antarctissa denticulata*, suggesting these cores range in age from latest Late Pleistocene to Recent (CHEN, 1975).

Reworked radiolarian fossils, regarded as Early Pliocene, are frequently found in the uppermost Upper Pleistocene sediments, which are approximately correlated to the boundary between *Stylatractus universus* Zone and *Antarctissa denticulata* Zone.

3.2. Terrestrial heat flow measurement

Analyzable heat flow values were acquired at seven sites and are shown in Fig. 4.

The heat flow values measured in the Amundsen Sea range from 43 mW/m^2 to 72 mW/m^2, with the average value approximately 56 mW/m^2, which is nearly equal to the average value of the Bellingshausen Sea concerning three measured values in the west of 90°W (57 mW/m^2, TSUMURAYA *et al.*, 1985). Both average values are lower than the world average (69 mW/m^2). From these it may be inferred that the sedimentary basins in the Amundsen Sea and the Bellingshausen Sea are continuous and that the eastern part of the sea floor in the Amundsen Sea is relatively old, although the heat flow value at G709 (72 mW/m^2) exceeds the world average.

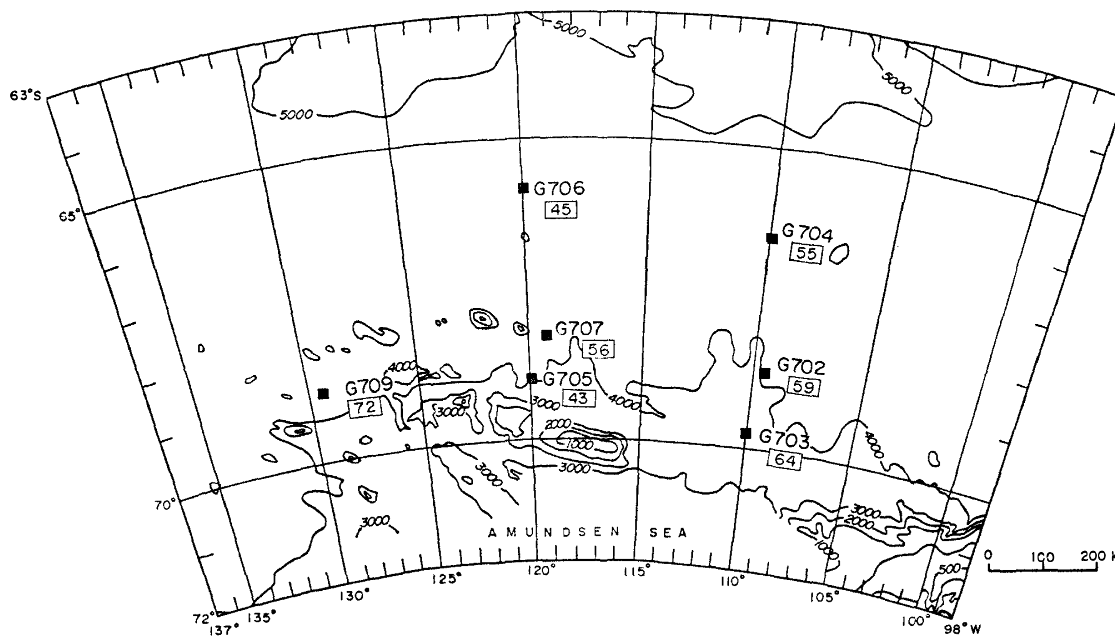

Fig. 4. Map of terrestrial heat flow distribution and value (unit: mW/m^2).

4. Gravity and Magnetic Surveys

Free-air gravity anomaly and magnetic anomaly in the study area are shown in Figs. 5 and 6, respectively.

