FRAMEWORK OF THE WEDDELL BASIN INFERRED FROM THE NEW GEOPHYSICAL AND GEOLOGICAL DATA

Yoshihisa OKUDA,

Geological Survey of Japan, 1-3, Higashi 1-chome, Yatabemachi, Tsukuba-gun, Ibaraki 305

Takashi YAMAZAKI,

Japan Petroleum Exploration Company, 17-22, Akasaka 2-chome, Minato-ku, Tokyo 107

Shunji SATO, Takao SAKI and Nobutaka OIKAWA

Technology Research Center, Japan National Oil Corporation, 2-2, Uchisaiwai-cho 2-chome, Chiyoda-ku, Tokyo 100

Abstract: Results of geological and geophysical survey in the Weddell Sea suggest that the sea has two sedimentary basins. The eastern one may extend to the Queen Maud Basin off the Queen Maud Land of East Antarctica, and the western one is developed at the back of the Antarctic Peninsula.

The age of the basements of the basins is tentatively assigned to Late Jurassic—Early Cretaceous. The "Weddell Sea Unconformity" by HINZ is recognized on the continental slope off the Princess Martha Coast. The unconformity is well developed on the outer margin of the basement of the basin on the continental shelf.

From these geological and geophysical data, the authors discuss two hypotheses about generation of the Weddell Sea floor in this paper. One is that the Weddell Sea seems to have been a marginal sea at the back of the island arcs during Late Jurassic to Early Cretaceous, judging from paleontological and seismic reflection data. The other is that the sea floor may have spread during Late Jurassic to Early Tertiary, judging from weak magnetic lineations in the ENE-WSW trend.

1. Introduction

The Weddell Sea is located between Antarctica and South America, and is separated from the Scotia Sea by the Antarctic Peninsula and the South Orkney Islands. The Queen Maud Land, east of the Weddell Sea, is composed mainly of Precambrian and Paleozoic and Early Mesozoic rocks. On the other hand, the Antarctic Peninsula, west of the sea, is mainly composed of Late Mesozoic to Cenozoic rocks, some of which suggest the Andean Orogeny during Late Mesozoic and Early Paleogene.

The oceanic feature of the Weddell Sea is presumed to be complicated, and its tectonic development is supposed to be related closely to the breaking up of the Gondwanaland. According to LABRECQUE and BARKER (1981), the Weddell Sea began to spread during the Jurassic age.

For the purpose of revealing these geologic features, our new geologic, paleontological and geophysical data from the Weddell Sea are combined with previous geo-

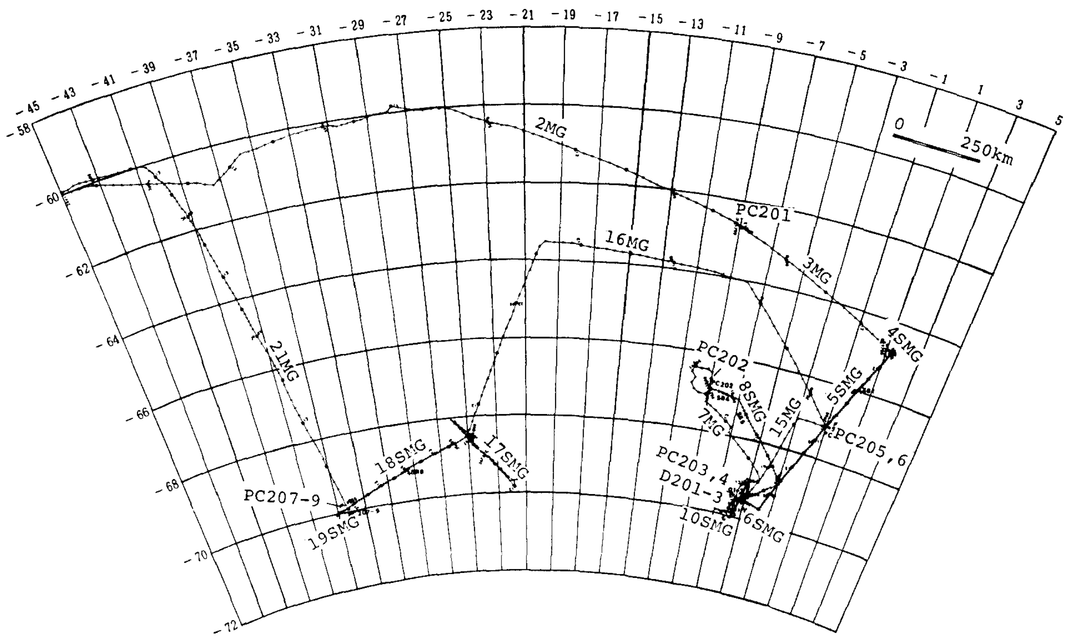

Fig. 1. Tracks of geophysical survey and sampling stations during the TH81 cruise. S: seismic, M: magnetic, G: gravity, PC: piston core, D: dredge.

physical observations to provide some explanations for the origin of the oceanic features of the sea in the framework of plate tectonics.

The data were obtained by R/V HAKUREI-MARU (1821.6 gross t) during the TH81 cruise (in the summer seasons of 1981–1982) of the Technology Research Center, Japan National Oil Corporation, in cooperation with the Geological Survey of Japan (Fig. 1). The vessel has equipments for 24 channel seismic reflection survey, seismic refraction survey, gravity survey, geomagnetic survey, dredging and 8 meter piston coring below the bottom of 10,000 meters in total depth, 3.5 kHz subbottom profiling survey, and 12 kHz bathymetric survey. Navigation was based upon the Navy Navigation Satellites System (NNSS).

2. Outlines of Bottom Sampling Results and Terrestrial Heat Flow Measurements in the Weddell Sea

Sampling of unconsolidated sediments by the piston corer with heat flow equipment was carried out at six stations. The calculations of the heat flow could be conducted only for the data of four stations due to some troubles of the thermistor sensors.

Dredged rocks were obtained at three stations from the walls of the submarine canyon on the continental slope off the Princess Martha Coast. They are angular unconsolidated sedimentary rocks, mudstones and hard shales with rounded gravels of metamorphic rocks and several kinds of igneous rocks which are presumably distributed in East Antarctica.

The outlines of sampling and terrestrial heat flow measurements are shown in Table 1 and Fig. 2.

The bottom sample of sediments from each station is divided into several core

Table 1. *Summary of bottom samples of sediments and rocks.*

St. No.	Sample No.	Date	Time (GNT)	Position		Depth (m)	Results	Heat flow
				Lat. (S)	Long. (W)			
1	PC201	7	1341 1644	62°33.93′	9°18.85′	5252	123 cm. Diatomaceous ooze, gray soft clay, and gray very fine sand	0.651 HFU
2	PC202	14	1202 1447	66°52.72′	9°00.56′	4980	158 cm. Olive gray soft clay, very fine sand and gray silt	
3	D201	16	1100 1324	69°29.66′ 69°29.66′	4°57.62′ 4°59.58′	2720 2450	Gravels (gabbro, gneiss, diorite, andesite, dacite; max. 16×10×10) and clayey silt	
4	D202	16	1503 1634	69°34.91′ 69°34.88′	5°43.67′ 5°42.67′	2245 2201	Gravels (granodiorite, dacite, gabbro, granite, andesite; max. 20×15×10), mudstone, and clay	
5	PC203	18	1107 1223	69°24.76′	5°16.98′	1794	170 cm. Fine silty clay and gray clay	0.393 HFU
6	PC204	18	1425 1543	69°34.18′	5°20.60′	1844	380 cm. Olive gray and gray clay	0.309 HFU
7	D203	18	1715 1905	69°29.30′ 69°29.34′	4°59.07′ 4°59.61′	2596 2523	Gravels (gneiss, hornfels, andesite, gabbro, diorite; max. 16×6×5), mudstone and clay	
8	PC205	19	1144 1442	67°06.39′	0°49.71′	4696	cc. Olive gray fine sand	
8A	PC206	19	1612 1911	67°07.02′	1°00.42′	4693	cc. Gray silt and fine sand	
9	PC207	27	1112	69°53.87′	34°13.59′	4363	226 cm. } Olive gray, dark gray, and pale greenish gray clay bearing clean sand and silt layers.	
9A	PC208	27	1503	69°54.33′	34°12.92′	4360	710 cm. }	2.03 HFU
9B	PC209	27	1924 2157	69°53.78′	34°14.52′	4364	365 cm. }	2.18 HFU

cc: core catcher.

