BSPE 00565-990-7

남극 섀클턴 파쇄대의 지체구조에 관한 연구

A Study on the Tectonic Structure of the Shackleton Fracture Zone, Antarctica

1997. 4

한 국 해 양 연 구 소

제 출 문

한국해양연구소 소장 귀하

본 보고서를 '남극 섀클턴 파쇄대의 지체구조에 관한 연구' 사업의 최종보고서로 제출합니다.

1997년 4월

연구책임자 : 김예동

연구원 : 진영근, 나광웅

요 약 문

I. 제목

남극 섀클턴 파쇄대의 지체구조에 관한 연구

II. 연구 내용 및 결과

섀클턴 파쇄대는 드레이크 해협의 열림작용으로 만들어졌으며 스코티아판과 남극판의 경계를 구성하고 있다. 또한 섀클턴 파쇄대는 남미판과 남극판의 상대적 이동 방향을 지시하고 있다. 섀클턴 파쇄대를 가로 지르는 탄성파 단면도에 의하면 섀클턴 파쇄대는 해저면에서 2000 m 높이로 솟아 있는 산맥과 1000 m 깊이의 함몰된 계곡으로 형성되어 있다. 섀클턴 파쇄대는 삼중점의 북쪽에서는 계곡이 존재하고 있으며, 남쪽에서는 단지 변형단층 운동만이 계속되고 있다. 섀클턴 파쇄대가 남섀틀랜드 대지와 충돌하는 삼중점에서는 산맥의 형태는 사라지지만 변형단층 운동은 삼중점의 남쪽에서도 계속되리라 기대된다.

삼중점의 바로 남쪽을 지나는 단성파 단면 KSL93-3을 보면 변형을 받은 25 km 넓이의 반지구 (half-graben)가 발달되어 있음을 볼 수 있다. 이 반지구는 섀클턴 파쇄대의 계곡까지 연장되어 있는 대규모 단층을 따라 형성되어 있다. 반지구내에서 스코티아해 지역의 판구조 운동 방향의 변화에 따라 만들어진 두가지 종류의 변형이 발견된다. 이러한 변형상은 북쪽의 섀클턴 파쇄대 계곡에서도 볼 수 있다. 반지구를 형성한 주된 구조운동은 단층운동에 수반된 확장작용으로, 드

레이크 해협의 열림작용 동안 섀클턴 파쇄대의 transtension 운동 때문에 이루어졌다. 약 6백만년전 드레이크 해협과 스코티아해의 열림작용이 끝난 후, 드레이크 해협 일대의 지역은 스코티아판의 서향 운동으로 인하여 구조적인 압력을 받게 되었다. 이에 따라 원래 지구를 형성했던 정단층은 역단층으로 다시 운동을 하여 상부 퇴적층을 변형 시켰다. 탄성파 단면도는 퇴적층에 남겨진 이지역에 가해진 최근의 압축력에 의해 변형된 모습을 뚜렷하게 보여준다. 주단층의 동쪽에 나타나는 심한 변형을 받은 구조는 계곡을 형성한 주단층과 반대 경사를 갖는 antithetic 단층에 의한 지각블럭의 회전에 따라 만들어진 것으로 생각된다.

남섀틀랜드 대지의 경계에서 엘레펀트섬의 북측을 가로 지르는 탄성파 단면 KSL93-7은 섀클턴 파쇄대의 남쪽 연장선상에서 각각 3개의 산맥과 계곡을 갖는 복잡한 해저지형을 보인다. 이러한 톱날 모양의 지형은 아마 섀클턴 단층대가 수개의 작은 단층으로 분리됨으로써 만들어졌을 것이다. 결론적으로 섀클턴 단층대는 삼중점의 남쪽으로 연장되어 스코티아해와 남섀틀랜드 대지의 일부 지각을 변형시켰다.

SUMMARY

Ⅰ. Title

A study on the tectonic structure of the Shackleton Fracture Zone, Antarctica.

Ⅱ. Results

The Shackleton Fracture Zone (SFZ) is a boundary between the Scotia and the Antarctic plates as a product of the Drake Passage opening, indicating the direction of the relative plate motion between the South American and the Antarctic plates. Seismic profiles running across the SFZ suggest that the SFZ consists of a ridge 2000 m high aand a trough 1000 m deep. To the south of the triple junction, the SFZ keeps only its transform movement forming the SFZ trough north of the triple junction. As the SFZ collides with the South Shetland Platform in the triple junction area, the SFZ ridge is terminated in front of the SSP, but the SFZ transform movement could be expected to extend farther to the south of the triple junction.

Profile KSL93-3, running just south of the triple junction, shows a 25 km wide half graben and corresponding deformations. A large-scale fault extending to the SFZ trough formed the half graben. In the graben two kinds of

deformation are observed depending on the variation of plate kinematics in the Scotia Arc region. This also occurs in the SFZ trough. Extension along the faults formed the graben. This deformation results from transtenstional motion of the SFZ during the opening of Drake Passage. After cessation of spreading in Drake Passage and the Scotia Sea at about 6 Ma, tectonic regime in the Drake Passage area changed into compression by a westward convergence of the Scotia plate. The major fault that once was a normal fault forming the graben reactivated with reverse sense and deformed in the recent sediments, which are indicative of recent compression in this area. The severely deformed structure east of the major fault may be caused by rotation of crustal blocks along the antithetic faults accompanied with large-scale down-faulting along the major fault.

The margin of the South Shetland Platform on Profile KSL93-7 across the northern margin of Elephant Island shows complex bathymetry composed of three ridge and troughs, which are laid on the southern extension of the SFZ trough. This crenulated topography was probably associated with the SFZ transform splaying into several small faults. Consequently the SFZ transform continues far south from the triple junction and deforms the crust of the Scotia Sea and the SSP.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1. INTRODUCTION

The Shackleton Fracture Zone (SFZ) is a boundary between the Scotia and the Antarctic plates as a product of the Drake Passage opening. This fracture zone is also an indicator of the direction of the relative plate motion between the South American and the Antarctic plates (Fig. 1-1).

The SFZ extends about 800 kilometers from the southernmost tip of South America to the northern tip of the Antarctic Peninsula (Fig. 1-1). The southern end of the SFZ meets the South Shetland Trench (SST) and the South Scotia Ridge (SSR) at a triple junction off the northern tip of the Antarctic Peninsula. Complex tectonic stresses, including convergence along the SST and the left-lateral strike-slip motion along the SFZ and the SSR, are expected at this triple junction area (Barker et al., 1989; Pelayo and Wiens, 1989).

During the Cenozoic a series of ridge crest segments of the Antarctic - Phoenix ridge arrived at the trench along the Pacific margin of Ellsworth Land and the Antarctic Peninsula. The arrival of these segments was progressively later from southwest to northeast along the margin. As each ridge segment arrived, it juxtaposed Antarctic lithosphere on the flanking of the ridge against Antarctic lithosphere on the landward side of the trench, thus the subduction stopped at the time of ridge arrival and trench basement topography was eliminated in the southwestern part of the Hero Fracture Zone (SFZ) (Herron and Tucholke, 1976; Barker, 1982; Larter and Barker, 1991). Only between the HFZ and the SFZ, trench topography still persists along the

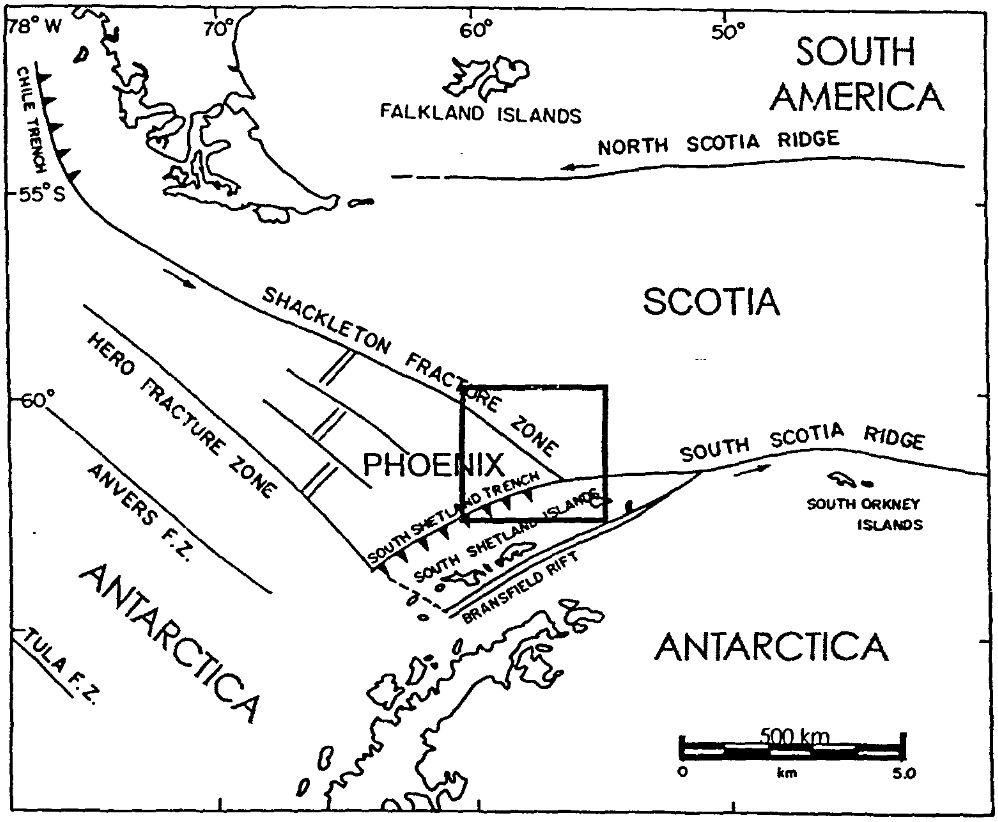

Figure 1-1. General physiography of the triple junction area in the north of the Antarctic Peninsula (modified from Maldonado et al., 1993). The box delineates the study area.

northern margin of the Antarctic Peninsula. Magnetic anomaly map shows that spreading in the Phoenix plate stopped at about 4 Ma before the stoppage of subduction along the SST (Barker, 1982).

The SSR forms another boundary between the Antarctic and Scotia plates. Pelayo and Wiens (1989) suggeted that the Scotia plate shows the general W or WNW motion relative to the Antarctic plate. They also proposed that convergence between the Scotia and the Antarctic plates in Drake Passage is accommodated by strike-slip faulting along the SFZ and diffuse compressional deformation in the passage area.

Because most of the previous studies in the area are concentrated on the SST and Bransfield Strait, the crustal structure of the SFZ has nearly not been documented. The SFZ has been deduced mostly by bathymetric, magnetic and gravity data (e.g. Barker and Burell, 1978; Renner et al., 1985; Klepeis and Lawyer, 1993; Livermore et al., 1994). Kim and Jin (1994) recently presented the multichannel seismic profiles crossing the southern part of the SFZ showing a transverse ridge 2000 m high and a deep trough (fracture zone valley) filled with sediments up to 1500 m thick. He also suggested that stress regime in the Drake Passage regions changed recently from extension to compression. According to his explanation, main morphology of the SFZ with a ridge and trough structure was formed by transtension along the SFZ during the Drake Passage opening before 4 Ma, whereas recent contractional structures around the top of the trough have probably formed by compression due to westward convergence of the Scotia plate.

As the southern end of the SFZ collides with the South Shetland Platform at the triple junction, the SFZ movement is expected to have given a large effect to the South Shetland Platform. In this study, two seismic profiles running just south of the triple junction area and bathymetric data are presented (Fig. 1-2). The aim of the study is to investigate the structural and morphological variation of the South Shetland Platform along the southern extension of the SFZ. This provides better understanding of the complex tectonic structure to the south of the triple junction.