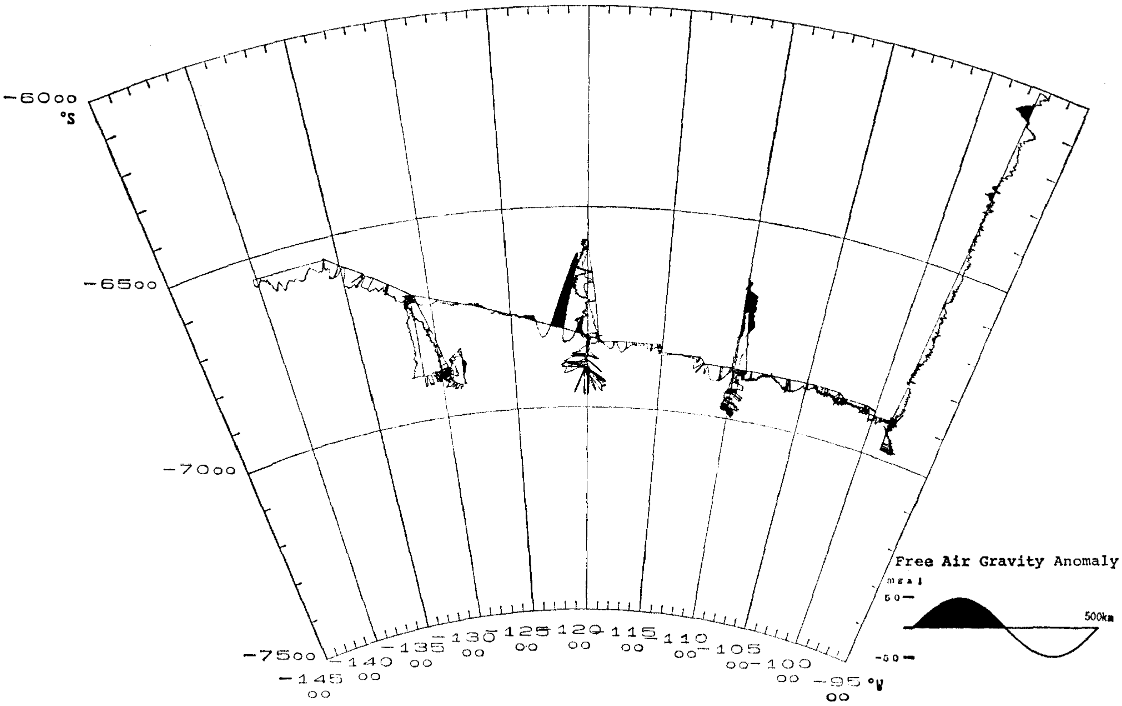

Fig. 5. Free-air gravity anomaly profile along the ship's track. Reference field: IGSN 71.

