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The characteristics of geophysical field and tectonic evolution in the Bransfield Strait*

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Abstract Having analysised the data collected by our survey ship "Ocean Ⅳ" in the Bransfield Strait in 1991, we recognized that the geomorphology, gravity and magnetic anomalies trending NE direction along bandings. The sediments in the Bransfield Strait can be subdivided into two sequences: the first rifting sequence and the second rifting sequence. The basement was faulted into a half-graben in northwestern side of the Bransfield trough. Considering the crustal structure crossing the South Shetland Islands, the Bransfield Strait and the Antarctic Peninsula, we propose a two-phase rifting tectonic evolution model and a layered-shear model for the lithospheric deformation under the effects of extensional stress field.

Key words geophysical field, crustal structure, tectonic evolution, layered-shear model.

1 Introduction

In 1991, we undertook geological and geophysical survey in the Bransfield Strait from Janurary 1 to February 25 with our survey ship "Ocean Ⅳ". We collected samples from about 5432 km water depth, 4622.5 km gravity, 2925.6 km magnetic, 2015.2 km multi-channel seismic reflection, 2 sonobuoy stations and 43 core sampling in the investigated area.

We had prepared a 48-channel seismic system before, but the tubes of electric cables were broken in cold water. So we had to do 9-channel seismic reflection work. The source we used there was EH-4 air guns, consisting of an array of six guns, with 24.8 litres total volume and 2000 PSI air pressure. The seismic instrument is the DFS-Ⅳ with 48 recording channels. The seismic data were processed in our computer system. The REF TEK-1 low band sonobuoy made by Refraction Technology INC. and the Raython 12 kHz bathymetric system for echo-sounding were operated in our survey work. In additon, the KSS-5 system made in Germany was used for the gravity survey, and the G801G magnetometer made in US was used for the magnetic survey. The square root er-

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ror of gravity survey in crossing lines is 2.24 mGal, and 55 nT for magnetic survey. The survey lines and core-sampling stations are shown in Fig. 1.

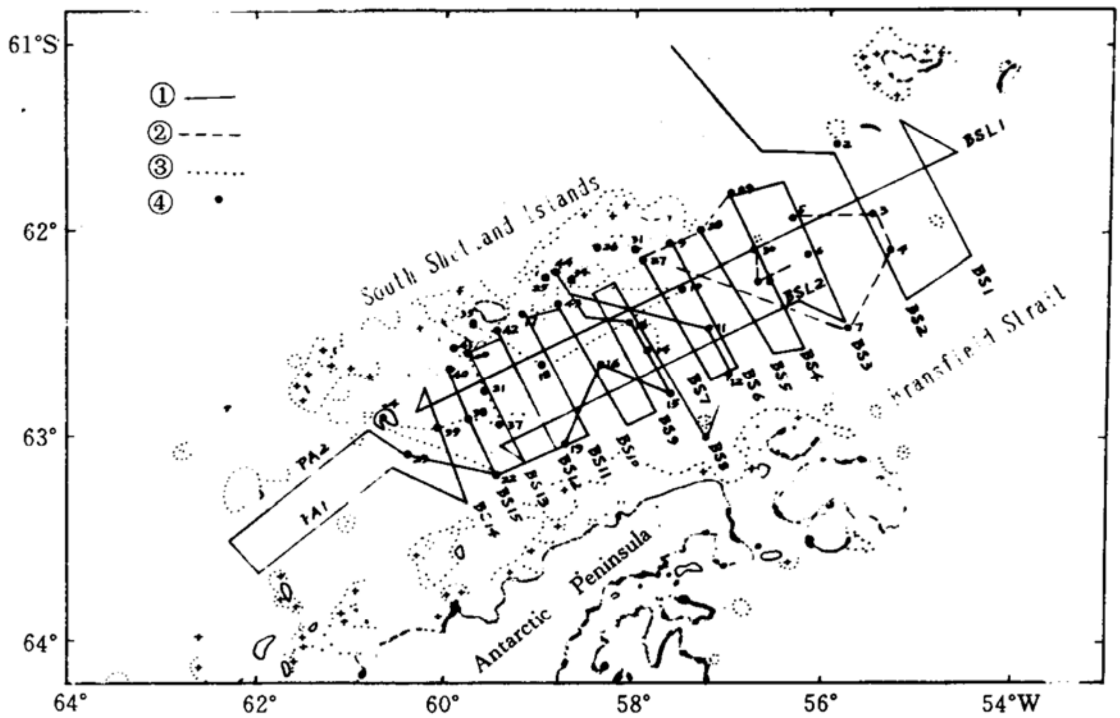

Fig. 1. The survey lines and core-sampling stations in the Bransfield Strait (by "Ocean Ⅳ", in 1991). ① The first voyage; ② The second voyage; ③ The third voyage; ④ core-sampling station.