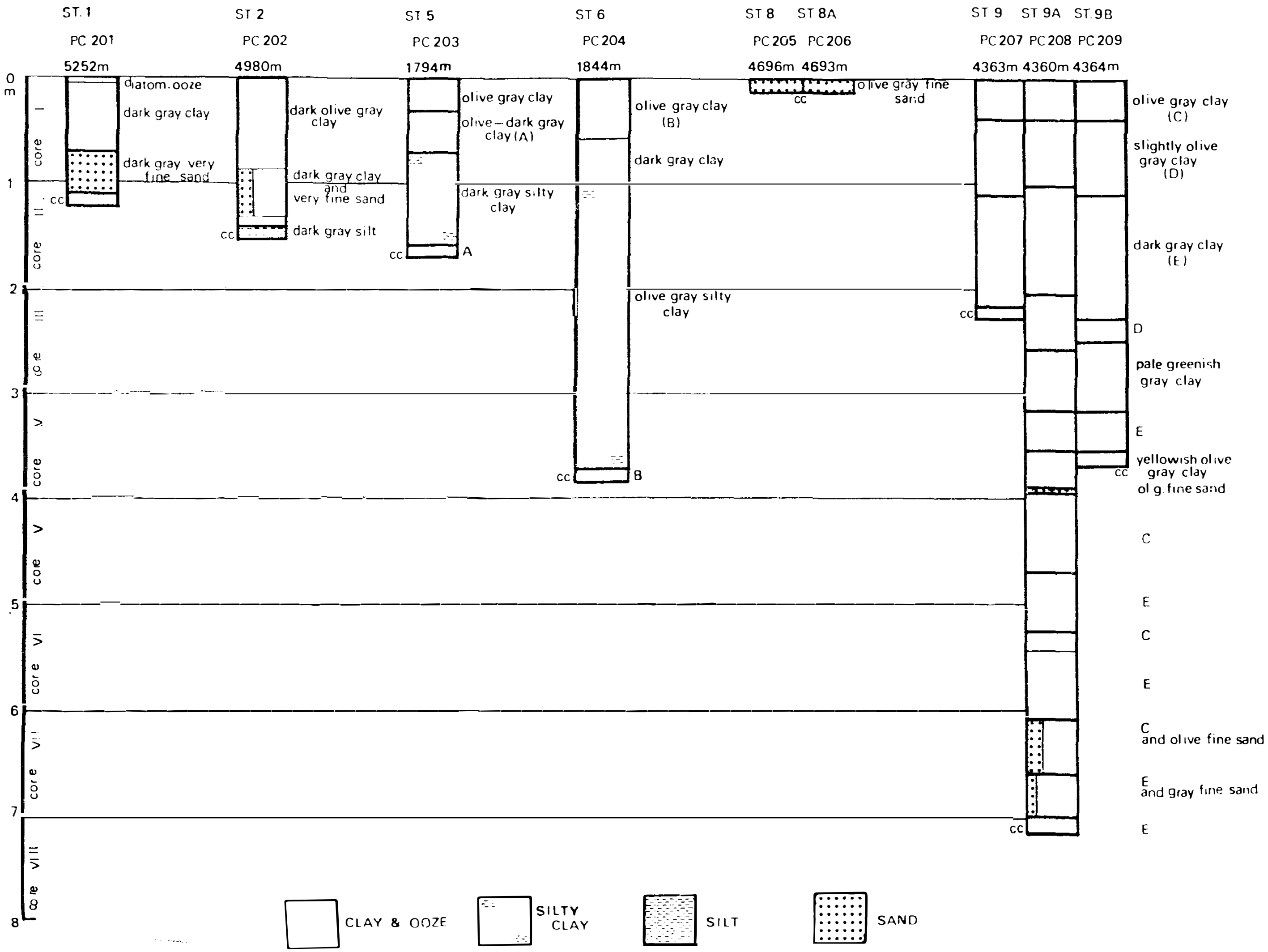

Fig. 2. Columnar sections of piston core samples. cc: core catcher.

units, which are named core I, core II,---in descending order, and each unit is one meter long. The number after the sample name indicates the length from the top of each sample unit in cm. The above-mentioned sample names are used later in this paper.

3. Micropaleontological Studies

3.1. Foraminiferal fossils

Occurrences of foraminiferal fossils from the Weddell Sea are characterized by vertical distributions of arenaceous assemblage, calcareous assemblage and "no foraminifera zone" (NF) in descending order. Occurrences of foraminiferal fossils determined by MAIYA and INOUE (1983) are shown in Table 2.

Generally speaking, the surface sediments from the bottom of the sea contain mostly arenaceous assemblages, dominated by *Cribrostomoides subglobosum* (SARS), *Cribrostomoides* sp. and *Rhabdammina abyssorum* SARS. But the surface sediments of PC201 and PC204 are exceptionally barren of foraminiferal fossils, and those of PC205 and PC206 contain calcareous assemblages composed mainly of *Eilohedra weddellensis* (EARLAND) and *Epistominella exigua* (BRADY), similar to the assemblages contained in the lower part of PC203 and PC204 to be mentioned later.

The assemblages in the cores generally change from the arenaceous assemblage or barren in the upper part to the calcareous assemblage in the lower part. The calcareous assemblage is commonly characterized by *Globigerina pachyderma* (EHRENBERG), *Eilohedra weddellensis* (EARLAND), *Eponides tumidulus* (BRADY) and *Epistominella exigua* (BRADY), such as the faunal facies of PC203 and PC204. In PC204, the zone of the calcareous assemblage is further divided into three sub-zones; *Nonionella bradii* (CHAPMAN)—*Epistominella exigua* assemblage accompanied by *Cassidulina carinata* SILVESTRI and *Globocassidulina subglobosa* (BRADY) in the upper part, *Epistominella exigua—Globocassidulina subglobosa* assemblage accompanied by *Eilohedra weddellensis* and *Cassidulina carinata* in the middle part, and *Epistominella exigua—Cassidulina carinata* assemblage accompanied by *Nonionella bradii* in the lower part. In PC208, assemblage of *Nuttalides umbonifera* (CUSHMAN) and *Oridorsalis tenerus* (BRADY) is found discontinuously.

Deep sea cores such as PC201, PC202 and PC208 have a barren zone beneath the calcareous zone.

Presence of an arenaceous assemblage in the top part of cores followed by a calcareous assemblage beneath it is a common phenomenon in the Antarctic Oceans such as the Bellingshausen Sea and the Ross Sea. Though these facts are presumed to be related closely to the change of paleoclimate, the generation mechanism is not clear yet. The age of these sediments is presumed to be Pliocene to Holocene because of common occurrence of *Globigerina pachyderma.*

In PC208 core IV20–22, *Chiloguembelina* sp., which may be a reworked species of Eocene to Early Oligocene age, is found.

3.2. Diatom fossils

Assemblages of diatom fossils from the Weddell Sea are similar to those from the Bellingshausen Sea (AKIBA, 1982; KOIZUMI, 1982), and occurrences of diatom fossils determined by AKIBA (1983) are shown in Table 3.

Table 2. Occurrences of selected foraminifera fossils (determined by MAIYA *and* INOUE, *1983).*

	PC201					PC202							PC203						
	I				II	I						II	I					II	
	8 11	27 29	45 47	65 67	2 5	4 10	25 27	40 42	55 57	70 72	85 87	45 48	0 2	20 22	40 42	60 62	81 84	47 49	60 62
Cribrostomoides subglobosum (SARS)	NF							NF					99	7				1	
C. sp.					NF	3						NF	6	1	1	1	2		1
Arenaceous Miscellaneous						3							40	8	1	1	1		1
Rhabdammina abyssorum SARS						1							1				1		1
Eilohedra weddellensis (EARLAND)																	48	94	33
Eponides tumidulus (BRADY)																	5	18	1
Nonionella bradii (CHAPMAN)																			3
Epistominella exigua (BRADY)		1																	3
Cassidulina carinata SILVESTRI									4										3
Globocassidulina subglobosa (BRADY)																			7
Nuttalides umbonifera (CUSHMAN)																			
Oridorsalis tenerus (BRADY)																			
Globigerina pachyderma (EHRENBERG)		10	2				3		3	4				7			32	225	1410
Chiloguembelina sp.																			