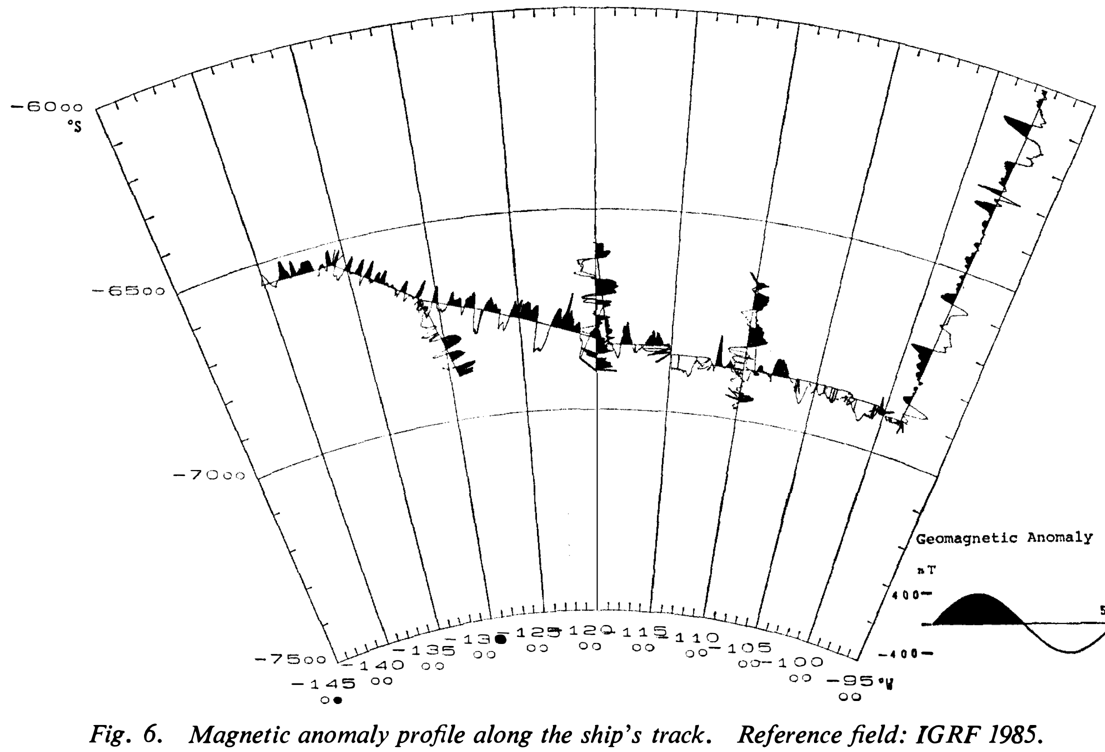

Fig. 6. Magnetic anomaly profile along the ship's track. Reference field: IGRF 1985.

In the Amundsen Sea, the free-air gravity anomaly is negative with several tens of mgal except for partly positive anomaly. This result well corresponds to a general tendency of free-air gravity anomaly in West Antarctica where negative anomaly is widespread (SEGAWA *et al.*, 1984). A remarkable positive anomaly is observed across the seamount on Line 8-SMG (s.p. 2000 to 2750).

In general, the magnetic anomaly shows a relatively short wavelength and regular pattern in the western part of the study area, while the anomaly pattern seems wide and irregular along the east-west survey lines in the eastern part. The boundary between these magnetic anomaly patterns is not clearly determined, but it probably has a relationship to the tectonics of the study area and the boundaries inferred from the seismic reflection sections.

5. Seismic Survey

5.1. Seismic refraction survey

Sonobuoy refraction and wide angle reflection survey was carried out at nine sites along the lines of seismic reflection survey as shown in Fig. 3. The sonobuoy data

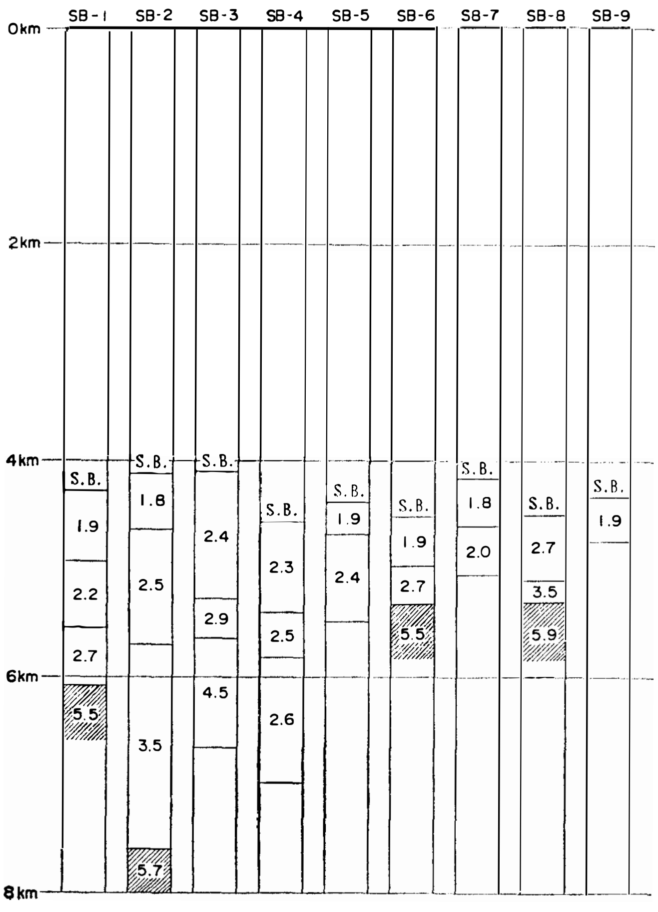

Fig. 7. Velocity-depth profile derived from sonobuoy survey (unit: km/s). S.B. represents a sea bottom. Hatched number represents velocity of basement.

were analyzed by means of both the conventional refraction method and the "reflection velocity analysis" method. The results are given in Fig. 7.