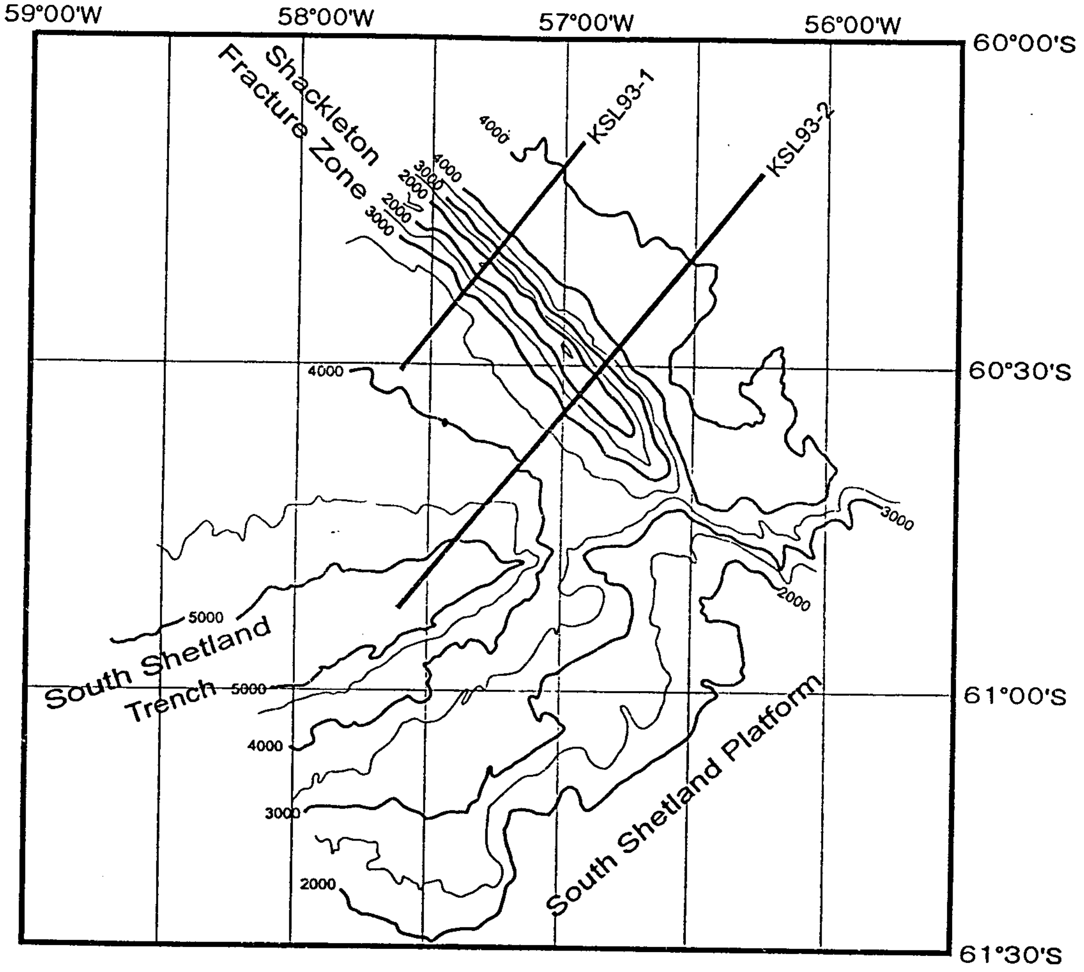

Figure 1-2. Location of multichannel seismic lines in the study area. HFZ-Hero Fracture Zone; SFZ-Shackleton Fracture Zone; SST-South Shetland Trench.

CHAPTER 2. TECTONIC SETTING

General Setting

The development of the Scotia Sea including Drake Passage is fundamentally related to the interaction between the South American and Antarctic plates. The Southern Andes and the Antarctic Peninsula (AP) have been recognized as geologically related and contiguous during the early Mesozoic (Suess, 1909; Matthews, 1959). Abrupt termination of structural trends at the southern tip of South America and at the northern end of the AP suggests that the Antarctic-Andean margin was disrupted by the formation of the Scotia Sea in Tertiary time (Barker and Burrell, 1977). Many of the tectonic features associated with the North and South Scotia Ridges are related to dispersal of an originally continuous convergent margin along the Pacific.

The Scotia Sea region, a marginal basin situated between the much larger South America and Antarctic plates, exhibits many active tectonic processes, including the fast back arc spreading behind the South Sandwich Arc and the left-lateral strike-slip motion along the North Scotia Ridge (NSR), South Scotia Ridge (SSR) and the SFZ (Fig. 2-1). The opening of the Scotia Sea was caused by plate-scale motions as Southernmost South America and the AP drifted away from Africa at different velocities along different, nonparallel trajectories (Cunningham et al, 1995).

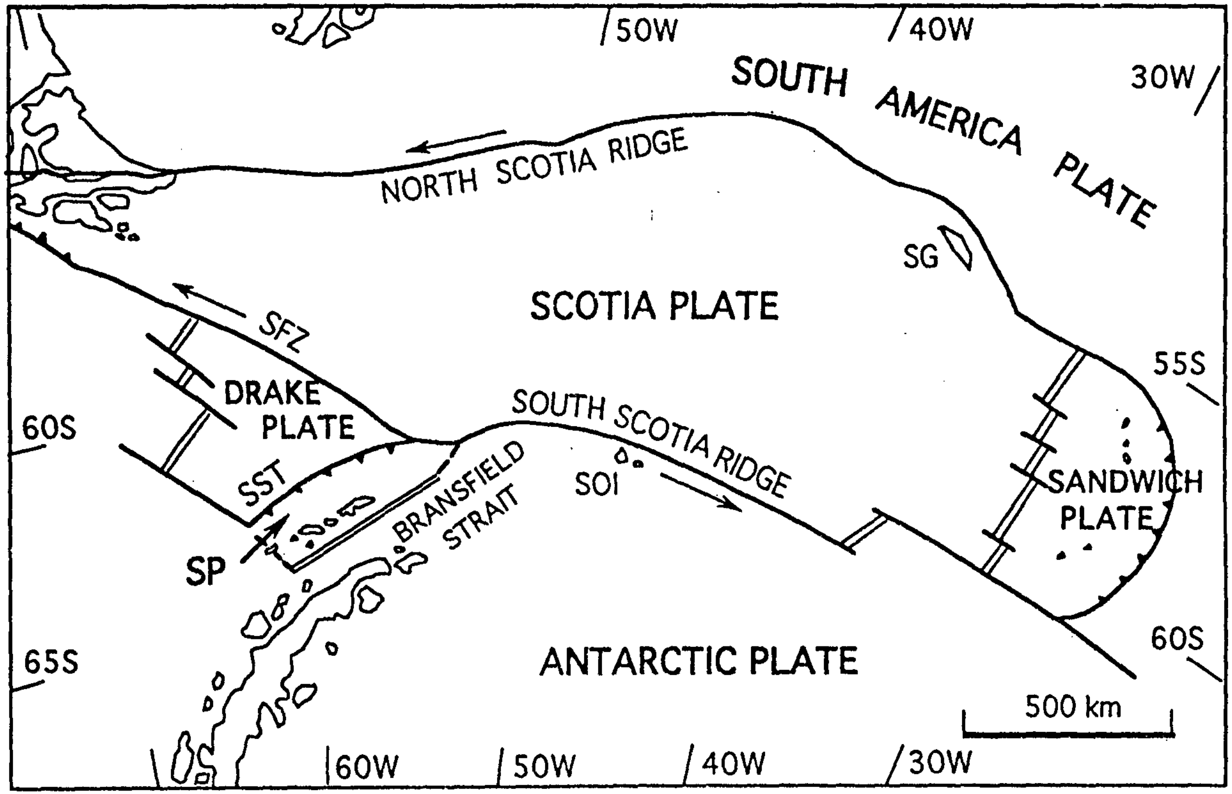

Figure 2-1. Tectonic setting of the Scotia Arc. SFZ-Shackleton Fracture Zone; SG-South Georgia; SOI-South Orkney Islands; SP-Shetland plate; SSR-South Scotia Ridge.

The NSR is composed of a series of elevated blocks stretching from Tierra del Fuego to South Georgia Island. The northern margin of the NSR consists of southward thickening wedge of deformed sediments that have been interpreted as a collision complex resulting from subduction of the south American plate beneath the Scotia plate. The timing of this subduction and the level of current activity are uncertain. South Georgia shows well-documented geological similarities with Tierra del Fuego, suggesting that it represents a continental fragment displaced 1600 kilometers to the east (e.g., Dalziel et al., 1975). The focal mechanism study suggests about 0.5 *cm/yr* of left-lateral strike-slip motion with a component of compression along the NSR (Pelayo and Wiens, 1989) (Fig. 2-2).

Similarly, the South Orkney Islands along the SSR are interpreted as a microcontinental fragment originally contiguous with the AP (Barker et al., 1991). Based on the focal mechanism of the teleseismic data, Pelayo and Wiens (1989) suggested about 1.0 *cm/yr* of the left-lateral strike-slip motion with a component of extension along the SSR. Farther eastward along the SSR, the Discovery Bank and the Jane Bank represent relict island arc segments originally part of an east facing proto-South Sandwich subduction zone, which became inactive through collision with segments of the Antarctic-South American ridge (Barker et al., 1982; King and Barker, 1988).

WNW-ESE spreading between 28 Ma and 6 Ma, with a deceleration at 16 Ma, generated the floor of the western Scotia Sea and eastern Drake Passage to the east of the SFZ (Barker and Burrell, 1977) (Fig. 2-3). Decrease of spreading rate at 16 Ma and cessation of spreading at 6 Ma (Barker and Hill, 1981) suggest some coupling to the larger spreading system to the west.

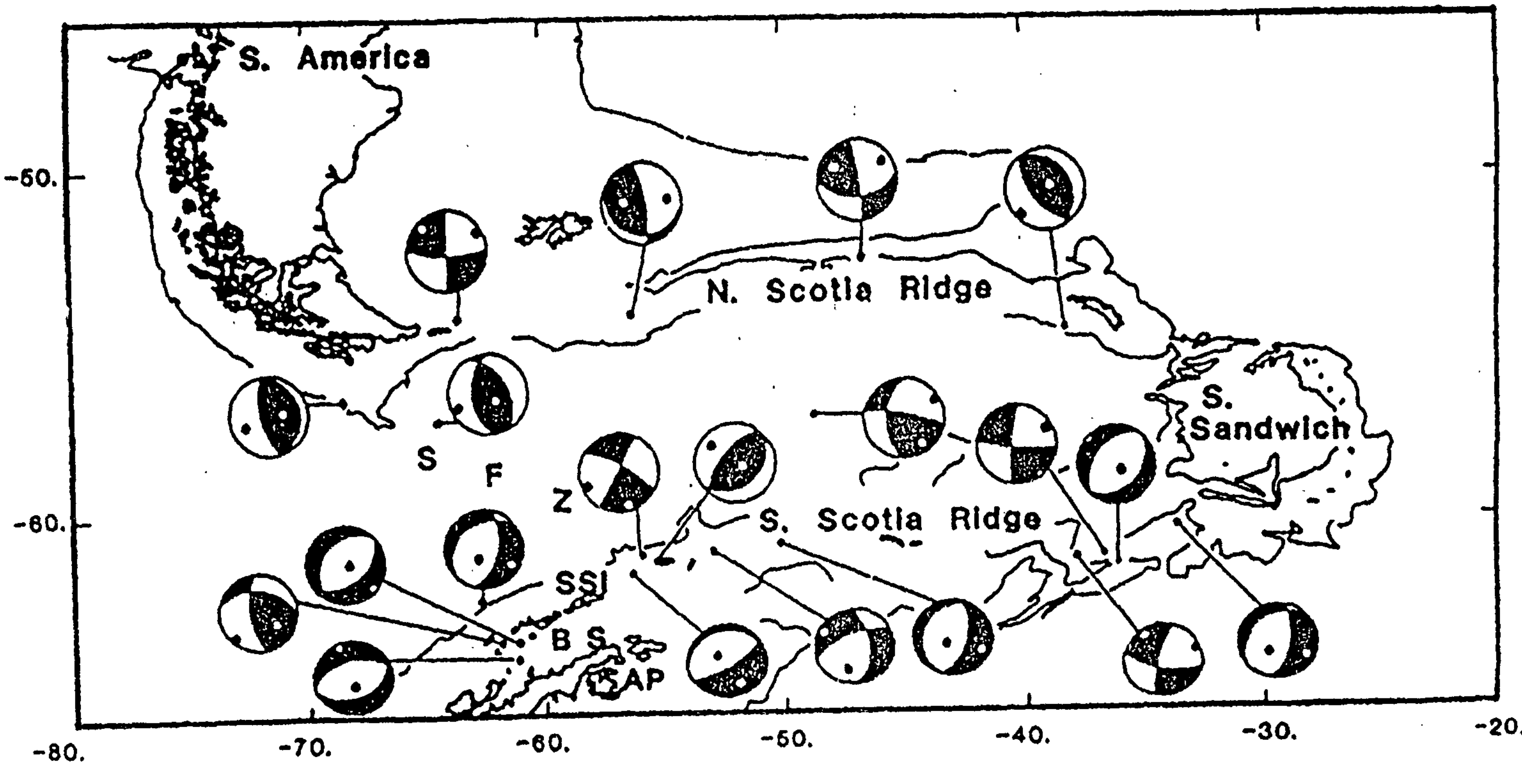

Figure 2-2. Focal mechanism solutions determined from body wave inversion (from Pelayo and Wines, 1989).