	PC204																						
	I					II					III					IV					cc	PC205	PC206
	0 2	20 22	40 42	60 62	80 82	0 2	20 22	40 42	60 62	80 82	0 2	20 22	40 42	60 62	80 82	0 2	20 22	40 42	58 60	67 69			
Cribrostomoides subglobosum (SARS)				3					1			1											
C. sp.		2	1	1	1				1		1	1											
Arenaceous Miscellaneous		2																					
Rhabdammina abyssorum SARS																							
Eilohedra weddellensis (EARLAND)		32	1		2	18	15	34	14	58	39	6	2	9		14	3	5	13	24	23	1	18
Eponides tumidulus (BRADY)		23				3	12	6	5	2	10	6	1	7	2	7		1	8	6	8		
Nonionella bradii (CHAPMAN)		37	48	137	7	19	35	48	16	36	55	8	3	2	11	14	34	17	16	38	34		

Epistominella exigua (BRADY)	23	7	90	84	52	37	54	78	82	38	15	12	76	46	22	35	42	33	45	90	10
Cassidulina carinata SILVESTRI	53	7	13	23	87	48	38	9	29	28	131	218	115	136	91	19	70	144	90	17	
Globocassidulina subglobosa (BRADY)	32	6	16	43	73	147	39	10	33	21	14	3	11	4	5	7	5	6	10	8	4
Nuttalides umbonifera (CUSHMAN)																					
Oridorsalis tenerus (BRADY)	5	4	10	1	1	2		1								1	1			2	1
Globigerina pachyderma (EHRENBERG)	■	■	■	□	□	□	■	■	■	■	■	□	□	■	■	□	■		■	□	18
Chiloguembelina sp.																					

	PC208																					
	I			II		III				IV				V			VI		VII			cc
	7–9	20–22	60–62	40–42	85–87	0–2	20–22	60–62	80–82	20–22	40–42	60–62	80–82	0–2	20–22	40–42	40–42	60–62	0–2	60–62	98–100	
Cribrostomoides subglobosum (SARS)																	NF		NF	NF		NF
C. sp.	6																					
Arenaceous Miscellaneous	3										1											
Rhabdammina abyssorum SARS																						
Eilohedra weddellensis (EARLAND)											2		25	1	7							
Eponides tumidulus (BRADY)			1							2	14											
Nonionella bradii (CHAPMAN)																						
Epistominella exigua (BRADY)											2	1	18		7							
Cassidulina carinata SILVESTRI																						
Globocassidulina subglobosa (BRADY)			2			1		1		3	7		3		4							
Nuttalides umbonifera (CUSHMAN)			1					6		3	29	1	91		23							
Oridorsalis tenerus (BRADY)																						
Globigerina pachyderma (EHRENBERG)	1	13	328	2	1	■	6	704	9	■	■	4	46	12	259	19		5			1	
Chiloguembelina sp.											2											

■ More than 1000, □ More than 10000

Table 3. Occurrences of selected diatom fossils (determined by AKIBA, *1983).*

Sample	PC201	PC202	PC202	PC203	PC203	PC203	PC204	PC204	PC204	PC204	PC204	PC204	PC205	PC206	PC208	D201	D202	D202	D203	D203	D203	D203
	I	I	I	I	I	II	I	I	II	II	III	IV		VII	VII	cy	cy		cy			
Diatom	65–67	4–10	98–100	20–22	60–62	47–49	0–2	60–62	0–2	60–62	0–2	20–22		cc	0–2					A	B	C
Actinocylus ingens RATTRAY	1	1	1					*						1				1				
Asteromphalus sp.		*		2			*						1									
Charcotia actinochilus (EHRENBERG) HUSTEDT		2	*	3	3		3	*					*			2	2		2		*	
Coscinodiscus lentiginosus JENISCH		4	3	6	2	1	2		*	3			3	3		7	11	1			3	
Coscinodiscus sp.					*		*				*	*			*			*	*			*
Eucampia balanstium CASTRACANE		6	2	3	11	*	3		*	9	2		5	5			10		12		2	
Denticulopsis hustedtii (SIMONSEN & NAKAYA) SIMONSEN		10	2	3		2			2	3	1		3	7		4	2	2	3		2	
Denticulopsis dimorpha (SCHRADER) SIMONSEN		3	2											1		11	11					
Denticulopsis cfr. maccolomii SIMONSEN													1									
Nitzschia curta (VAN HEURCK) HASLE		1	2	27	12	1	11	*					1			2	2					
Nitzschia kerguelensis (O'MEARA) HASLE		149	52	99	139	11	120	6	*	1	1		164	153		155	137		143		23	*
Paralia sulcata																		1		3		4
Pseudopodosira cfr. marginata HAJÓS																				2		9
Pyrgupyxis sp.	1													2					*	8		7
Rhizosolenia barboi (BRUN) TEMPERE & PERGALLO																		4				
Schimperiella antarctica KARSTEN	*	1		1	1	1							1			1	1		3		*	
Stephanopyxis sp.	*	2			11		1	*	*	*	*	1	7	7			3	4		17		13
Thalassionema nitzschioides GRUNOW ex. V.H.		2	1										1	1		1	1					
Thalassiosira antarctica COMBER				19	3	2	6						1	2		4	4		5		2	
Thalassiothrix longissima CLEVE & GRUNOW		7	3	1	*	*	2	*			*		1	1		2	4		1	*		
Total number of diatom values counted	2	200	71	200	200	19	200	6	2	16	4	1	200	200	*	200	200	20	200	33	35	33
Abundance of diatoms	2	1800	71	3600	250	19	1800	6	2	16	4	1	900	900	*	900	600	20	1800	33	35	33

*: exten cy: Cylinder dredge sample

Though *Coscinodiscus* sp. and *Pyrgupyxis* sp. are found in PC201 core I 65–67, PC201 is generally barren of diatom fossils. Therefore, it is impossible to determine the age of the sample of PC201 solely by diatoms. Diatom fossils are generally absent in PC202, though *Nitzschia kerguelensis, Denticulopsis hustedtii* and *Thalassiothrix longissima* are rarely found in the upper part. The age of the sample is considered to be Quaternary as *N. kerguelensis* and *D. hustedtii* are presumed to be reworked diatoms from middle to upper Miocene rocks.

In the top part of PC203 (core I 0–2 to core II 60–62), diatom fossils are abundantly found. Diatoms are absent in the lowermost part of the core (core II 60–62). The diatom assemblage of PC203 is characterized by predominant *Nitzschia kerguelensis* with *Coscinodiscus lentiginosus, Charcotia actinochilus, Eucampia balanstium* and *Schimperiella antarctica*, which is correlated with the *N. kerguelensis* zone by ABBOTT (1975). This assemblage suggests Quaternary age.

PC204 is barren of diatoms except rare *Coscinodiscus* sp., though the top of the core includes the same assemblage as that in PC203. Also, diatoms do not occur so frequently in the sand remained on the surface of the corer tube, and the assemblage is similar to that in PC203. PC206 rarely contains diatoms and the assemblage is similar to that in PC203. PC208 rarely contains diatoms except *Coscinodiscus* sp. from core VII 0–2.

D201 contains Late Quaternary assemblage in which *Nitzschia kerguelensis* is predominant.

Two samples of D202 were analyzed. One sample contains a similar assemblage to D201, but the other sample scarcely contains diatoms lacking *Nitzschia kerguelensis.* The latter has a few individuals of *Rhizosolenia barboi* and is presumably correlated with the *R. barboi* zone (Late Pliocene to Early Pleistocene) by DONAHUE (1970). The fact may indicate that two formations of different ages, that is, Late Pleistocene to Holocene and Late Pliocene to Early Pleistocene, exist close to each other.

Two rocks of D203 were analyzed. One contains Late Quaternary assemblage with predominant *Nitzschia kerguelensis*, and the other contains a special assemblage in which the Paleogene type genus predominantly occurs with *Pseudopodosira marginata, Pyrgupyxis* sp. and *Paralia sulcata.* The age of the latter is presumed to be Late Eocene to Early Oligocene. These two strata of different geologic ages, that is, Late Pleistocene to Holocene and Late Eocene to Early Oligocene, may be present within the sampling position (ST. 5).

3.3. Radiolarian fossils

Radiolarian fossils occur in more samples than foraminiferal fossils and diatom fossils, and they are more efficient to determine the ages of rocks. Occurrences of radiolarian fossils determined by NAKASEKO and NISHIMURA (1983) are shown in Table 4.