P wave velocities of acoustic basements were determined at SB-1, SB-2 (Line 3-SMG, Fig. 8), SB-6 and SB-8. They range between 5.5 km/s and 5.9 km/s, which are typical of the second layer (Layer 2) of oceanic crust.

Sedimentary layers have wide-ranging values of velocity. They are divided into 4～3 velocity layers at SB-1 to SB-4 and 3～2 at SB-5 to SB-9 (Line 10-SMG, Fig. 10) in consideration of the total thickness of sediments (Fig. 12). Velocities of top layers below the sea bottom at SB-3, SB-4 and SB-8 are a little higher than those of other sites. The third velocity layer below the sea bottom at SB-3 is interpreted as a sedimentary one just above the acoustic basement in spite of its large velocity (4.5 km/s), because a reflector is clearly seen under this layer in the seismic reflection section.

5.2. Seismic reflection survey

Seismic reflection data collected along seven lines were processed using a conventional seismic data processing software. They are 2-SMG series, 3-SMG series, 4-SMG series, 6-SMG, 8-SMG, 9-SMG and 10-SMG (Fig. 3).

The geological units are classified on seismic sections into acoustic basement and three sedimentary units, *i.e.*, Unit A, Unit B and Unit C (Figs. 8, 9 and 10) in descending order by three horizons with reference to seismic Line 18 of KIMURA (1982). According to KIMURA (1982), in the Bellingshausen Sea, Unit A is terrigenous turbidite, ice-rafted detritus and pelagic sediments of Pliocene to Pleistocene, Unit B is terrigenous turbidite and ice-rafted detritus of Middle to Late Miocene, the upper part of Unit C is Early Miocene terrigenous, hemipelagic sediments and the lower part of Unit C is Cretaceous to Paleocene pelagic sediments, although an internal boundary in Unit C is not clearly identified on our seismic sections.

As a whole, each Unit becomes thin toward the west in proportion to the total

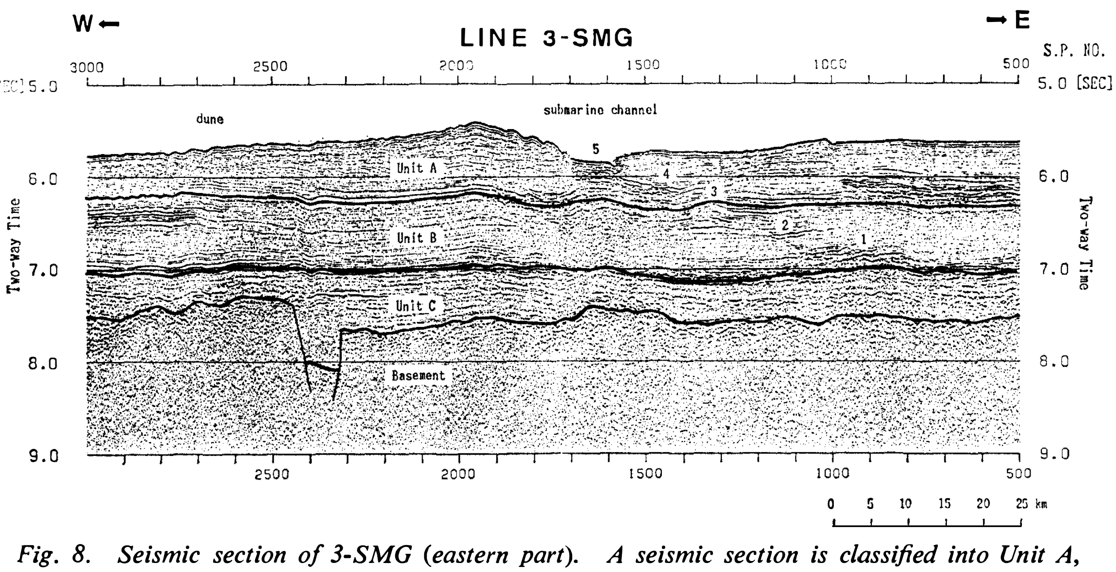

Fig. 8. Seismic section of 3-SMG (eastern part). A seismic section is classified into Unit A, Unit B, Unit C and basement. Note small dunes at the west bank of a channel and shifting submarine channel and turbidite sedimentation (1 to 5). Basement is of Type 1.