2 Regional geological setting

As shown by several authors (Dalziel, 1984; Andres *et al.*, 1993; Dott *et al.*, 1982; Farquharson, 1982; Forsythe, 1982; Harrison *et al.*, 1979; Thomson *et al.*, 1983; Elliot, 1983; Saunders and Tarney, 1982), the Antarctic Peninsula bears many similarities in the geological structure to southernmost South America. The plate reconstructions (Lawver and Scotese, 1987; Dalziel, 1983; Dalziel, 1984; Barker *et al.*, 1976; De Wit, 1977) indicated that an active magnatic arc continuously extended from the Andes to the Antarctic Peninsula. This arc formed the western margin of Gondwana and was active at least since the Triassic (Smellie and Clarkson, 1975; Storey and Carrett, 1985; Thomson *et al.*, 1983). The opening of the Drake Passage and the formation of the Scotia Arc isolated the Antarctic continent from South America after the Oligocene (Barker and Burrell, 1977).

At present, the Antarctic Peninsula is surrounded by oceanic crust. The evolutionary history of the western margin of the peninsula has been inferred primarily from the studies of the magnetic anomalies in the adjacent ocean floor (Herron and Tucholke, 1976; Herron *et al.*, 1981; Barker, 1982). These studies indicated that the Bellingshausen continental margin, to the south of the South Shetland Islands, evolved from an active margin with a subduction zone into an inactive margin. In front of the South Shetland Islands the deep sea trench is visible, but not presenting along the Bellingshausen continental margin.

The South Shetland Islands are located at the southwestern end of the South Scotia ridge. The geological and geophysical evidence proved that the South Shetland Islands were orignially part of the Antarctic Peninsula, before the formation of the Bransfield Strait Basin(Ashcroft, 1972; Davery, 1972; Barker, 1970; Thomson *et al.*, 1983). A magmatic-arc has existed in this region since Jurassic period. Until the formation of the Bransfield Strait Basin, the arc was situated on the Antarctic Peninsula. The Bransfield Strait Basin seperates the South Shetland Islands, the present location of the volcanic arc, from the Antarctic Peninsula. The existing evidence indicated that the Bransfield Strait was formed less than 4 Ma(Barker, 1982; Storey and Garrett, 1985) ago. As we will discuss later, our research result shows that the Brnasfield Strait Basin must be older than previouly estimated.

3 The characteristics of geophysical field

Based on the data analysis, we find that the Bransfield Strait trends in a NNE-SSE direction (Fig. 2) and the Bransfield trough can be subdivided into three subtroughs: Northern, Central and Southern subtroughs. The deepest water depth in Northern and Central subtroughs is 2784 m, and they are deeper than the Southern subtrough, in which the water depth is less than 1000 m. In the northwestern side of the Bransfield trough the slope is abrupt and its gradient is $84\times10^{-3}\sim194\times10^{-3}$ (4°50′ ~ 10°54′), while in the southeastern side the sea floor dips gently with $38\times10^{-3}\sim81\times10^{-3}$ (2°10′ ~ 4°40′) gradient.

The magnetic anomalies in the Bransfield Strait area can be subdivided into three anomaly areas(Fig. 3): South Shetland Block anomaly area, Bransfield trough anomaly area and Bransfield shelf anomaly area. In the Bransfield Shelf (Antarctic Peninsula Shelf) anomaly area, the magnetic anomaly is higher and positive, and the value is 100~400 nT. In the Bansfield trough anomaly area the magnetic anomaly is negative, with −300 nT average anomaly. However, positive anomalies still cross some seamounts in the Bransfield trough, and its value is 200 ~ 900 nT. This kind of phenomenon can reflect the seamounts are volcanos younger than the basement. In the South Shetland Islands and South Shetland trench there is the South Shetland Block anomaly area. The magnetic anomaly is positive with 300 ~ 1000 nT value. It reveals the magnetic anomaly of oceanic crust.