Though the upper part of PC201 is barren of radiolarians, the lower part contains radiolarian fossils. The assemblage is composed mainly of *Antarctissa cylindrica, A. longa, Desmospyris spongiosa, Prunopyle titan, Lithelius nautiloides*, and *Spongoplegma antarcticum* group. The assemblage of *Stylatractus universus, Eucyrtidium calvertense* and *Helotholus vema* occurs only in core II 2–5, which may be correlated with the

Table 4. Occurrences of selected radioralian fossils (determined by NAKASEKO *and* NISHIMURA, *1983).*

Samples	PC201			PC202					PC203				PC204						PC208	D201 A	D202		D201 B
	I		II	I			II		I			II	I		II	III	IV		VII		A	B	
Radiolaria	65 67	83 85	2 5	4 10	40 42	98 100	0 2	30 32	20 22	40 42	60 62	47 49	0 2	40 42	80 82	90 100	67 69	cc	0 2				
Spongoplegma antarcticum group			−	⊕	−	⊕		−	+	−	−	−	+	−	⊕	−	−	−					−
Antarctissa sp.	−		−	−		+	+	−							−					+			
A. cylindrica		−	−						⊕	+	+	−	−			−	−	+		−	−	−	−
A. denticulata		−	−						⊕	+	+	+	−		−		−					−	−
A. longa	−	−	−						+			−									−	−	
Stylatractus universus			−																			⊕	
Prunopyle titan		−	+																			⊕	
P. antarctica								−	+		−	−	−										
Helotholus vema			−																				
Desmospyris spongiosa	−		+																			−	
D. sp.			−																			+	
Eucyrtidium calvertense			−																			+	
Lychnocanium grande rugosum			−																				
Actinomma sp.					−		−													−		−	
A. leptodermum									+	⊕	−	−	−		−								
A. delicatulum			−			−			−			−	−							−	−		−
Lithelius sp.																							
L. nautiloides			−						⊕	⊕	−	−	−										−
Eucyrtidium sp.									−									−					
E. inflatum																					−		
Spongaster sp.																							
Heliodiscus asteliscus																		−					
Druppatractus sp.		−																	−				
Stichocorys delmontensis							−												+				

−: 1–5, +: 6–10, ⊕: 10<.

Helotholus vema zone of Early Pliocene in the Antarctic region by CHEN (1975).

The assemblage of PC202 is characterized by predominant *Spongoplegma antarcticum* group, *Antarctissa cylindrica* and *Actinomma leptodermum*. *Stichocorys delmontensis* in core II 0–2 indicates Late Miocene age.

PC203 and PC204 frequently contain radioralian fossils, which are mainly *Spongotrochus glacialis, Spongoplegma antarcticum* group, *Antarctissa cylindrica, A. denticulata, Lithelius nautiloides* and *Actinomma leptodermum*. *Antarctissa denticulata* and *A. longa* from PC203 may indicate that the age of the sediments may be younger than Pliocene. *Heliodiscus asteliscus, Spongaster* sp. and *Eucyrtidium* (?) sp. accompanied by abundant *Antarctissa denticulata* in the lowermost part of PC204 may indicate the age of Early Pliocene for that part.

PC208 is barren of radiolarian fossils except the lower part (core VII 0–2), containing *Stichocorys delmontensis* and *Druppatractus* sp. which may indicate Late Miocene age.

The mudstone from D202 contains abundant *Eucyrtidium calvertense* and *Prunopyle titan*, which suggest the *Helotholus vema* zone of Pliocene.

4. Magnetic Anomalies

Magnetic anomalies in the Weddell Sea are shown in Fig. 3. Judging from the patterns of calculated magnetic anomalies, the surveyed area is divided into three; eastern, central to western, and northwestern areas.

In the eastern area, the magnetic anomalies have the amplitude of more than 500 nT and the wavelength of more than 100 km, and clear magnetic lineations in the WSW-ENE trend are observed.

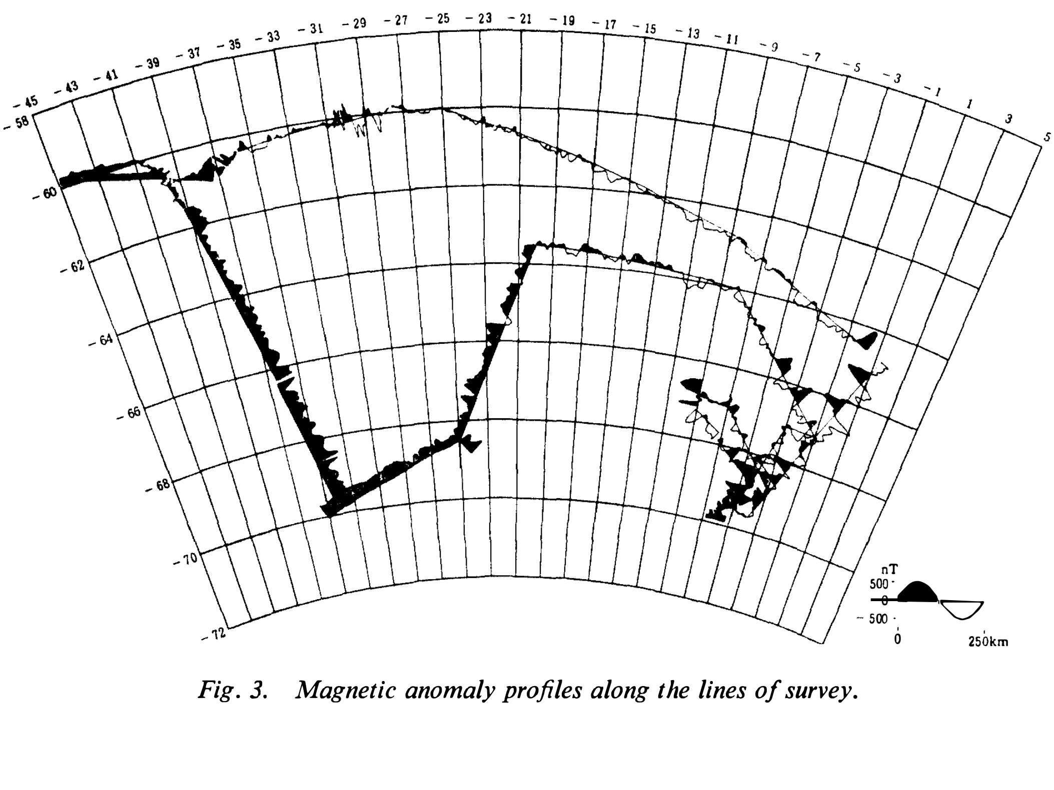

Fig. 3. Magnetic anomaly profiles along the lines of survey.

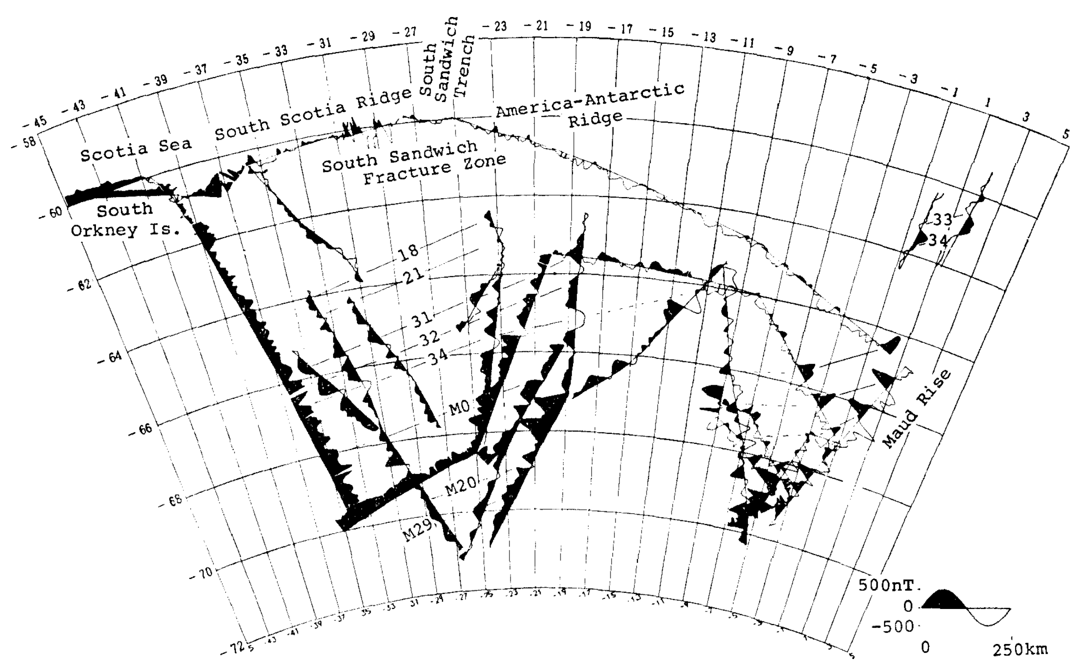

Fig. 4. Magnetic anomaly profiles and estimated ages combining our data with those of LABRECQUE and BARKER (1981) and BERGH and BARRETT (1980).

In the central to western area, the magnetic anomalies have the bias level of approximately 200 nT, and the wavelength is several tens of kilometers. These anomalies are relatively smoother than those of the eastern area.