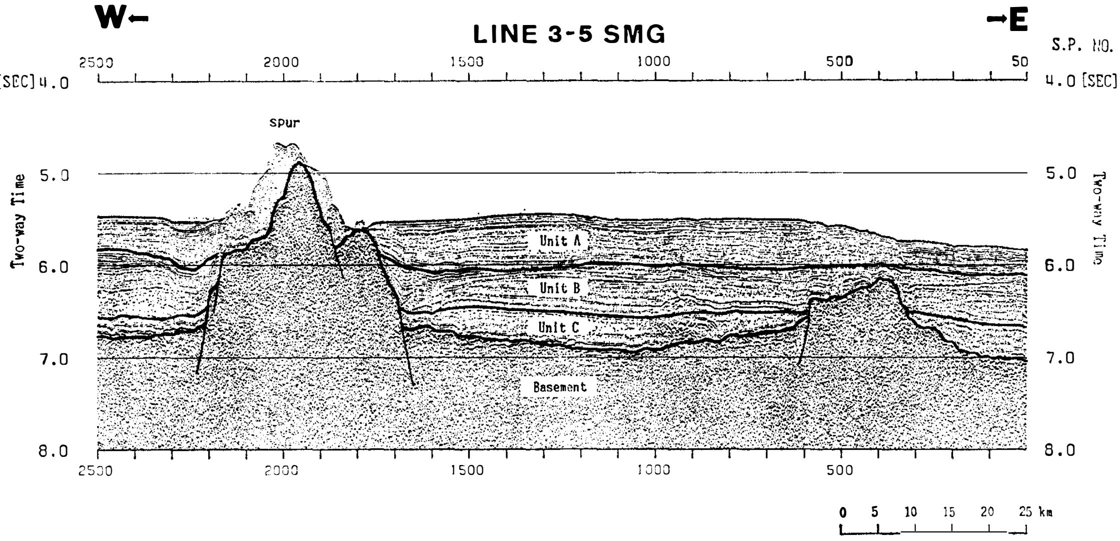

Fig. 9. Seismic section of 3-5-SMG (central part). Note a spur at s.p. 2000 and an uplift of basement at s.p. 500. Basement is of Type 2.

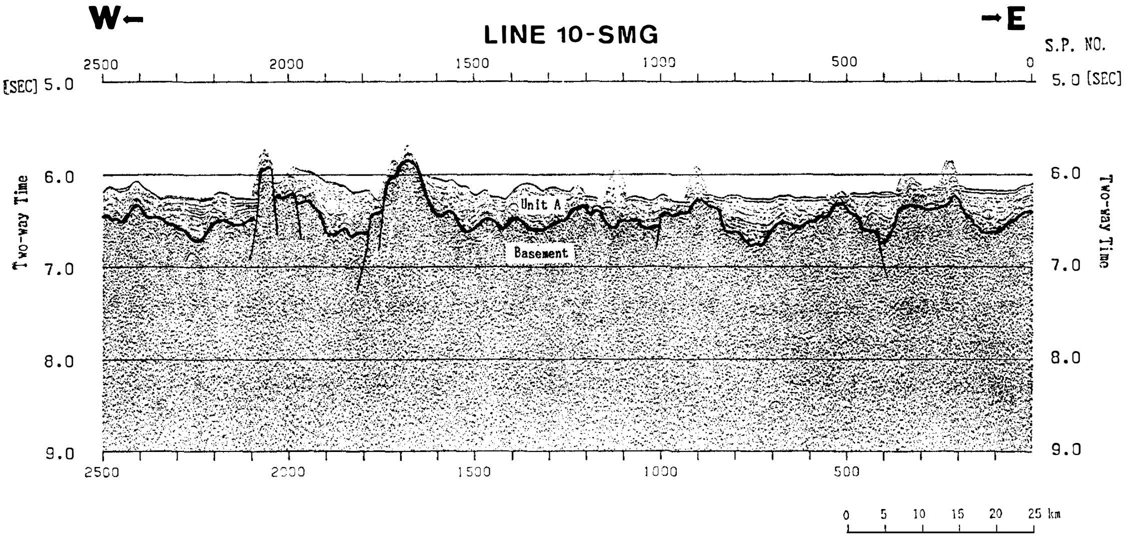

Fig. 10. Seismic section of 10-SMG (western part). Note complex relief of basement, thin sedimentation and distorted reflection pattern. Basement is of Type 3.

sedimentary thickness, and a lateral change of reflection configuration suddenly occurs at several sites, which may suggest frequent changes of sedimentary process.