The free-air gravity anomaly in the Bransfield Strait trends in NE direction (Fig. 4), parallel to the Islands, trough and Peninsula. In the South Shetland trench there is a negative zone, and the value is −20 ~ −120 mGal. In the South Shetland Islands there is a positive anomaly zone with 60 ~ 90 mGal value. There are variational anomalies in the Bransfield Strait, and the vlue is −30.8 ~ 112 mGl. In the northwestern side of the strait the horizontal gradient of the gravity anomaly is 5 mGal/km, and the maximum is

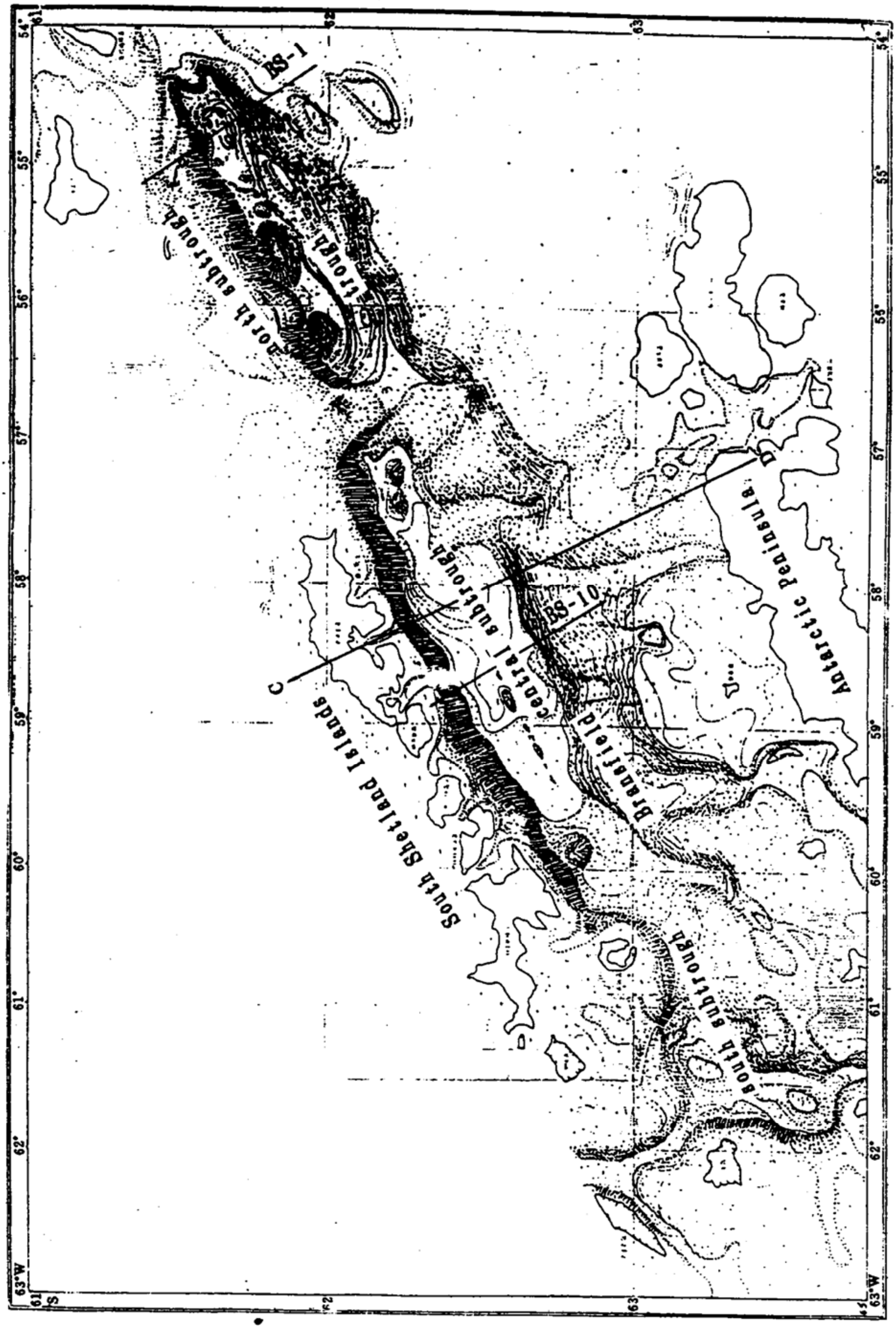

Fig. 2. The geomorphology of the Bransfield Strait.