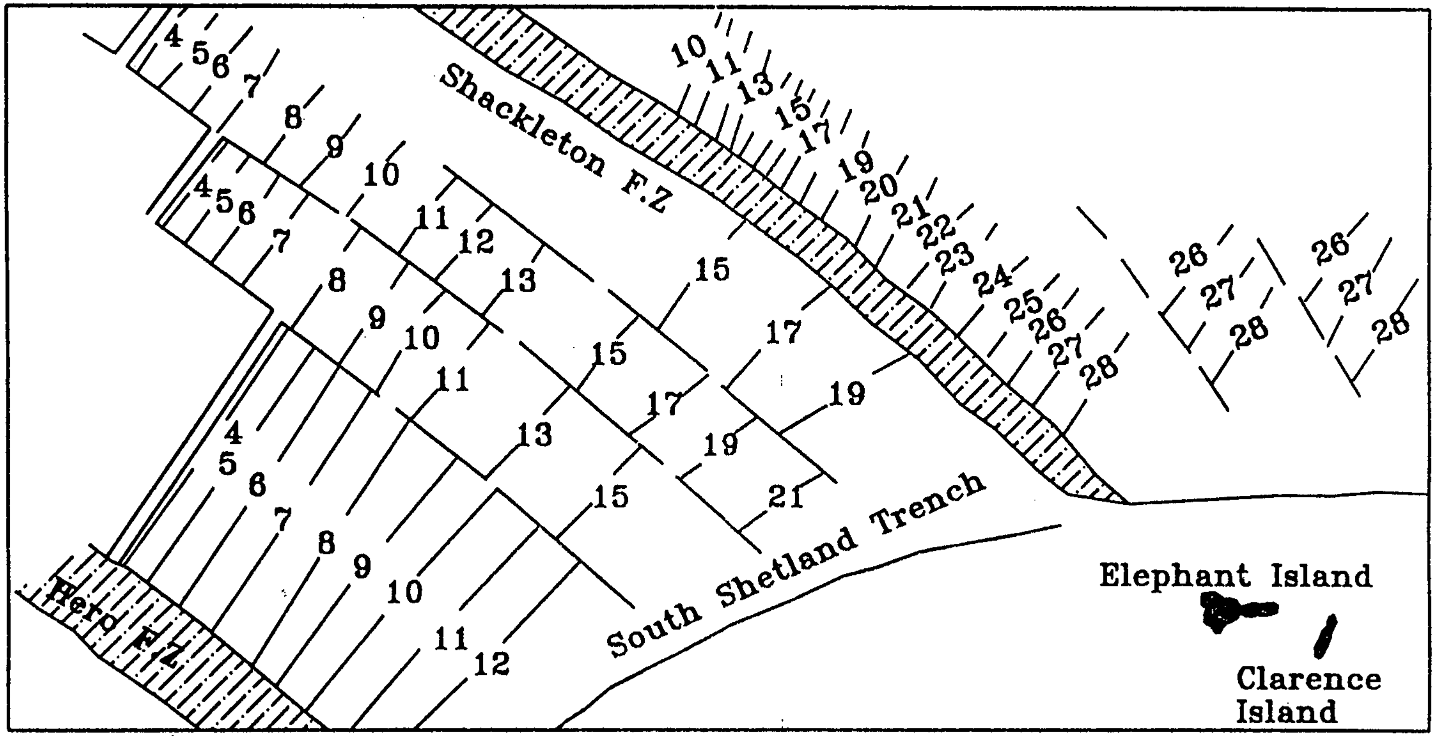

Figure 2-3. Seafloor isochron map interpreted from Tectonic Map of the Scotia Arc (modified from Henriet et al., 1992).

In the eastern Scotia Sea a still-active regime started up 8 Ma and about 1.5 Ma accelerated from 5-7 *cm/yr*. Extension here complements the rapid eastern migration of the hinge line of the South Sandwich Trench, and the spreading center has produced some of the best magnetic lineation of any back-arc spreading center (Paleyo and Wiens, 1989).

The earthquake data along the Scotia Arc suggest that the Scotia plate is convergent to the Antarctic plate. Thus the SFZ, a boundary between the Scotia and Antarctic plates, is a transpressional regime at present (Pelayo and Wiens, 1989).

Development of the western Scotia Arc

A longstanding problem in the interpretation of the tectonic evolution of the Scotia Arc region has been constraining the relative motion history between the AP and the Southernmost South America (SSA) since 84 Ma. Modern plate reconstructions based on paleomagnetic and geologic data (e.g., Grunow et al., 1991) indicate that the northern tip of the AP was located adjacent to the southern tip of SSA along its Pacific margin at 150 Ma (late Jurassic), forming a part of the active convergent margin of Gondwana. The Neogene opening of Drake Passage (Barker and Burrell, 1977) and seafloor spreading in the western Scotia Sea were clearly related to the relative plate motions of SSA-AP.

The SSA and AP has moved approximately westward relative to a fixed Africa (Fig. 2-4). However, SSA's rate of westerly motion in that reference frame has been significantly more rapid than AP's rate. Approximately 1320 kilometer of east-west, left-lateral strike-slip displacement and 490 km of north-south, divergent displacement have occurred between the southern tip of SSA and the northern tip of AP since 84 Ma. Increased rates of SSA-AP interplate separation and a change in the angle of plate divergence at approximately 55-40 Ma marked the onset of accelerated continental separation. The SSA-AP separation eventually led to seafloor spreading in the western Scotia Sea at 30 Ma and the development of the Scotia Arc (Fig. 2-5).

Both the east-west and north-south components of separation may have been accommodated in various locations by different mechanisms. It is most likely that east-west strike-slip and north-south divergent components of interplate motion were dominantly accommodated by (1) seafloor spreading in the Scotia Sea and left-lateral motion along the SFZ, (2) by left-lateral and divergent motion along a fault system that must have existed to accommodate the initial separation of AP from SSA prior to seafloor spreading in the Scotia Sea, (3) by internal deformation in SSA and within some of the continental fragments that were a part of the formerly linked SSA-AP continent but are now scattered around the periphery of the Scotia Plate (e.g., South Georgia and the South Orkney blocks) (Cunningham et al., 1995).

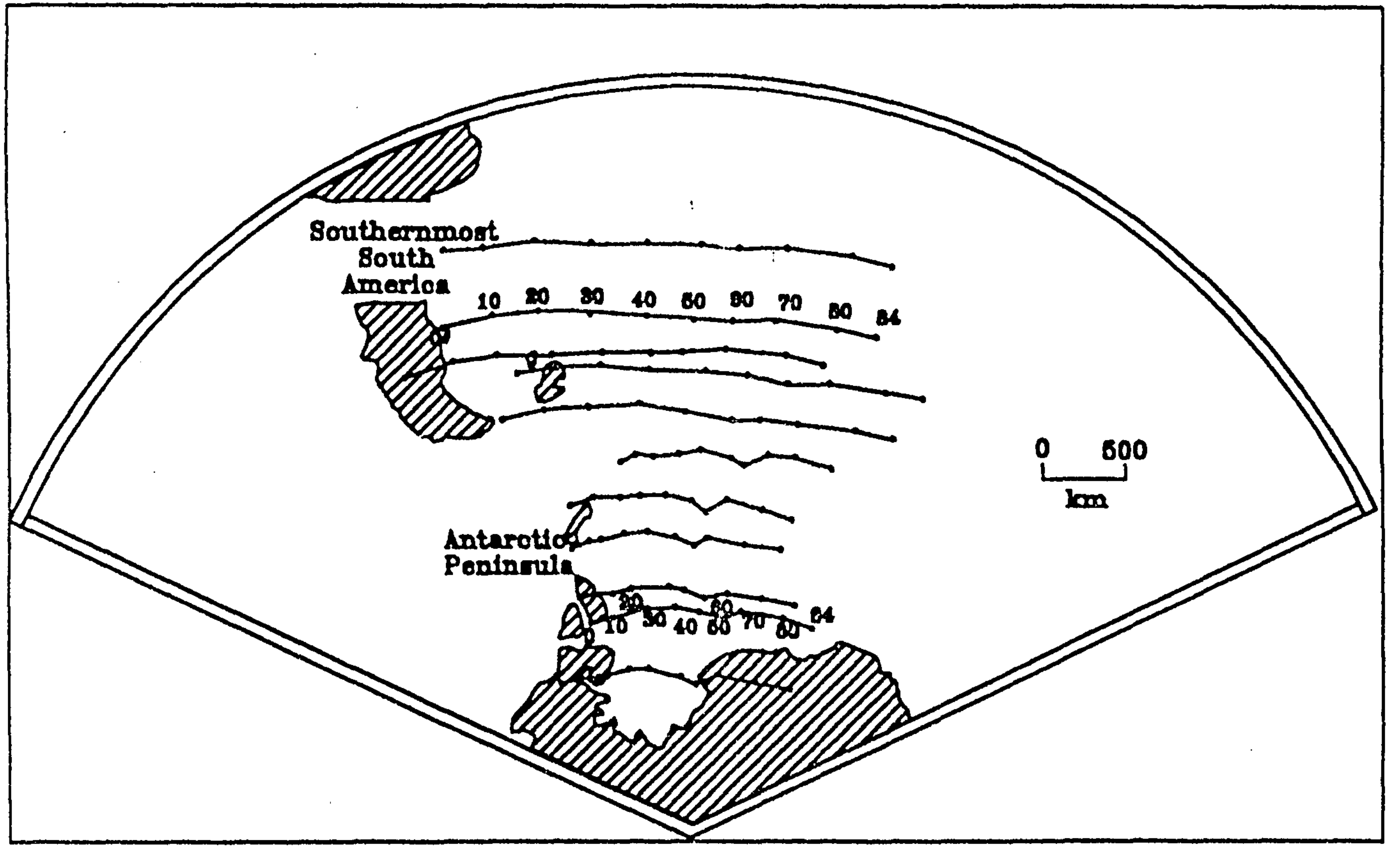

Figure 2-4. Southernmost South America and Antarctic Peninsula flow lines relative to a fixed southern Africa for the last 84 Ma (modified form Cunningham et al., 1995)