Unit A, partly unconformably overlying Unit B, is widespread in the study area. It decreases in thickness toward the west. In Unit A and partly in Unit B, remarkable seismic facies like channel fills, dunes and migrating waves are well observed. A chronological sequence of channels as well as present active channels are clearly identified as shifting submarine channels and turbidite sedimentation between s.p. 800 and 1700 of 3-SMG (Fig. 8). Facies of migrating wave type and dune type are often observed on banks of channels, which suggests the secondary effect of bottom currents to deep sea bottom sediments on the continental rise. Irregular discontinuous reflection lineations are observed at structual lows of basement relief in the western part of the study area

(Fig. 10), which suggests movement of the basement as well as the effect of bottom currents (HELLON and TUCHOLKE, 1976; TUCHOLKE and HOUTZ, 1976; TUCHOLKE *et al.*, 1976a, b).

Unit B, conformably overlying Unit C in general, is distributed in the eastern and central parts of the study area. It has the thickest sediments in the eastern part, becomes thin toward the west and disappears at 8-SMG s.p. 3500, which corresponds roughly to 128°W meridian.

Unit C is distributed in the eastern part and partly in the central part of the study area. It is the thickest in the eastern part, gradually becomes thin toward the west like Unit B and terminates at 3-5-SMG s.p. 2800, which corresponds roughly to 119°W meridian. Features of Unit C are weak amplitude and subparallel reflection patterns except for locally high amplitude reflections with diffractions.

A full detail of the acoustic basement is given in the following section.

6. Seismic Interpretation and General Features of the Sedimentary Basin

Basements in the study area are highly varied in acoustic character and can be divided into three types from the viewpoint of basement depth, location, configration and reflection pattern.

Type 1 (eastern part): Low amplitude, flat and discontinuous reflection events are observed mainly in the east of middle 3-SMG series (Fig. 8).

Type 2 (central part): Type 2 basement is of high undulation with high amplitude, continuous reflections, uplifted basements and seamounts or hills. This type appears between middle 3-SMG series and middle 8-SMG (Fig. 9).

Type 3 (western part): Type 3 is characterized by strong hyperbolic diffractions and irregularities of the reflection lineations. It is distributed in the west of middle 8-SMG (Fig. 10).