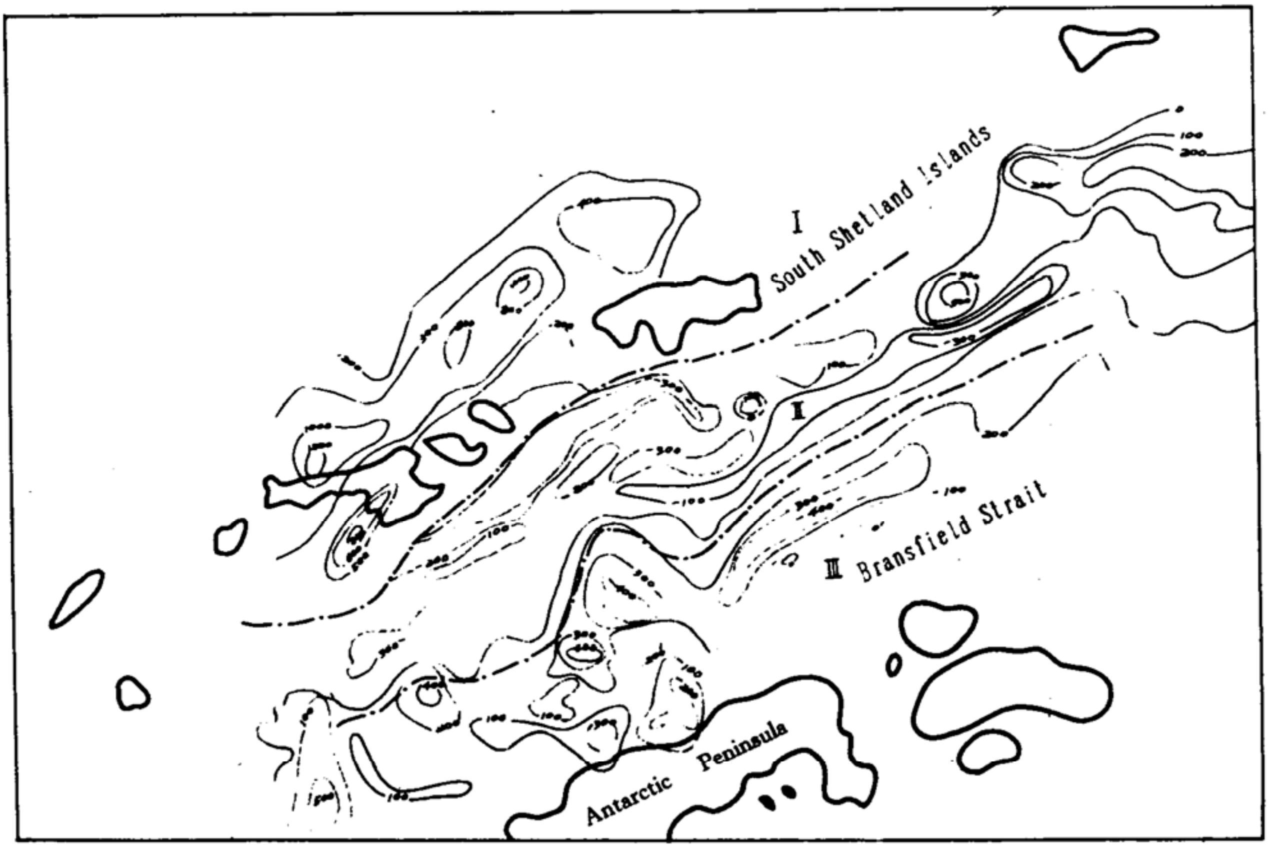

Fig. 3. The magnetic anomaly in the Bransfield Strait. I : The South Shetland anomaly area; II : The Bransfield Strait anomaly area; III : The Bransfield shelf anomaly area.

9. 6 mGal/km. In the Antarctic Peninsula shelf the anomaly is 60～90 mGal, and the value of this gentle gradient is 3. 2 mGal/km. In the Bransfield trough the gravity anomaly is low anomaly zone, which can be subdivided into two areas by Bridgeman rise (II b) : the North subtrough(II a), central subtrough(II c) and South subtrough(II e). In the North subtrough the anomaly is －30～50 mGal. In the Central subtrough and South subtrough, the average anomaly is 34 mGal.

According to the above analysis, in the Bransfield Strait there are three gravity anomaly areas: South Shetland Islands high gravity anomaly area, the Bransfield Strait low gravity anomaly area and Antarctic Peninsula Shelf higher gravity anomaly area. In the boundary of the anomaly area there are gravity step zones where the gravity step is steeper in the northwest of the Bransfield trough. Therefore the gravity anomaly crossing the Bransfield Strait is asymmetric.