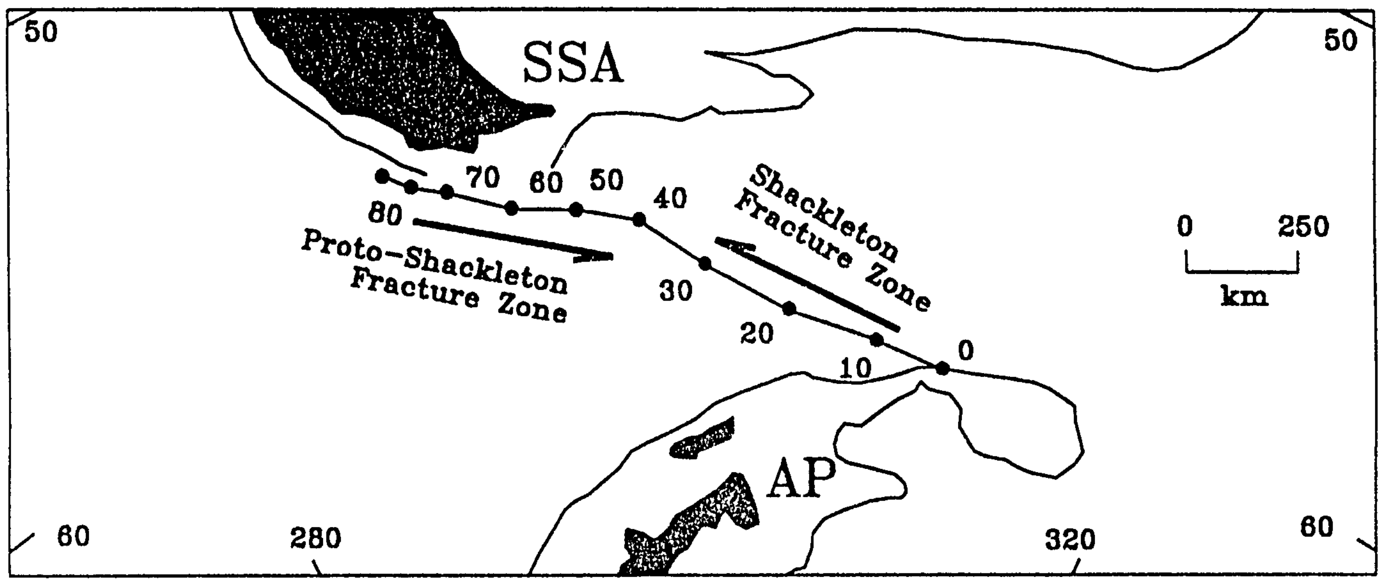

Figure 2-5. Motion of northern tip of AP relative to fixed SSA for 84 - 0 Ma

CHAPTER 3. DATA ACQUISITION

Data acquisition was conducted on the R/V Onnuri as a part of Korea Antarctic Research Program (KARP) during the 1992/93 austral summer season. The study area covers the triple junction of the Shackleton Fracture Zone, South Shetland Trench and South Scotia Ridge offshore northern Antarctic Peninsula. The four multichannel seismic profiles and tens of gravity survey lines with bathymetric data are obtained in the southern end of the SFZ. All the data were positioned by Global Positioning System (GPS) satellite navigation. Among these, two seismic profiles (KSL93-3 and KSL93-7) are used in this study.

The main characteristics of the multichannel system are: (1) energy source of an array of sixteen sleeve guns with 22.61 liter in total volume; (2) an analog channel streamer with 96 channels 2400 m long; (3) 24 hydrophones per group and 25 m of group interval; (4) 4 ms sampling intervals and 10 sec record length, considering the maximum water depth of 7 sec; (5) 50 m shot interval.

Table 3-1. Acquisition parameters used in the seismic survey.

Line Name : KSL93	
Shot by :	Seismic Research Group of KORDI
Date :	Jan. 1993
Location :	Drake Passage, Antarctica
Vessel :	R/V Onnuri
Navigation System :	Konmap intergrated navigation system
Source :	
Source Type :	Sleeve-Gun array of HGS
Total Volume :	22.61 liters
Pressure :	13.3 MPa
Shot interval :	50 m
Source depth :	6.5 m
Streamer :	
Length :	2400 m
Number of Group :	96
Hydrophones per Group :	24
Group Interval :	25 m
Streamer Depth :	6.5 m

CHAPTER 4. PREVIOUS STUDY: SHACKLETON FRACTURE ZONE

Seismic Structure

Profile KSL93-1, running 50 km northwest of the triple junction, reveals a distinctive feature of the SFZ with a pronounced ridge 2000 m higher and a topographic low 12 km wide and 300 m deeper than the surrounding sea floor (Fig. 4-1). The other profile, KSL93-2 having a 20 km data gap to the east of the fracture zone crosses the SFZ near the triple junction (Fig. 4-2). Profile KSL93-2 is located 30 km southeast from profile KSL93-1. The flat seafloor at the southwestern end of profile KSL93-2 is a part of the South Shetland Trench floor.

The transverse ridge of the SFZ is almost symmetrical in shape, but the eastern slope is slightly steeper than the western slope on profile KSL93-1. Almost no sediments are observed over the ridge except at the foot. The symmetrical shape of the ridge continues to the southeast on profile KSL93-2.

To the west of the ridge slightly convex-upward sea floor extends from the foot of the ridge on profile KSL93-1. The oceanic sediments are almost undisturbed. The thickness of the sediments increases from 500 m at the foot of the ridge to 900 m at the SW end of the profile as the underlying oceanic basement deepens more rapidly than the seafloor. A large fault offsets

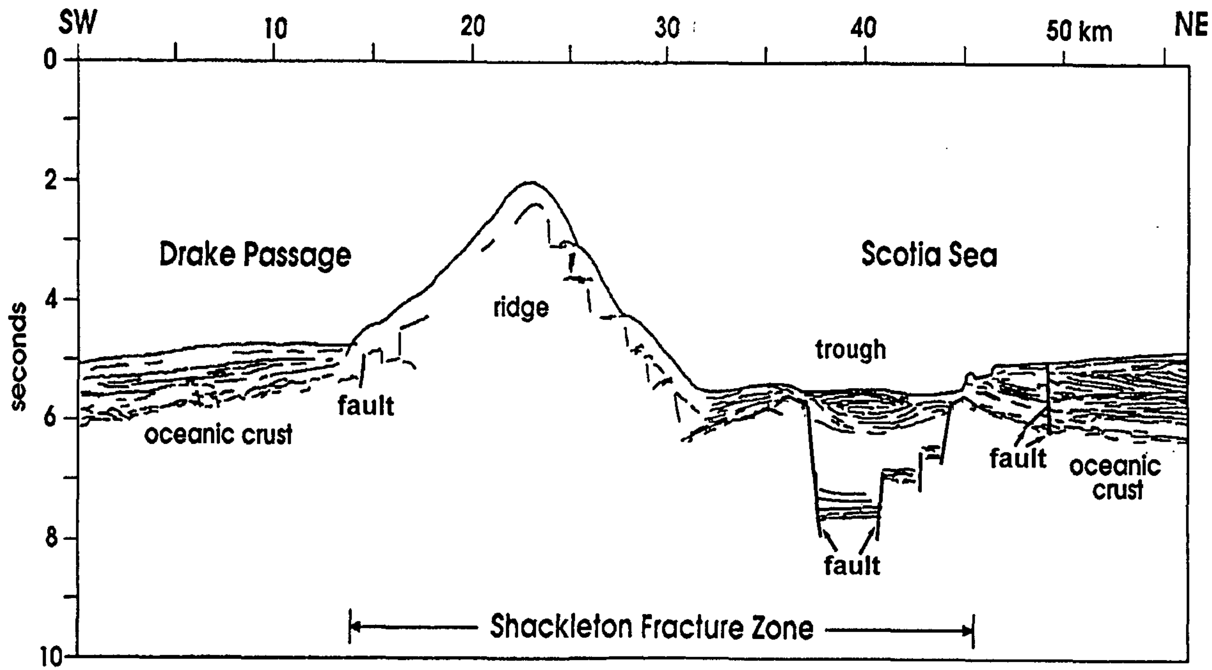

Figure 4-1. Interpretive line drawings of profile KSL93-1. The SFZ is characterized by a pronounced ridge 2000 m higher and a topographic low 12 km wide and 300 m deeper than the surrounding sea floor (from Kim and Jin, 1994).

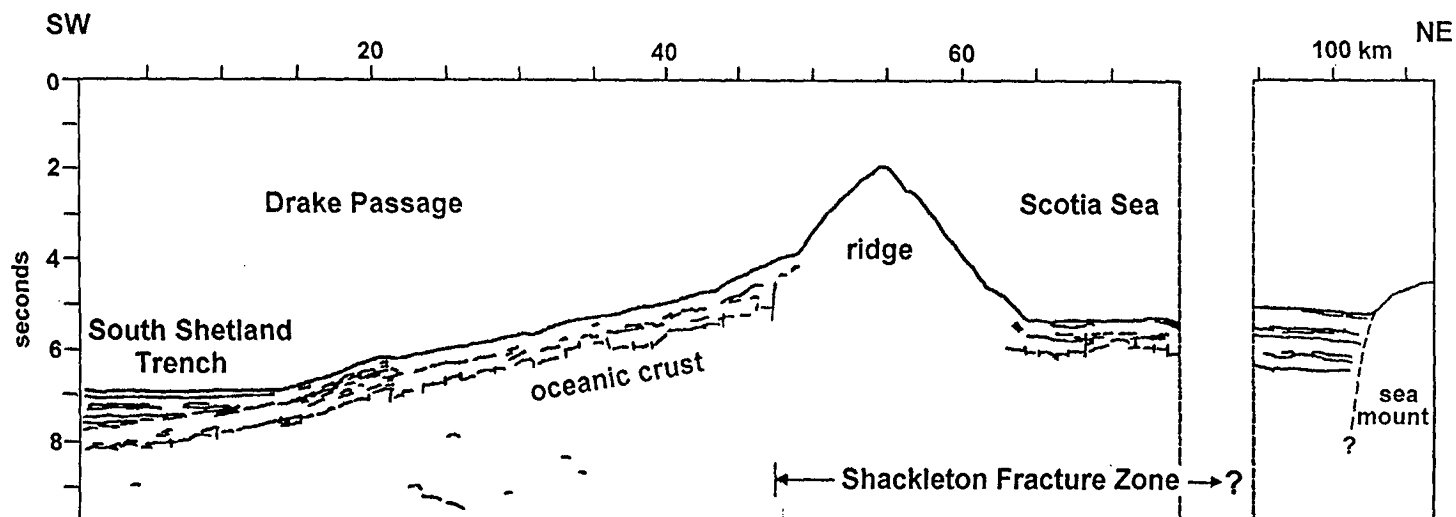

Figure 4-2. Interpretive line drawings of profile KSL93-2. The sedimentary cover continues up to the western mid-slope of the ridge (from Jin, 1995).

the oceanic basement by 300 m at the western foot of the ridge. On profile KSL93-2, the oceanic basement deepens parallel to the seafloor with the dip of about 2.5° to the east from the ridge, and the overlying sedimentary cover persists almost constant thickness of about 600 m all the way to the SW end. This sedimentary cover continues up to the mid-slope of the ridge.

To the east of the ridge numerous strong diffractions with low frequency occur beneath the topographic low on profile KSL93-1. Diffractions appear on both sides below the low and their depths increase to the center. A migrated profile suggests that crustal faulting occurred along high-angle faults and formed a deep trough under the topographic low (Fig. 4-3). The sediments more than 1000 m thick filled up the trough. The lower part of trough fill shows chaotic internal reflections, whereas a lenticular sedimentary body with strong, well-laminated internal reflectors form the upper part of trough fill. Such lenticular sediments were probably formed by sediment deposition controlled by bottom currents flowing along the axis of the trough. Between the trough and the ridge, a sedimentary cover with an anticlinal structure is laid on a tilted block of the basement. This sedimentary cover extends under the lenticular sediments in the trough. The lenticular sediments onlap this extending cover at the western end of the trough.

On profile KSL93-2 the trough is not seen to the east of the ridge. The distance from the foot of the ridge to data gap is more than 7 km that is twice as long as that from the foot to the trough on profile KSL93-1. In this interval the basement is tilted ridgeward and the sedimentary cover shows a subtle anticlinal structure just west of data gap. This feature is similar with that observed to the west of the trough on profile KSL93-1. Although the trough can not be seen, it is very likely that the trough exists within data gap. Bathymetry chart also supports this. The area of bathymetric low deeper than 4000 m below sea-level becomes wide from 12 km on profile KSL93-1 to 20 km on profile KSL93-2.

To the east of the trough, well-laminated sediments with a maximum thickness of 1200 m are observed over the oceanic basement of the Scotia plate on profile KSL93-1. The sediments wedge out toward the trough, so that the basement is almost exposed on the sea floor near the trough. A small sedimentary mound appears on the seafloor at the edge of the wedge. Dipping layers are shown between flat layers within the sediments. These layers downlap onto the underlying flat layers indicating an unconformity. The seafloor shallows by more than 500 m at the NE end, whereas the oceanic basement deepens by 800 m. Around 5 km east from the edge a fault offsets the oceanic basement and overlying sediments, and its western block tilts by 6°. At the NE end of the profile KSL93-2, ocean floor with strong diffractions shallows abruptly by 450 m. A small seamount 5 km wide and 1000 m high can be identified at the same location on the bathymetric chart compiled by Klepeis & Lawver (1993). This seamount disturbed both oceanic crust and overlying sediments, suggesting that it was intruded lately.