In the northwestern area, the magnetic anomalies are not so large due to the complicated geomorphological structures of the Scotia Sea, the South Sandwich Trench and the South Sandwich Fracture Zone. Clear anomalies with short wavelength are observed around 60°S–29°W and 60°S–31°W. These are presumably accompanied with a fracture zone. Previous data by LABRECQUE and BARKER (1981), and BERGH and BARRETT (1980) are combined with our data in Fig. 4.

According to LABRECQUE and BARKER (1981) and BERGH and BARRETT (1980), the age of the ocean floor in the central to western area is presumably 45 to 150 Ma, and 80 to 100 Ma in the northwestern area.

5. Free Air Gravity Anomalies

Free air anomalies in the surveyed area are shown in Fig. 5. In the Weddell Sea, general free air anomaly is approximately −20 mgal.

Negative anomalies of approximately −100 mgal are recognized over the South Sandwich Trench and the South Sandwich Fracture Zone. The South Scotia Ridge, the America-Antarctic Ridge, and the Endurance Ridge have anomalies of several tens mgal.

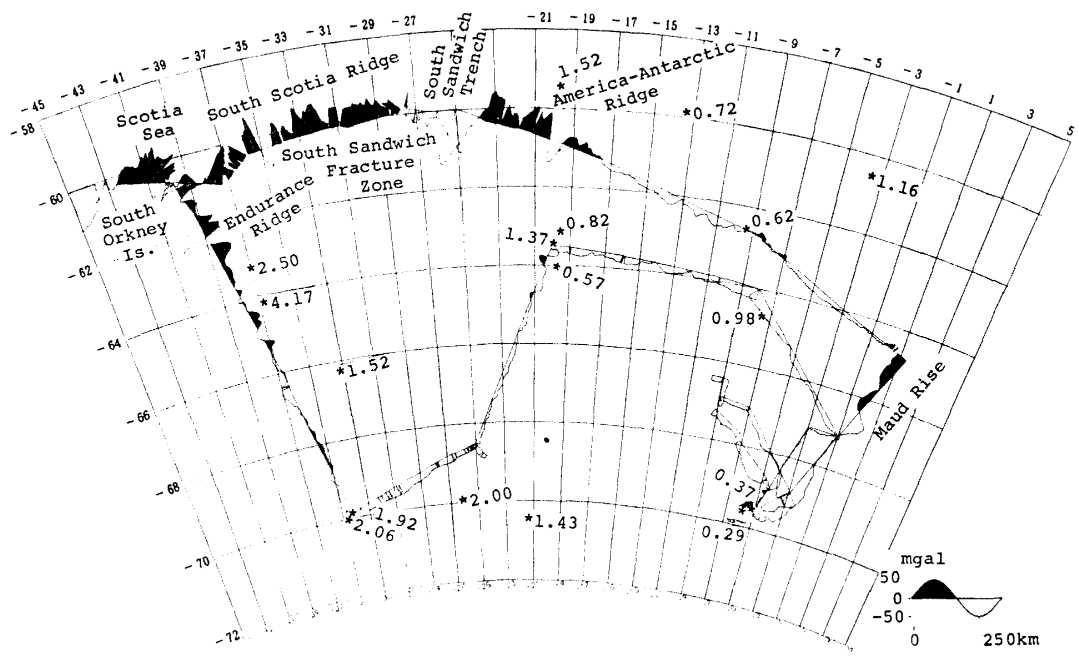

Fig. 5. Free air gravity anomaly profiles along the survey line.

6. Seismic Reflection Profile

Seismic reflection profiling during the TH81 cruise was carried out in the eastern and the central parts of the Weddell Sea. Track lines of the seismic reflection survey are shown in Fig. 6.

The profile of line 5 was obtained from the Maud Rise to the continental slope through a well-developed basin which is considered a western extension of the Queen Maud Basin. The profile continues to that of line 6 which crosses line 12. An interpretative geologic section along line 5 to line 6 is shown in Fig. 7. The strata of the area on the acoustic basement are divided into five formations, named A, B, C, D and E in descending order. These formations are clearly recognized on the profile of line 6 as shown in Fig. 8, where several submarine canyons exist on the continental slope and some of the formations outcrop at the walls of the canyons due to erosion. The A, B and C formations can be correlated with the dredged rocks mentioned before, referring by reflecting the dredge stations to the distribution of the outcrops from the profiles and water depth. The A formation may contain rocks of Late Pliocene to Quaternary age from D202 (which is determined by diatom fossils). The B formation may contain rocks of Early Pliocene age from D202 (which is determined by radiolarian fossils). The C formation may contain rocks of Eocene to Oligocene age obtained from D203 (which is determined by diatom fossils).

Though we did not obtain any sample which is correlatable to the D and E formations, the age of the formations is presumed to be older than Eocene. The interval velocities of the formations from the seismic processing data generally show more than 3.0 km/s, sometimes more than 3.5 km/s where thin sediments cover the formations. These facts suggest that the formations are fairly old, probably older than Paleogene.

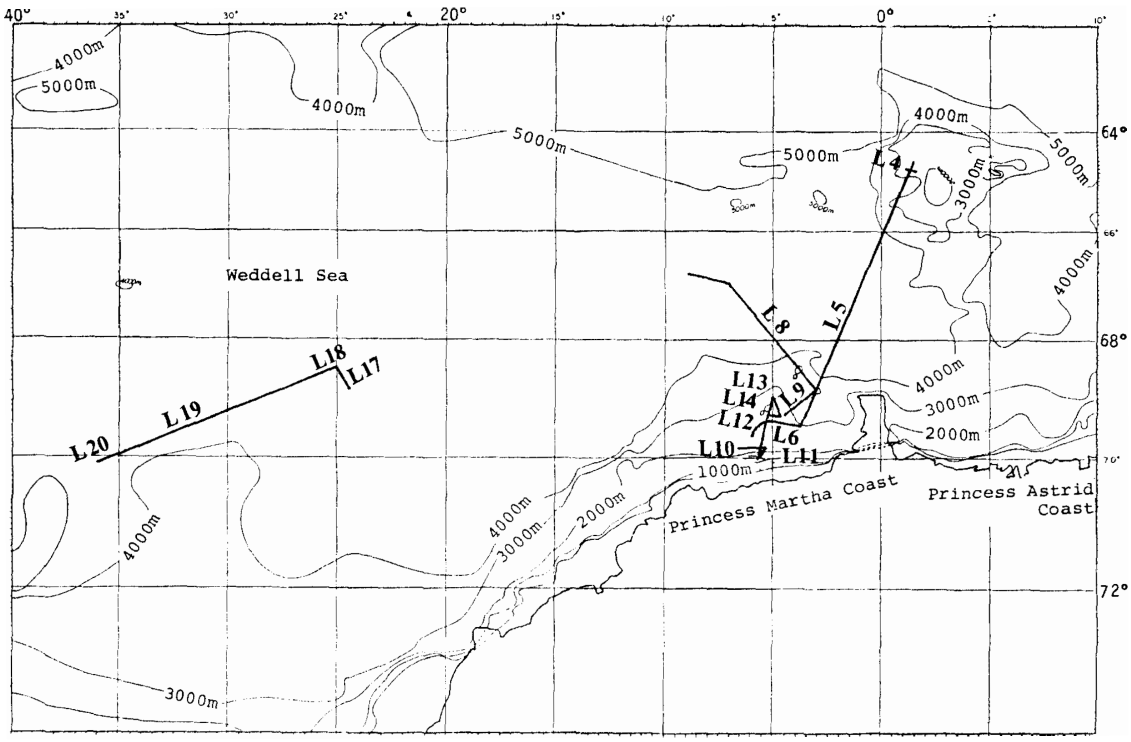

Fig. 6. Tracks of seismic reflection survey.

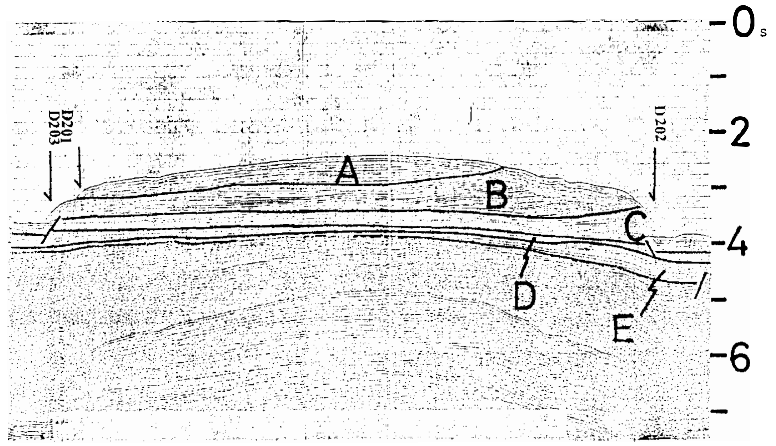

Fig. 7. Seismic reflection profile on the continental slope off the Princess Martha Coast (L-6) which cuts a ridge between two submarine canyons. Vertical scale is shown by two way travel time in seconds.