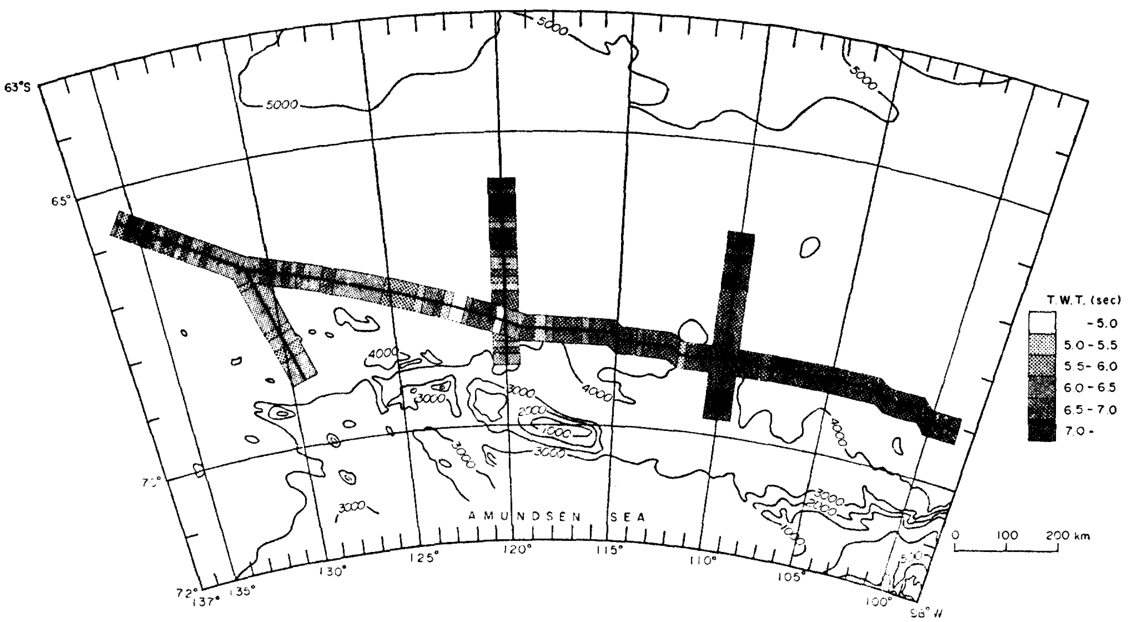

Fig. 11. Acoustic basement depth in second from the sea level (two-way travel time).

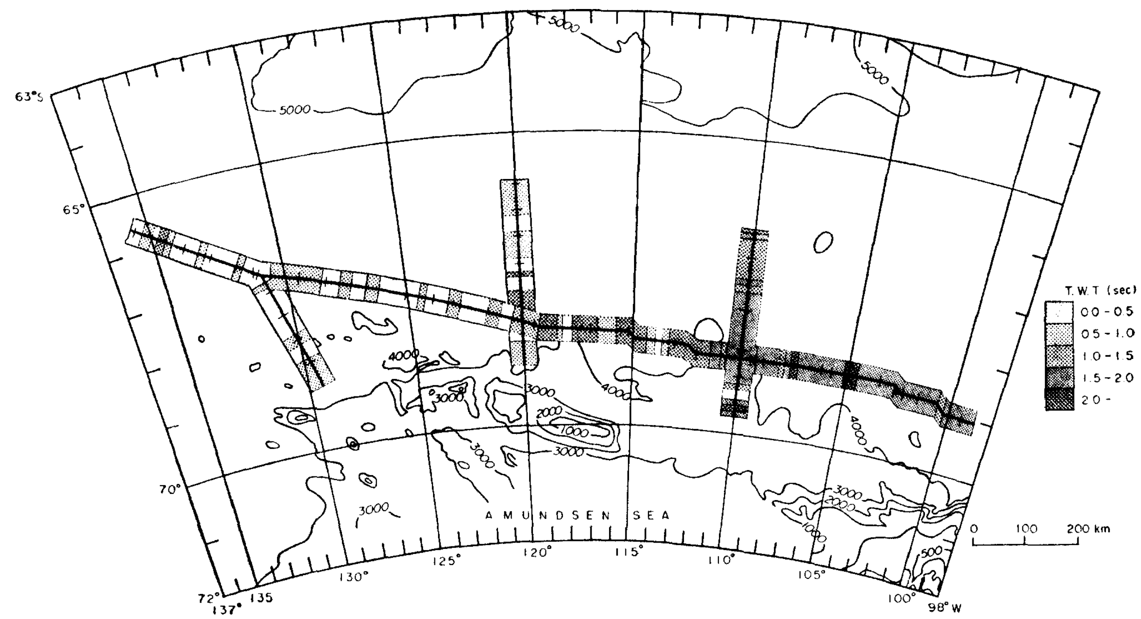

Fig. 12. Thickness of total sediments in second (two-way travel time).

Figures 11 and 12 show maps of the acoustic basement depth from the sea level along the seismic lines and the total thickness of sediments, respectively. Thickness of sediments corresponds to three types of basement. That is, the total sediments are about 2 s in two-way time in the area of Type 1 basement (eastern part), 1.2 s on an average at Type 2 (central part) and 0.5 s at Type 3 (western part), respectively.

As mentioned before, several fracture zones are confirmed to exist in the north and west of the study area and some of them may extend across the study area in the direction of northwest-southeast. Considering all these factors, a border between the eastern part and the central part and one between the central part and the western part are assumed to correspond to the extensions of the fracture zones, respectively, or the central part as a whole is assumed to correspond to the extension of the fracture zones. And Type 1 basement is inferred to be the oldest in age and Type 3 the youngest among the three types, which are consistent with the plate tectonic framework of the south-eastern Pacific Ocean.

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