Tectonic Implications

In the trough two stages of tectonic stresses deforming the oceanic crust and overlying sediments are inferred depending on the variation of plate

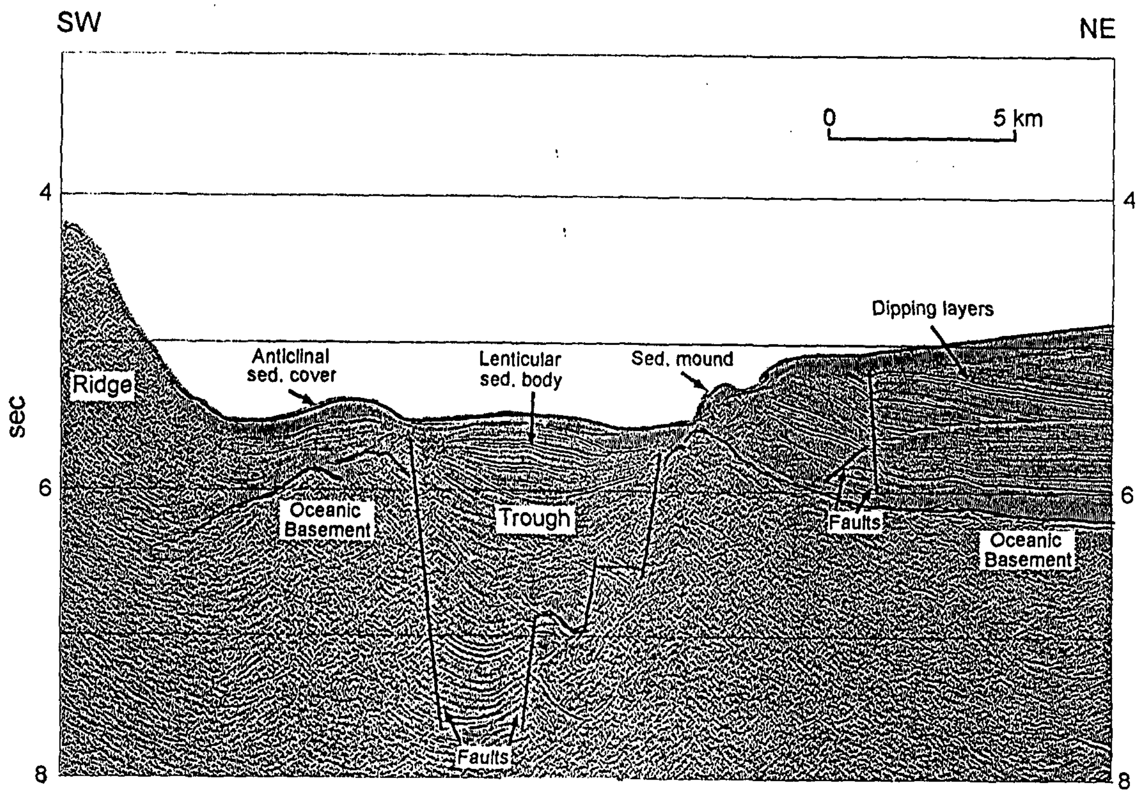

Figure 4-3. A part of migrated profile KSL93-1 showing the trough with high angle faults under the bathymetric low. A lenticular sedimentary body with well-laminated internal reflections is laid on the top of the trough. The trough was formed by transtension along the SFZ. An anticlinal sedimentary cover to the west of the trough indicates the change of stress regime to compression (from Jin, 1995).

kinematics in the Scotia Arc region. Transtension along the SFZ had formed the trough during the opening of Drake Passage between 29 Ma and 4 Ma. Basement tilting outward on both sides the trough would be resulted from the uplift by elastic upbending during crustal drops of the inner block when the trough was formed. This suggests Vening Meineszs type rift structure of the SFZ. Relatively small scale contractional structures appear on the top of the sediments around the trough, indicating that the area may be under recent compression due to the current convergence between the Scotia and Antarctic plates since 6 Ma. The trough becomes distant from the ridge and broaden southward from 12 to 20 km.

A gravity model of the SFZ suggests that the thin crust is confined primarily beneath the ridge rather than beneath the center of the trough, where Moho shallows by about 2.5 km. The crust becomes thick from the ridge to both ends of the profile, ranging from about 3 km to 6 km in thickness. The pattern of crustal thinning is not uniform along the fracture zone. A crust 8 km thick is assumed beneath the western slope of the ridge in KSL93-2 near the triple junction. This thick crust may be formed by the collision of the SFZ ridge against the South Shetland Platform when subduction continued along the South Shetland Trench. A low density model (about 2.45 g/cm3) of the ridge provides the possibility of serpentinite intrusion as its origin. The gravity low associated with the trough is due to the trough-fill sediments 2 km thick.

CHAPTER 5. SEISMIC STRUCTURES

KSL93-3

This line runs just south of the triple junction where the SFZ, SST, and SSR are met (Fig. 1-2). The SFZ ridge can not be identified in this profile because the ridge collides against the South Shetland Platform at the triple junction and terminates abruptly there. Bathymetric map shows a deep submarine valley between the SFZ ridge and the South Shetland Platform (SSP) (Jin, 1995). This valley is a gap through which the strong bottom current flow westward from the Weddell Sea to the SST (Nowlin and Zenk, 1988).

The shallower region to the west of profile KSL93-3 (Fig. 5-1) belongs to the SSP, and the deep seafloor is a part of the Scotia Sea. Very steep slope of the platform (up to 28°) is connected with the oceanic crust by a large fault at the foot of the slope. A small bathymetric mound occurs at the foot. Similar mounds are observed at the foot of the accretionary wedge in the SST (Larter, 1991; Kim and Jin, 1994). These mounds are known to be formed in a regime of compression.

Profile KSL93-3 shows a subtle bathymetric low more than 4000 m deep to the east of the foot of the SSP. Seafloor shallow slightly to the NE end of profile (Fig. 5-2). A high amplitude, rough topographic, and gently eastward-dipping reflector at 6.7 s two-way travel time (twt) beneath the low

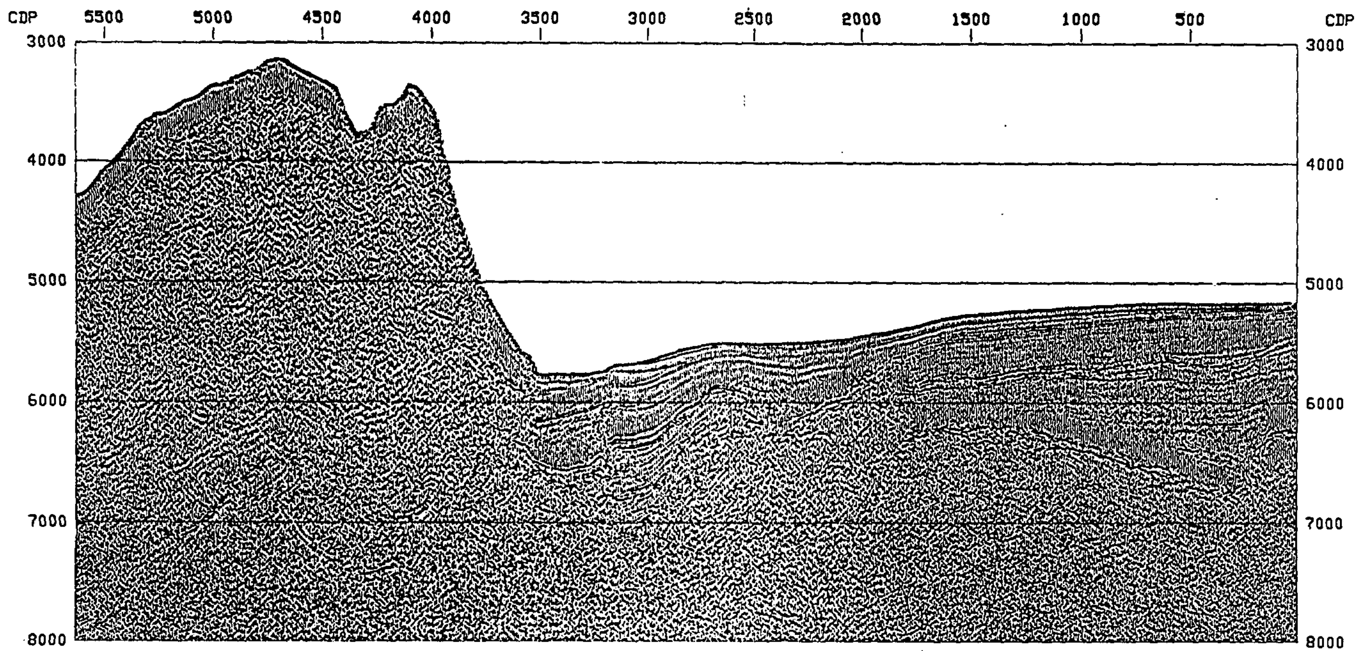

Figure 5-1. Migrated seismic profile KSL 93-3 running from the South Shetland Platform to the Scotia Sea just south of the triple junction.

seems to be the top of the oceanic crust. The overlying sedimentary layers, however, show the westward dip. The thickness of the sedimentary cover is about 1000 m. This cover can be divided into two units showing different seismic characters. The upper unit, which is up to 700 m thick, is almost transparent on the profiles. The strong, high amplitude, well-stratified lower unit onlaps the oceanic basement, and its thickness increases eastward up to 300 m.

A remarkable discontinuity of the basement and sedimentary cover by a large-scale fault is shown at the eastern boundary of the low. To the east of the fault, the basement appears at more than 8 s twt, which is more than 1000 m deeper than that to the west. This indicates that the eastern crustal block dropped along the fault forming a half graben. The throw of the fault is apparently up to 1000 m on the profile. The sediments 2000 m thick in the graben can be also divided into two sedimentary units which are correlated with the sediments to the west of the fault. The upper unit shows the same thickness and reflection pattern with the western one, whereas the lower unit is much thicker. The increment of sediments thickness equivalent to the vertical displacement of the fault (about 1000 m) occurs in the lower unit.

A most significant feature is that large-scale fault, which composed a wall of the half graben, offsets recent sediments and reaches to the seafloor. However the antithetic faults accompanied with large-scale normal faulting is limited within the lower unit. In addition, the seafloor and the top of the lower unit to the east of the major fault is both about 100 m higher than those to the west. This indicates that the major fault has changed its sense of movement recently.