The acoustic basement on the profile in Fig. 8 has weak reflectors. The stratigraphic relation between the acoustic basement and the E formation on the continental slope off the Princess Martha Coast is clearly an unconformity, which may be correlated with the "Weddell Sea Unconformity" of tentative Jurassic age proposed by HINZ (1982). Our data in Fig. 7 also suggest that thick sediments of the D and E formations below the C formation of Paleogene age exist in the Queen Maud Basin and that the acoustic basement on the continental slope seems to be older than the E formations.

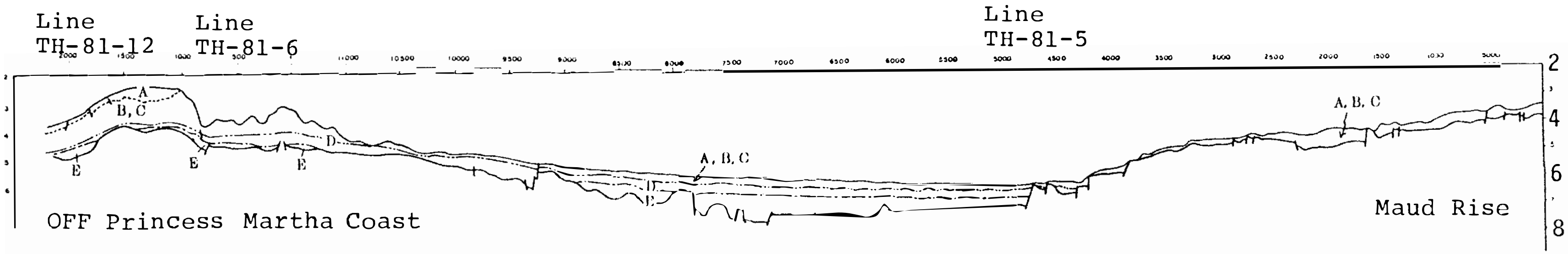

Fig. 8. Interpretative geologic section from the Maud Rise to the continental slope of the Princess Martha Coast.

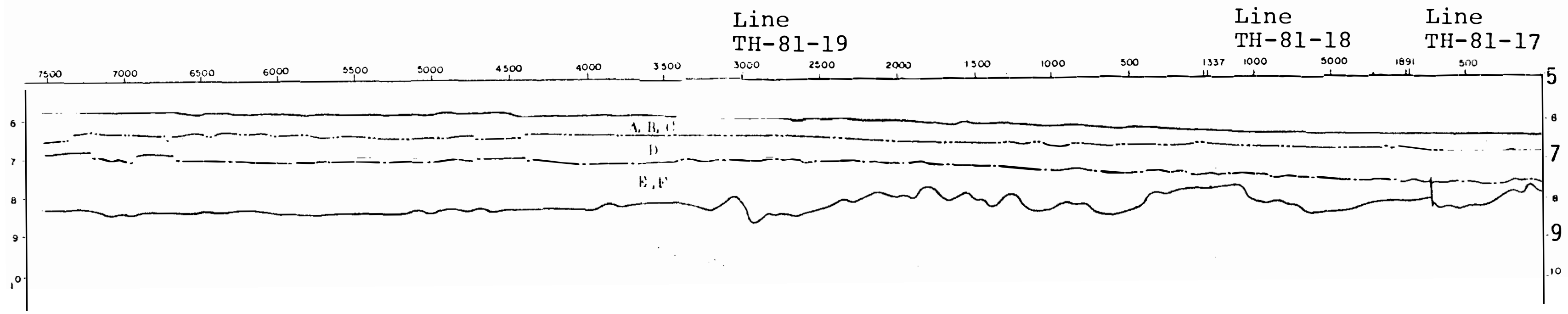

Fig. 9. Interpretative geologic section in the western basin of the Weddell Sea.

Though HINZ (1982) suggests that the acoustic basement on the slope may be composed of oceanic igneous rocks, the present authors have an idea that the basement is a continental crust because of its weak reflectors and its lower interval velocity than 5.0 km/s at the surface. The basement may be correlated with the complex of Precambrian, Paleozoic and Early Mesozoic of the Queen Maud Land of East Antarctica.

Continental rise is not so well developed on line 5 and normal faults that cut the acoustic basement are recognized. This fact may suggest that the transform faults were produced by tensional fields during the period of the "Weddell Sea Unconformity" at the breaking up of the Gondwanaland around the present flank of the continental slope. The boundary between the oceanic and the continental crust is presumed to have existed there.

Thin sediment covers the acoustic basement on the Maud Rise, and several normal faults exist on the southern slope of the rise.

Another cross section in the central part can be interpreted as shown in Fig. 9. The section shows that thick sediments of 2 to 3 s are deposited in the Weddell Basin. The basement of the western part is relatively smooth.

Judging from the acoustic transparency and the radiolarian assemblage of Late Miocene in PC208, the upper part of the sediments was formed under a slow sedimentation rate.

The middle part of the sediments is presumed to be turbidities, judging from the acoustic features of stratification. Diatoms and foraminifera in PC208 show that many Eocene to Oligocene fossils have been transported to the central part of the Weddell abyssal plain. These facts suggest that large amounts of Paleogene sediments may have been deposited in the neighborhood, and have been reworked by turbidity currents. So the age of the turbidities is presumably Paleogene to Middle Miocene. The lower part of the sediments is thick, and buries the relief of the acoustic basement. The acoustic features of this part is similar to those of the lower part of the Queen Maud Basin, and the age of the part is tentatively assigned to Cretaceous to Early Paleogene. The lowermost part of the sediments may include older sediments than Cretaceous.

7. Distribution of the Sedimentary Basins

An isochron map of the total sediments and an acoustic basement map of two-way travel time map are shown in Figs. 10 and 11, referring to HINZ (1978). They indicate that two basins exist in the Weddell abyssal plain. The 1.5 s isochron and 7.5 s acoustic basement lines clarify that the western one is presumed to extend to the Queen Maud Basin as mentioned above.

Another small basin seems to exist on the continental slope off the Princess Martha Coast from the acoustic basement map. But the isochron map does not reflect the basement topography because of the deep erosion of sediments around the submarine canyons. The authors name this basement depression the Princess Martha Basin.

Isochron maps of the lower part of the sediments ("E" and "F" formations), the middle part of the sediments ("D" formation) and the upper part of the sediments ("A", "B" and "C") are shown in Figs. 12, 13 and 14, respectively. Distribution of

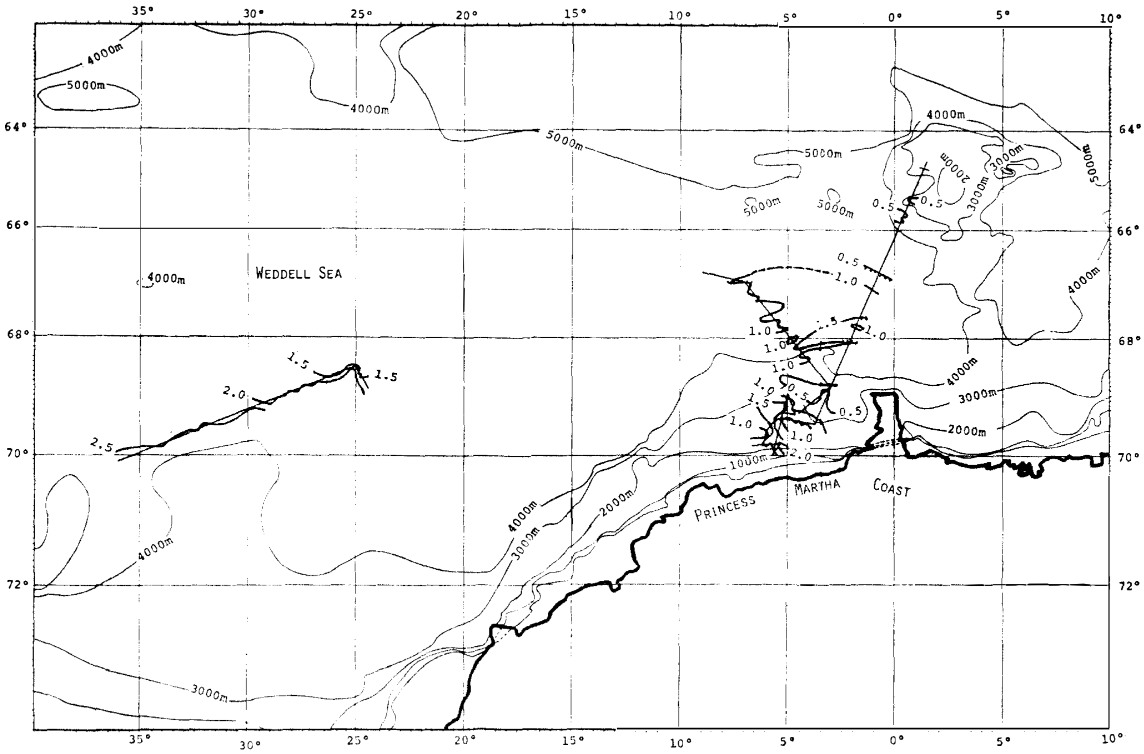

Fig. 10. Isochron map of the total sediments in seconds.