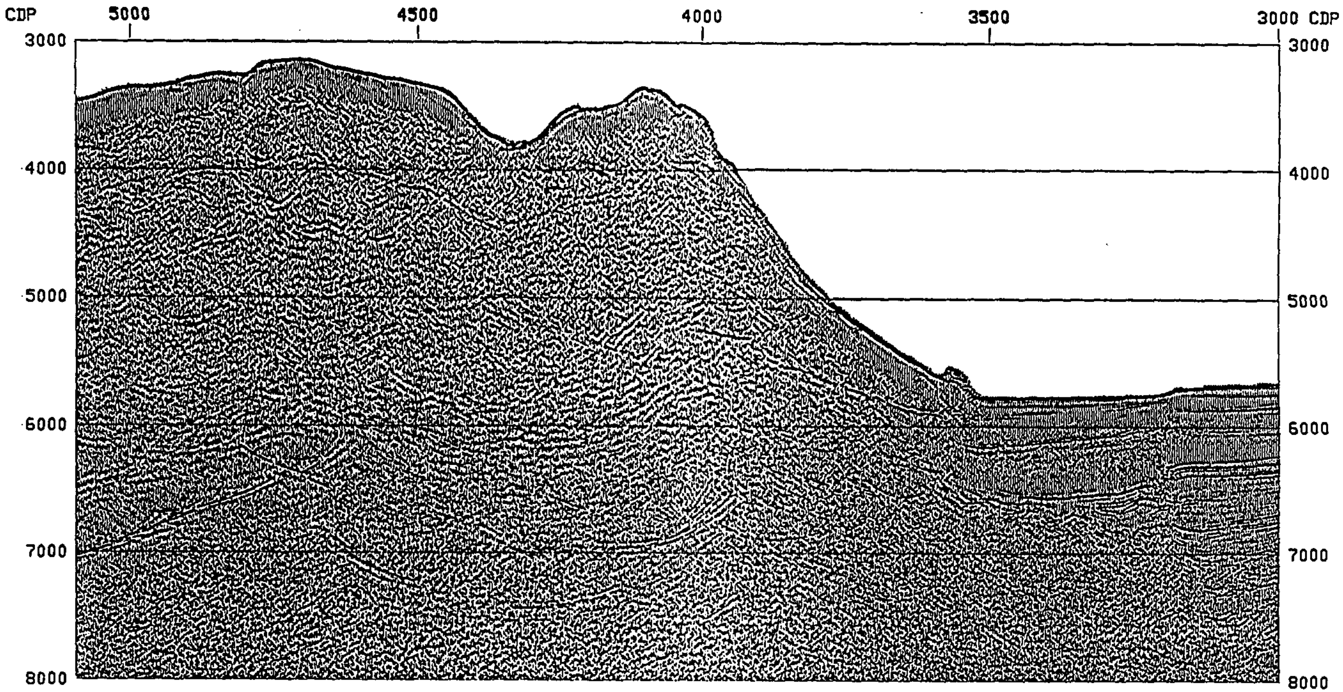

Figure 5-2. A part of migrated profile of KSL 93-3 over the South Shetland Platform.

The other intrigue structures, two apparent overthrusted structures, appear to the east of the graben. These are tilted toward the fault and their tops appear beneath 0.5 - 0.7 s below the seafloor (Fig. 5-3). Both structures have almost same width of 8 km. Among them the western one occurs in the sediments. The sediments within the western one are tilted to the wall of the graben and forms a subdue anticlinal structure at its top. The eastern one occurs in the oceanic basement with irregular reflection. Its top is 500 m higher that to the east. The basement beneath the western one extending from the top of the northwestern one appears as a strong event near 8 sec.

The depth of the oceanic basement deepens from the overthrused structures to the NE end of the profile, but the seafloor is almost flat (Fig. 5-4). At the NE end of the profile, the basement was deformed by large-scale normal fault with the maximum offset of 0.5 s. This fault, however, does not disturb the overlying sediment, suggesting it activated before sedimentation. As this large fault becomes rather distant from the extension of the SFZ trough, it is unclear whether its origin was related to the SFZ evolution.

As the basement deepens, the overlying sedimentary cover becomes thick from 800 to 1500m. The cover is divided into two layers. The upper layer in the cover continues to the overthrusted structure with a constant thickness of 500 m. The lower layer is gradually thinning out to the west and was disturbed by the overthrusted structure. This layer does not appear on the eastern overthrust. The top layer of the western overthrust shows very a similar reflection with the top of the lower layer. It seems that two layers

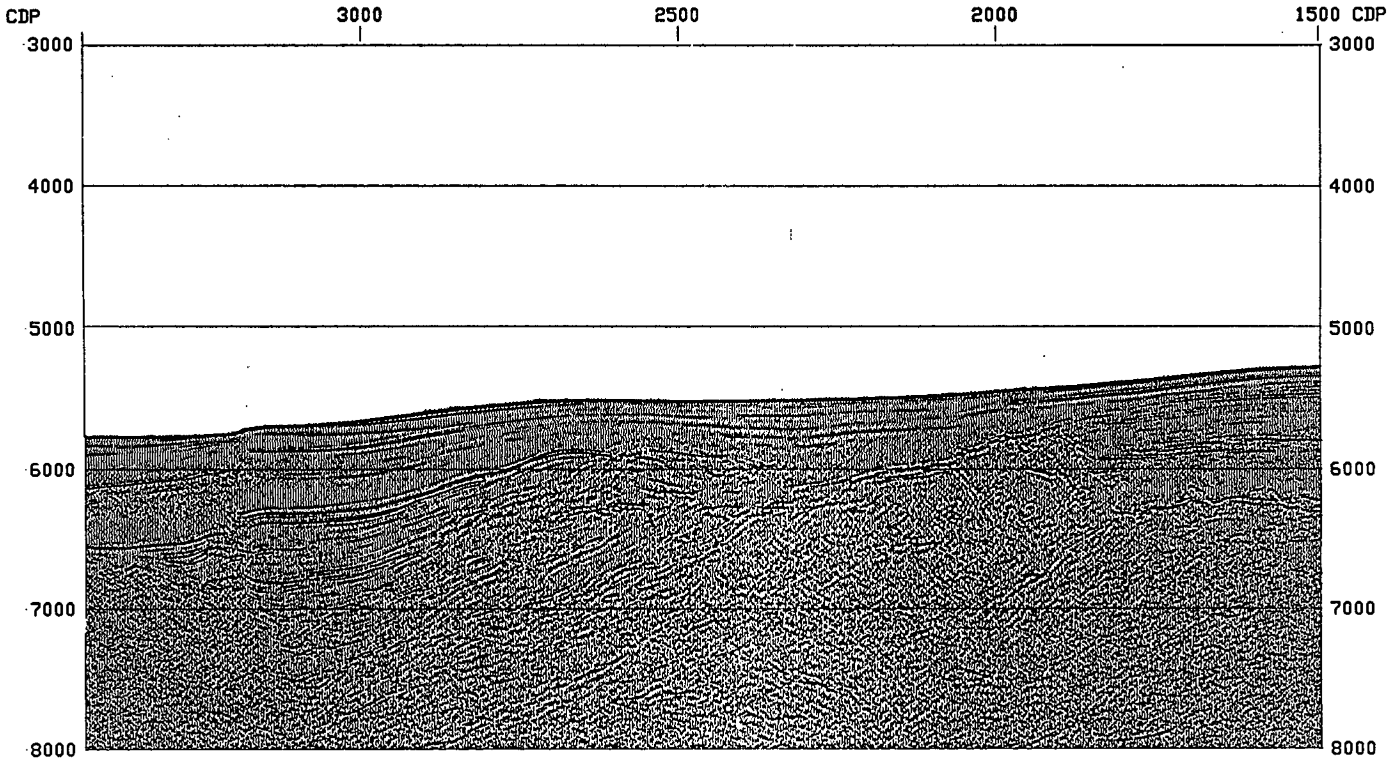

Figure 5-3. A part of migrated profile of KSL 93-3 showing a large-scale fault and two overthrusted structures in the Scotia Sea region.

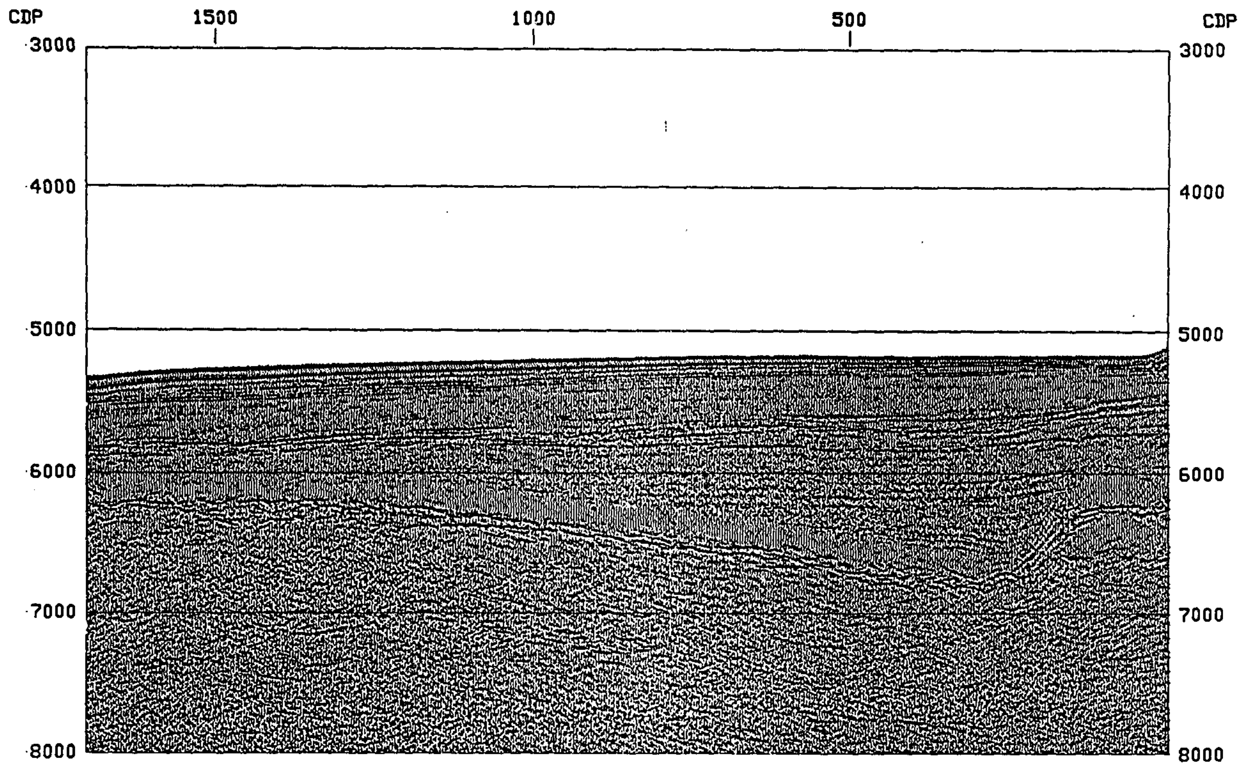

Figure 5-4. A part of migrated profile of KSL 93-3 showing thick sedimentary cover and deformed oceanic basement.

correlates with each other. The sedimentary sequences show a striking cyclic character, indicating that the depositional environments are periodic.

KSL93-7

A NE-SW profile KSL93-7 is about 130 km long at the northwestern margin of Elephant Island. This line runs 20 km southeast from the KSL93-3 (Fig. 1-2).

This profile can be divided into three parts by water depth (Fig. 5-5). The western part of the profile is a shallow region with water depths of 1500 - 2700 m. An intensely crenulated topography occurs in the central part with water depths ranging from 2800 to 3300 m. These two parts belong to the continental crust of the Antarctic plate. The deepest part to the east with water depths of 3500 - 3700 m belongs to the Scotia Sea.

In the shallow part two distinct reflectors with lateral continuity appear below the seafloor (Fig. 5-6). The shallow reflector at about 500 m below seafloor is sub-parallel to seafloor, which reflects from a sequence boundary in sediments or bottom simulating reflector of gas-hydrates (Nam et al, 1996). The other reflector occurs at 1500 to 2000 m below the seafloor. This seems to be a basement although its nature is rather uncertain. Three small mounds with an interval of about 7 km appear on seafloor. These become high and narrow toward the east. Such mounds can be formed by glacial deposition or uplift of the basement.