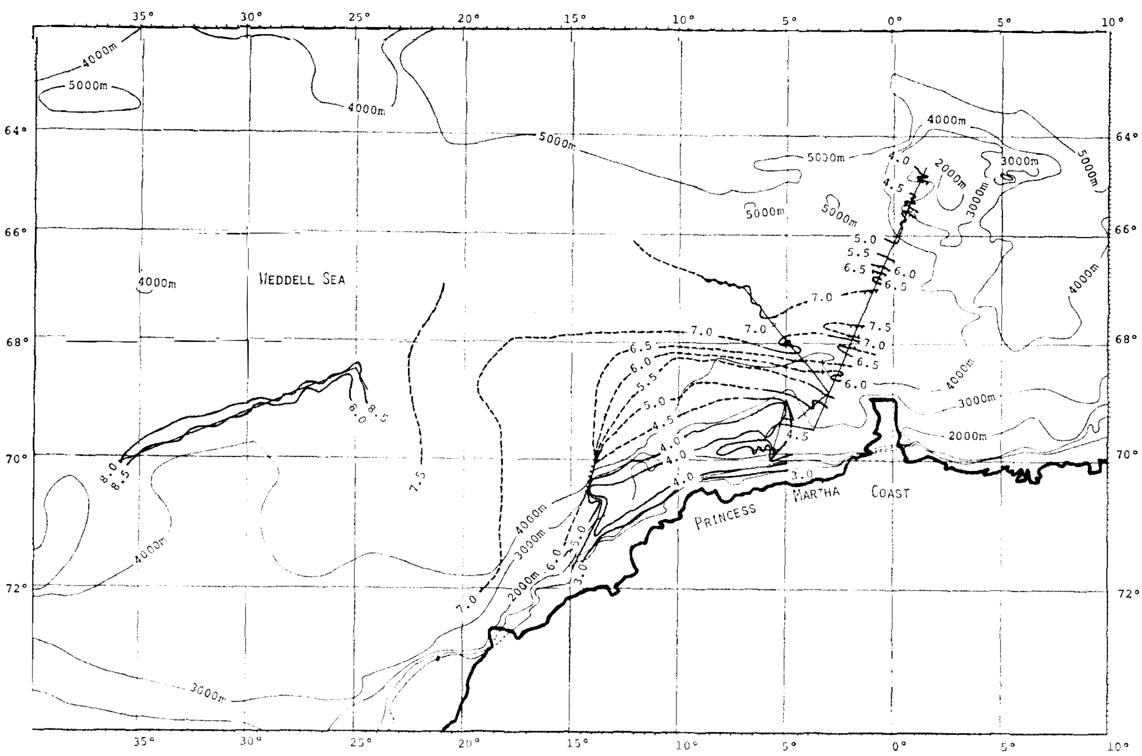

Fig. 11. Acoustic basement map of two-way travel time (s).

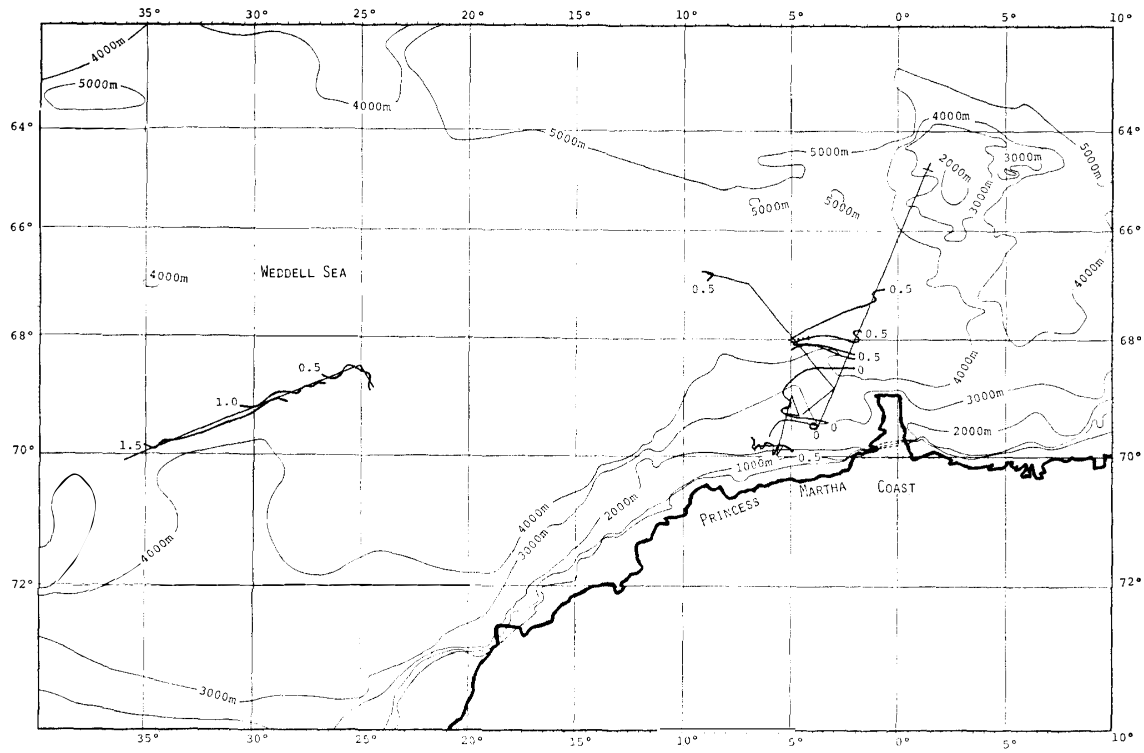

Fig. 12. Isochron map of the lower sediments (E, F) in seconds.

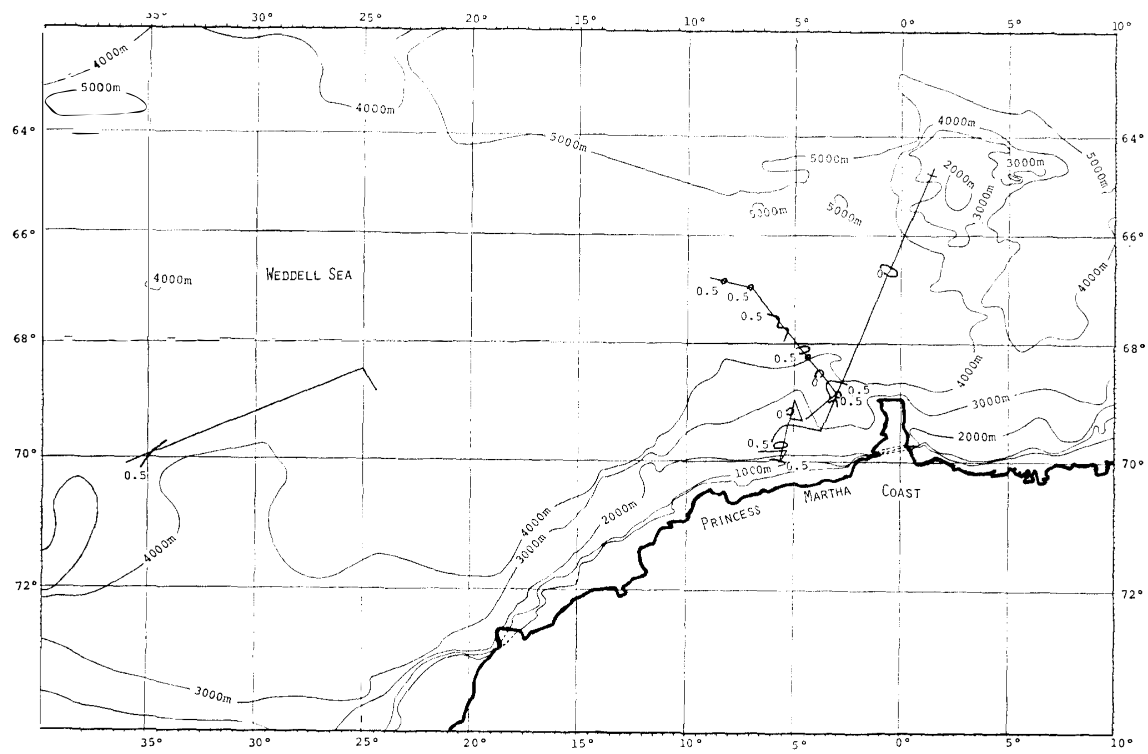

Fig. 13. Isochron map of the middle sediments (D) in seconds.