The central part, a margin of the SSP, shows severe crenulated

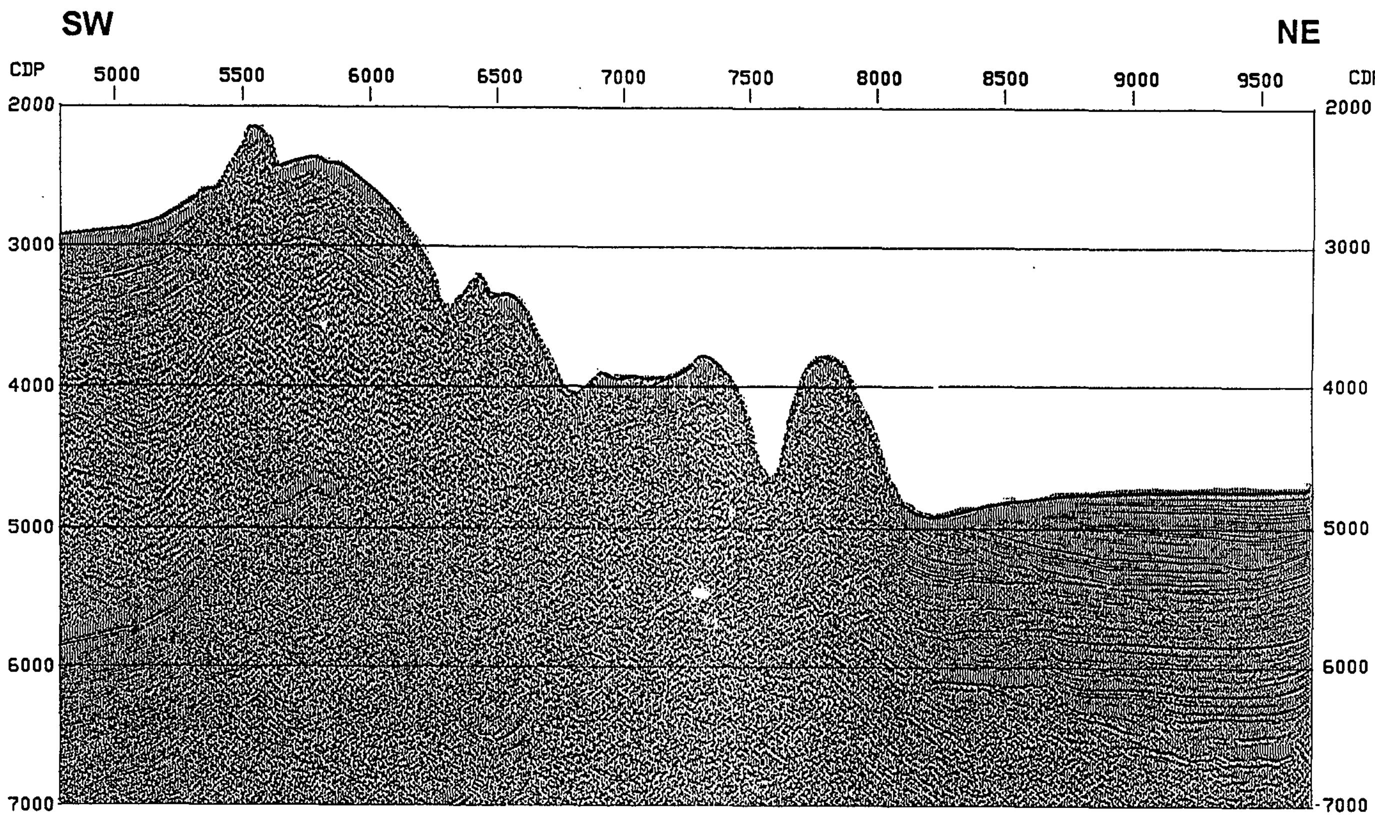

Figure 5-5. Migrated seismic profile KSL 93-7 running from the South Shetland Platform to the Scotia Sea.

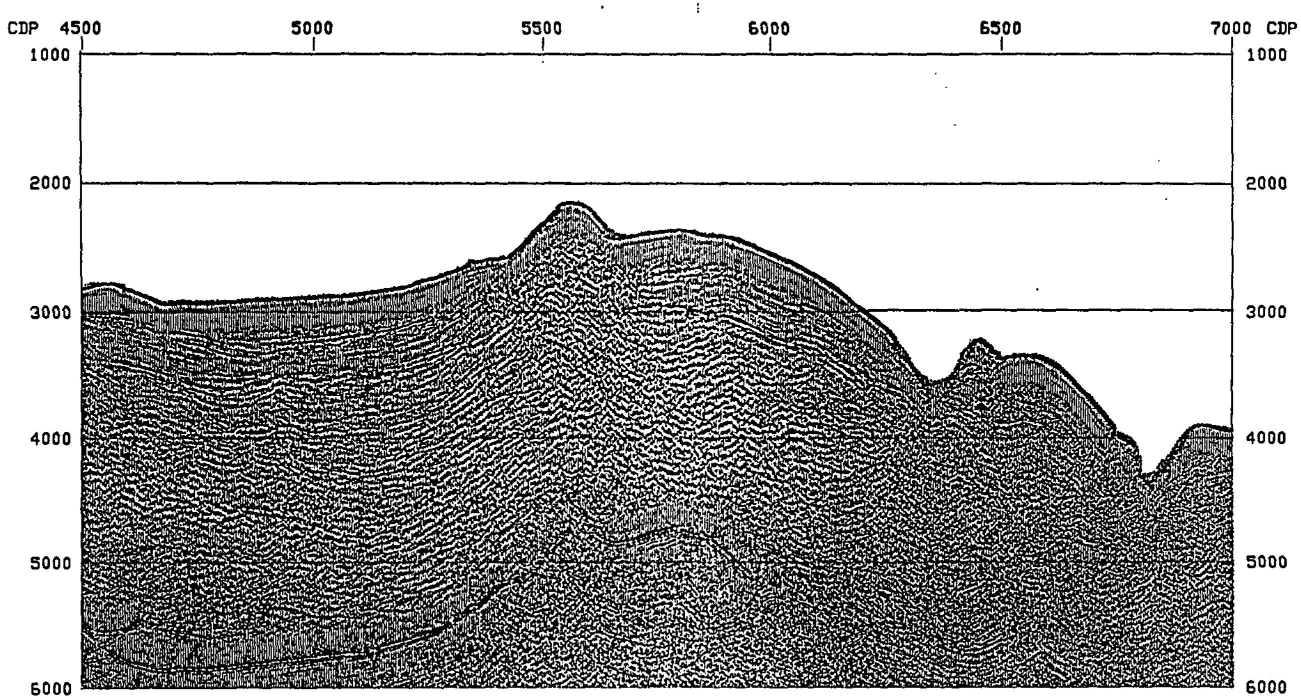

Figure 5-6. A part of migrated profile of KSL 93-7 over the South Shetland Platform.

topography that three ridges are separated by troughs (Fig. 5-7). The western ridge, the highest one among them, has an additional mound at the summit. The eastern ridge shows a symmetrical shape like the SFZ ridge on profile KSL93-1. The middle ridge has very different shape from the other. A flat terrace with a width of 2000 m occurs on the top. These ridges and troughs are laid on the extension of the southern SFZ trough shown on profile KSL93-1 (Fig. 3-1).

The deep sea to the western part of profile KSL93-7 belongs to the Scotia Sea. The well-laminated sedimentary cover is very thick up to 2000 m near the NE end of the profile. This cover seems to continue to some extent beneath the ridge of the SSP, although which is unclear due to a complex topography of the ridge and trough. Such complex topography of seafloor is known to have an effect called 'velocity pull-up' to the underlying structure.

Seafloor shows subtle convex-upward bathymetry from the foot of the SSP margin to the NE end of profile (Fig. 5-7). The oceanic basement in this part was deformed by several faults. The major high-angle fault with 0.5 sec offset occurs at the NE end of the profile. A similar fault is observed in the eastern part on profile KSL93-3. This large-scale fault, therefore, seems to extend from KSL93-3 to KSL93-7. Although the lower sediments follow somewhat the topography of the basement, the fault in the basement is believed not to continue to the upper sediments.

The upper sediments with well-laminated and undisturbed reflectors formed a lens-shaped structure. The thickness of these sediments gradually decreases westward, so that this sediments merge to a single unit at the foot of the SSP margin. Near the foot the sediments show different reflections characteristics from that to the east. The lower layers show chaotic inner reflection and its top is somewhat higher due to the underlying basement topography. In the upper layers some reflectors lap out seaward, suggesting that progadation/aggregational deposition and erosional process occurred.

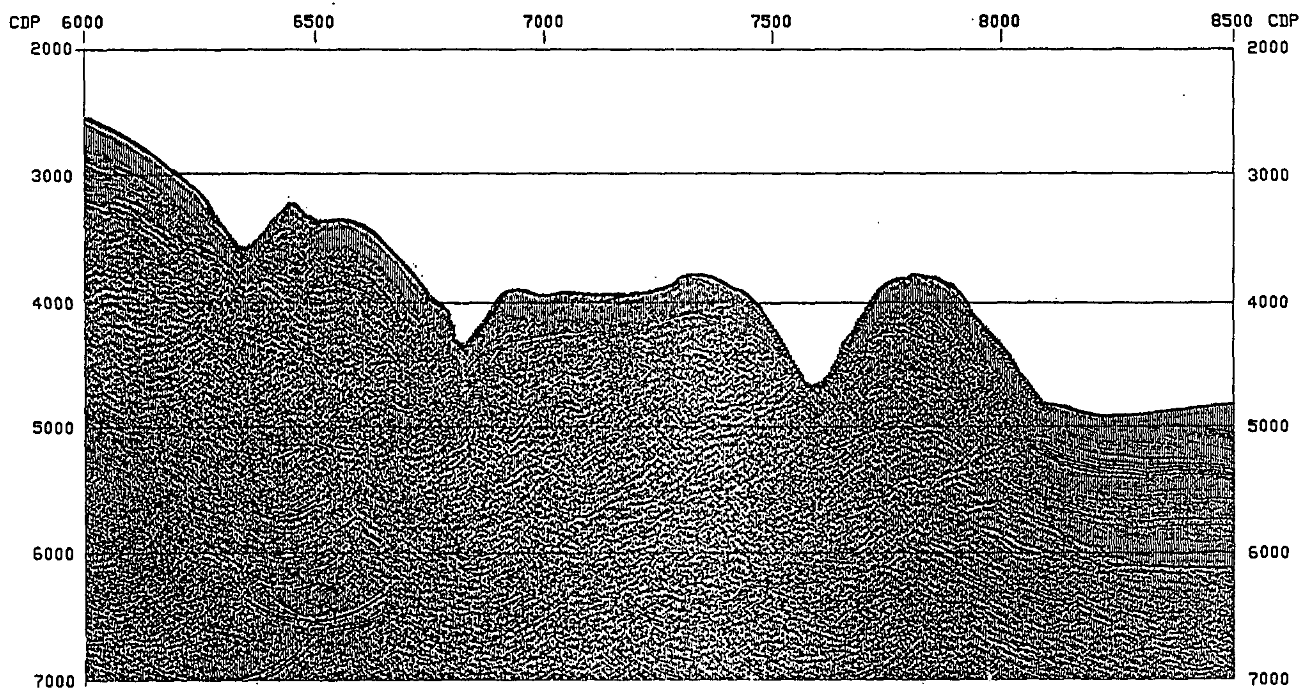

Figure 5-7. A part of migrated profile of KSL 93-7 over the South Shetland Platform margin showing complex bathymetry composed with three ridge and troughs.