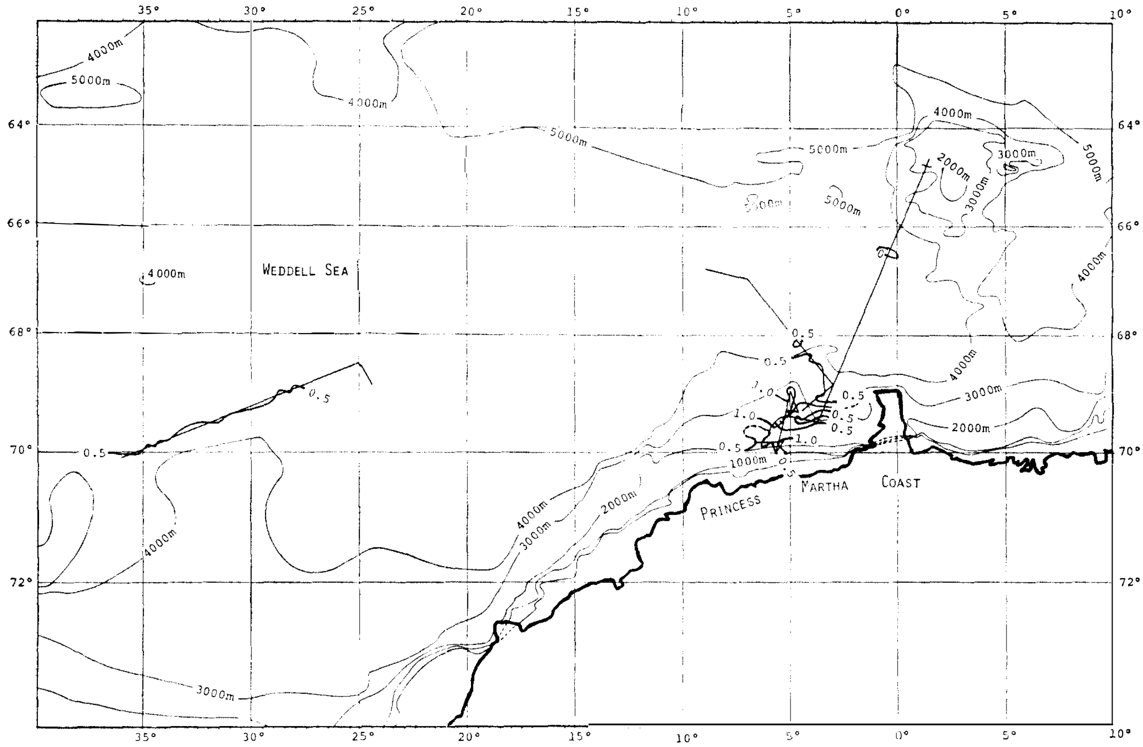

Fig. 14. Isochron map of the upper sediments (A, B, C) in seconds.

the lower part of the sediments almost coincides with that of the total thickness of the sediments, and it suggests that the basin configuration was roughly defined before the deposition of the middle part. The isochron map of the middle part shows that the thickness of the part is uniform almost of 0.5 s in the abyssal basin. The southward extension of the southern rim of the basin suggests that the rapid transgression occurred during the deposition of this area. The isochron map of the upper part shows that the thickness of this part is uniform except for the continental slope. It may be possible to consider that Antarctic Continent was uplifted relative to the abyssal plain, and submarine canyons have been formed at the later depositional stage of the upper part.

8. Consideration on the Generation of the Weddell Sea

The authors propose two alternative hypotheses about the origin of the Weddell Sea.

(1) In South America, the Patagonian Batholith belt of mafic rocks (Late Jurassic), the Rocas Verdes belt of ultrabasic rocks (Late Jurassic to Early Cretaceous) and older belts (Cretaceous) are ranging from west to east, and the Rocas Verdes belt is regarded as a small marginal sea (DALZIEL *et al.*, 1974). This marginal basin became wider in the Tierra del Fuego, and the trend of the basin development changed from N-S to E-W. The basin extends toward South Georgia Island where basic rocks are distributed, and the dike orientation changes to southward there (DE WIT, 1977).

The Scotia Sea floor, south of South America, is composed mainly of the oceanic crust (BARKER and GRIFFITHS, 1972), but partly of the continental crust in areas of the North Scotia Ridge including South Georgia Island and the South Scotia Ridge including South Orkney Islands (DALZIEL and ELLIOT, 1973). The continental crust is considered to extend to the Antarctic Peninsula.

Magnetic lineations of the Scotia Sea show that the age of the eastern and western parts is Cenozoic, and the age of the central part is Early Cretaceous (BARKER and GRIFFITHS, 1972; DE WIT, 1977). Seismic refraction data by EWING *et al.* (1971) show that the layers of 3.3, 6.3 and 6.7 km/s in the central part of the Scotia Sea suggest the oceanic crust of the marginal sea like the Japan Sea. Complex igneous bodies are inferred in the central part of the Scotia Sea, which are correlated with the ultrabasic to basic pillow lava, basic to intermediate pillow lava and volcanoclastic rocks of Cretaceous of South Georgia Island (TRENDALL, 1959). These facts suggest that the oceanic rocks of the marginal sea of South Georgia Island have been extruded by overlying calc-alkaline rocks, which are correlated with the layer of 3.3 km/s velocity (DE WIT, 1977).

On the other hand, the andesitic volcanoclastic rocks overlying the ultrabasic rocks of the Rocas Verdes belt of South Georgia Island are supplied from south (DALZIEL *et al.*, 1975), and the layer of 6.6 km/s velocity is recognized in the central part of the Scotia Sea (ALLEN, 1966), and the layer of 6.0 km/s velocity recognized in the central part of the Scotia Sea is correlated with the Patagonian Batholith belt or older belt (DE WIT, 1977).

Therefore, it is possible to consider that the marginal basin at the back of the Antarctic Peninsula of Late Jurassic to Cretaceous might extend to the south of the central part of the Scotia Sea, namely, the western part of the Weddell Sea.

Our seismic data indicate that the acoustic basement of the western part of the Weddell Sea (the Weddell Basin) is relatively smooth, and the amplitude of the magnetic anomalies is smaller than that of the normal oceanic floor. The free air anomaly of the Weddell Sea is also a little negative value, and the eastern rim of the Weddell Basin shows a N-S direction. The age of the basement is also presumed to be Late Jurassic to Cretaceous as mentioned before. From these facts the Weddell Basin is presumably considered as a marginal basin at the back of the Antarctic Peninsula of Late Jurassic to Cretaceous. The high heat flow value at ST 9 seems to support the explanation of the marginal sea, too.

(2) The other paradoxical hypothesis of the generation of the Weddell Sea can be considered as follows.

From the magnetic lineations, LABRECQUE and BARKER (1981) determined the age of the ocean floor of the Weddell Sea, as ranging from Jurassic to Early Paleogene. Our paleontological data of the occurrence of Eocene to Oligocene diatom flora at D203 and seismic data of thick sediments in the basin beneath the strata which are correlated with D203 suggest that a Paleogene age of the ocean floor seems doubtful. Anyhow, the basic idea of generation of the Weddell Sea is based on the ocean floor spreading which began at the initial breaking up of the Gondwanaland during Late Jurassic. According to their age determination, spreading rate is calculated as less than 1 cm/yr, which seems to be slower than the rate of normal ocean floor spreading. Plotting of the heat flow value obtained at ST. 9 vs. the age by PARSONS and SCLATER

(1977) suggests that their determination of the age may have to be redetermined, though the present authors have not yet done so.

The possibility of generation of the Weddell Sea by the ocean floor spreading may be high, if the magnetic lineations by LaBrecque and Barker (1981) are attributed to the ocean floor spreading.

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