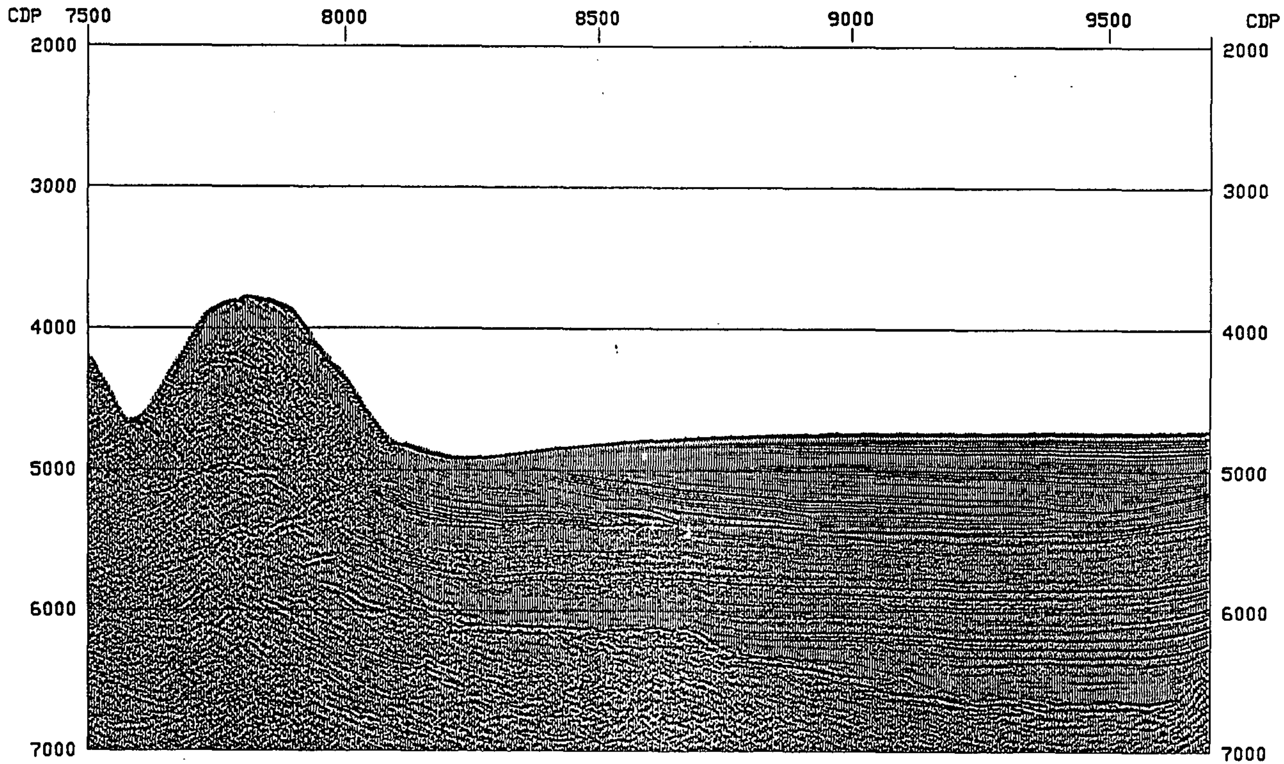

Figure 5-8 A part of migrated profile of KSL 93-7 over the Scotia Sea region covered by thick sediments

CHAPTER 6. DISCUSSION

Profiles KSL93-1 and KSL93-3 show well-defined deformations in the SFZ in response to two sets of tectonic stresses. The major deformation can be observed in the SFZ trough. Profile KSL93-1 shows that the oceanic crust dropped largely along high-angle faults in the trough. This indicates that the SFZ experienced extensional deformation. The effect of extensional deformation along the SFZ can be traced to the south of the triple junction. In profile KSL93-3, a half graben was built along a large-scale fault. This half graben seems to be an extension of the SFZ trough. Apparent vertical offset of the fault is more than 1000 m. Such a large-scale extension resulted from transtensional movement of the SFZ through the period of the Drake Passage opening between 29 and 4 Ma (Barker and Burrell, 1977). The main structure of the SFZ with a huge ridge and deep trough, was probably built during the opening period.

To the south of the triple junction, profile KSL93-3 reveals distinct features that are indicative of recent change in tectonic regime in this area. A large fault, that bounds the half graben, extends to the sea floor and cuts recent sediments as well as the oceanic basement. The depth of the basement to the eastern side of the fault is 1000 m deeper than that to the western side, whereas the sea floor and upper unit in the sedimentary cover are rather 100 m shallower (Fig. 5). The former is considered to be formed by normal faulting, but the latter by reverse faulting. The antithetic faults due to major normal faulting along the large-scale fault are observed only in the lower unit, not extending to the upper unit. Relatively less deformed upper unit keeps constant thickness across the large-scale fault. These features suggest that extensional movement of the SFZ had ceased before the upper unit was deposited, and after then the SFZ has shown compressional movement. In other words, the large-scale fault, which once showed normal sense, has reactivated recently with reverse sense. A bathymetric mound at the foot of the continental slope was probably formed by recent compression. Also on profile KSL93-1, the contractional structures around the top of the trough, including a bathymetric mound and the anticlinal sedimentary cover, may be produced by compression.

The recent compression in this area is the result of an important change in the mode of Scotia Sea evolution occurred at 6 Ma. At that time South Georgia collided with the northeast Georgia Rise, consequently which caused the cessation of sea floor spreading in Drake Passage and the central Scotia Sea (Barker et al., 1991). Cessation of the Drake Passage spreading led to lessen subducting activity along the SST. The buoyant ridge of the Shackleton and Hero Fracture Zone may have played an important role in stoppage of subduction (Henriet et al., 1992). The Scotia plate now shows a slow westward motion with respect to the Antarctic plate. This east-west compressive stress by the movement of the Scotia plate is assumed to be sufficient to overcome the ridge-push force of the Antarctic-Phoenix spreading center (Larter and Barker, 1991). Based on focal mechanism study, Pelayo and

Wiens (1989) suggested the relative motion of the Scotia plate at a rate of 1.4 cm/yr toward the WSW and east-west convergence in the Drake Passage region at 1.1 cm/yr. They reported the earthquakes with a component of compression in Drake Passage, and also concluded that convergence between the Scotia and Antarctic plates in the Drake Passage region is taken up through diffuse compressional deformation in the passage as well as strike-slip faulting along the SFZ.

Profile KSL 93-7, running from the Scotia Sea to the northern margin of Elephant Island, shows a distinctive crenulated topography of the SSP margin. This crenulated area is composed of three ridges and troughs. Its location is associated with the southeastward extension of the SFZ trough. It is likely that the SFZ transform movement forming the SFZ trough probably splays into faults associated with the small troughs on the SSP. Klepeis et al. (1990) indicated the series of small ridges and troughs observed in our profiles from bathymetric data. They noted that these features are absent to the west and southwest of the SFZ and elsewhere along the margins surrounding Elephant and Clarence Islands. They also suggested that these troughs are associated with transcurrent motion along the Antarctic-Scotia plate transform boundary as with the linear troughs located closer to the SFZ.

A hot issue in this area is the change of present-day plate boundary geometry. Recently Klepeis and Lawver (1996) suggested that the SFZ transform on the floor of the Scotia Sea widens to the southeast or steps eastward at its southeastern end across the northern margin of the Elephant and Clarence Islands. This means the presence of a new segment of plate boundary that connects the SFZ with the SSR, although prior to 4 Ma, the SFZ, SST and SSR met at the triple junction north of the Elephant Island. Our profiles provide rather any certain evidences related with the above hypothesis than the SFZ transform continues to the south of the triple junction and the SSP.

CHAPTER 7. CONCLUSION

To the south of the triple junction, the SFZ keeps only its transform movement forming the SFZ trough north of the triple junction. As the SFZ collides with the South Shetland Platform in the triple junction area, the SFZ ridge is terminated in front of the SSP, but the SFZ transform movement could extend to farther south of the triple junction.

Profile KSL93-3, running just south of the triple junction, shows a 25 km wide half graben and corresponding deformations. A large-scale fault extending to the SFZ trough formed the half graben. In the graben two kinds of deformation are observed depending on the variation of plate kinematics in the Scotia Arc region. This also occurs in the SFZ trough. Extension along the faults formed the graben. This deformation results from transtenstional motion of the SFZ during the opening of Drake Passage. After cessation of spreading in Drake Passage and the Scotia Sea at about 6 Ma, tectonic regime in the Drake Passage area changed into compression by a westward convergence of the Scotia plate. The major fault that once was a normal fault forming the graben reactivated with reverse sense and deformed in the recent sediments, which are indicative of recent compression in this area. The severely deformed structure east of the major fault may be caused by rotation of crustal blocks along the antithetic faults accompanied with large-scale down-faulting along the major fault.

The margin of the South Shetland Platform on Profile KSL93-7 across the northern margin of Elephant Island shows complex bathymetry composed of three ridge and troughs, which are laid on the southern extension of the SFZ trough. This crenulated topography was probably associated with the SFZ transform splaying into several small faults. Consequently the SFZ transform continues far south from the triple junction and deforms the crust of the Scotia Sea and the SSP.

REFERENCES

Barker, P. F., 1982, The Cenozoic subduction history of the Pacific margin of the Antarctic Peninsula: Ridge crest-trench interactions, *J. Geol. Soc. London*, 139, 787-801.

Barker, P. F. and Burrell, J., 1977, The opening of Drake Passage, *Mar. Geol.*, 25, 15-34.

Barker, P. F., Dalziel, I. W. D. and Storey, B. C., 1991, Tectonic development of the Scotia Arc region, *in* Tingey, R.J. (ed), *Antarctic Geology*, Oxford University Press, 215-248.

Barker, P. F. and Hill, I. A., 1980, Asymmetric spreading in the back arc basins, *Nature*, 285, 652-654.

Biddle, K. T., Uliana M. A., Mitchum Jr R. M. ., Fitzgerald M. G. and Wright R. C., 1986, The stratigraphic and structural evolution of the central and eastern Magallanes Basin, southern South America, *Spec. Publ. Int. Assoc.* Sedimentol., 8, 41-61.

British Antarctic Survey, 1985, Tectonic map of the Scotia arc, Scale 1:3,000,000 Bas (Misc.) 3, Cambridge.

Cunningham, W. D., Dalziel, I. W. D., Lee, T. Y. and Lawver, L. A., 1995, Southernmost South America-Antarctic Peninsula relative plate motions since 84 Ma: Implications for the tectonic evolution of the Scotia Arc region, *J. Geophys. R.*, 100, 8,257-8,266.

Dalziel, I. W. D., de Wit M. J. and Palmer K. F., 1975, Fossil marginal basin in the southern Andes, *Nature*, 250, 291-294.

Grunow, A. M., Kent, D. V. and Dalziel, I. W. D., 1991, New paleomagnetic data from Thurston Island: Implications for the tectonics of West Antarctica and Weddell Sea opening, *J. Geophys. Res.*, 96, 17,935-17,954.

Henriet, J. P., Meissner R., Miller H. and the GRAPE Team, 1992, Active margin processes along the Antarctic Peninsula, *Tectonophysics, 201*, 229-253.

Herron, E. M. and Tucholke, B. E., 1976, Seafloor spreading patterns and basement structure in the Southeastern Pacific, *Initial Rep. Deep Sea Drill. Proj.*, 35, 263-278.

Jin, Y. K., 1995, Crustal structure of the South Shetland Trench and the SFZ of the Northern Antarctic Peninsula, Ph. D. Thesis, Seoul National University.

Kim, Y. and Jin, Y. K., 1994, Crustal Structure beneath the southeastern end of the Shackleton Fracture Zone and the South Shetland Trench, *Terra Antarctica, 1*, 297-298.

Klepseis, K. A. and Lawver, L. A., 1993, Bathymetry of the Bransfield Strait, southeastern SFZ, and South Shetland Trench, Antarctica., *Antarct. J. U.S.*, 28(5), 103-105.

Klepseis, K. A. and Lawver, L. A., 1996, Tectonics of the Antarctic-Scotia plate boundary near Elephant and Clarence Islands, West Antarctica, *J. Geophys. R.*, 101, 20,211-20,231.

Klepseis, K. A., Lawver, L. A., Zeller, S., Miller J. and Nelson G., 1990, Bathymetry of the Shackleton Fracture Zone, Elephant Island and Clarence Island regions, Antarctica., *Antarct. J. U.S.*, 29(5), 71-73.

Larter, R. D. and Barker, F., 1991, Neogene interaction of tectonic and glacial processes at the Pacific margin of the Antarctic Peninsula, in Sedimentation, Tectonics and Eustasy, edited by D.I.M. MacDonald, *Spec. Publs. Int. Ass. Sediment.*, 12, 165-186.

Livermore, R., McAdoo, D. and Marks K., 1994, Scotia Sea tectonics from high resolution satellite gravity, *Earth Planet. Sci. Lett.*, 123, 255-268.

Maldonado, A., Larter, R. D. and Aldaya, F., 1994, Forearc tectonic evolution of the South Shetland Margin, Antarctic Peninsula, *Tectonics*, 13,1345-1370.

Matthews, D. H., 1959, Aspects of the geology of the Scotia Arc, *Geol. Mag.*, 96, 425-441.

Pelayo, A. M. and Wiens, D. A., 1989, Seismotectonics and relative plate motion in the Scotia Sea region, *J. Geophys. Res.*, 94, 7293-7320.

Renner, R. G. B., Sturgeon, L. J. S. and Garrett, S. W., 1985, Reconnaissance Gravity and Aeromagnetic Surveys of the Antarctic Peninsula, British Antarctic Survey Scientific Reports, No. 110, Cambridge, 95pp.

Suess, E., 1909, The Face of the Earth, vol. 4, Clarendon Press, Oxford, England.