4 The characteristics of seismic reflection and sediments

In accordance to analysing and contrasting the seismic profiles crossing the Bransfield Strait, we can recognize two reflection sequences: T_g to T_6 and T_6 to sea floor (Fig. 5). The reflection sequence of sea floor to T_6 is subhorizontal and continuous reflection. There are some curved reflections in the trough, for example, in BS-1, its interval veloc-

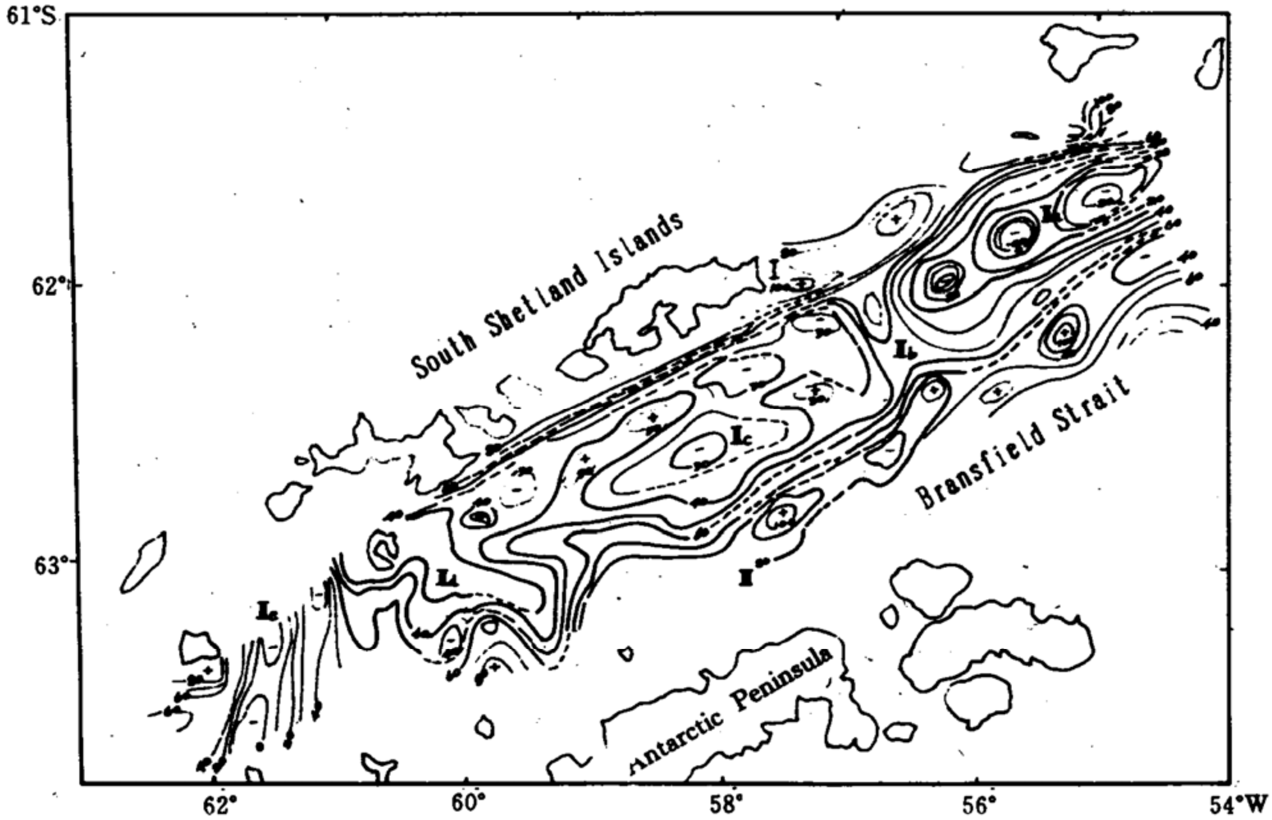

Fig. 4. The free-air gravity anomaly in the Bransfield Strait.

ity is 1.9～2.4 km/s according to the sonobuoy data. The reflection sequence between T_6 to T_g is chaotic and discontinuous reflection. There have been several diffractions in the trough, for example, in BS-1. It may reflect the characteristics of volcanic rock, and its interval velocity is 2.8 ～3.2 km/s, calculated from sonobuoy data. The T_g is the basement of the sediments in the Bransfield trough. There is a basement fault in the northwestern side of the Bransfield trough (Fig. 6). In the BS-1, the fault throw is 2.8 km, and 1.3 km in BS-10. When the basement faulted, its block dropped down along the faulting surface, while appearing a half-graben on the basement surface. The fault is F shown in Fig. 5 and Fig. 6.

The sedimentary sequence between T_g and T_6 was deposited in the half-graben. It is the sediment in the first rifting phase, belonging to clastic sediment. The sedimentary sequence of T_6 to sea floor was deposited in a widened half graben. The sediment in the second rifting phase should be the bathyal sediment.

5 The tectonic evolution of the Bransfield Trough

The basement was a half-graben and widened half-graben in the Bransfield trough (Fig. 6). This structure shows that the volcanic arc(the South Shetland Islands and the

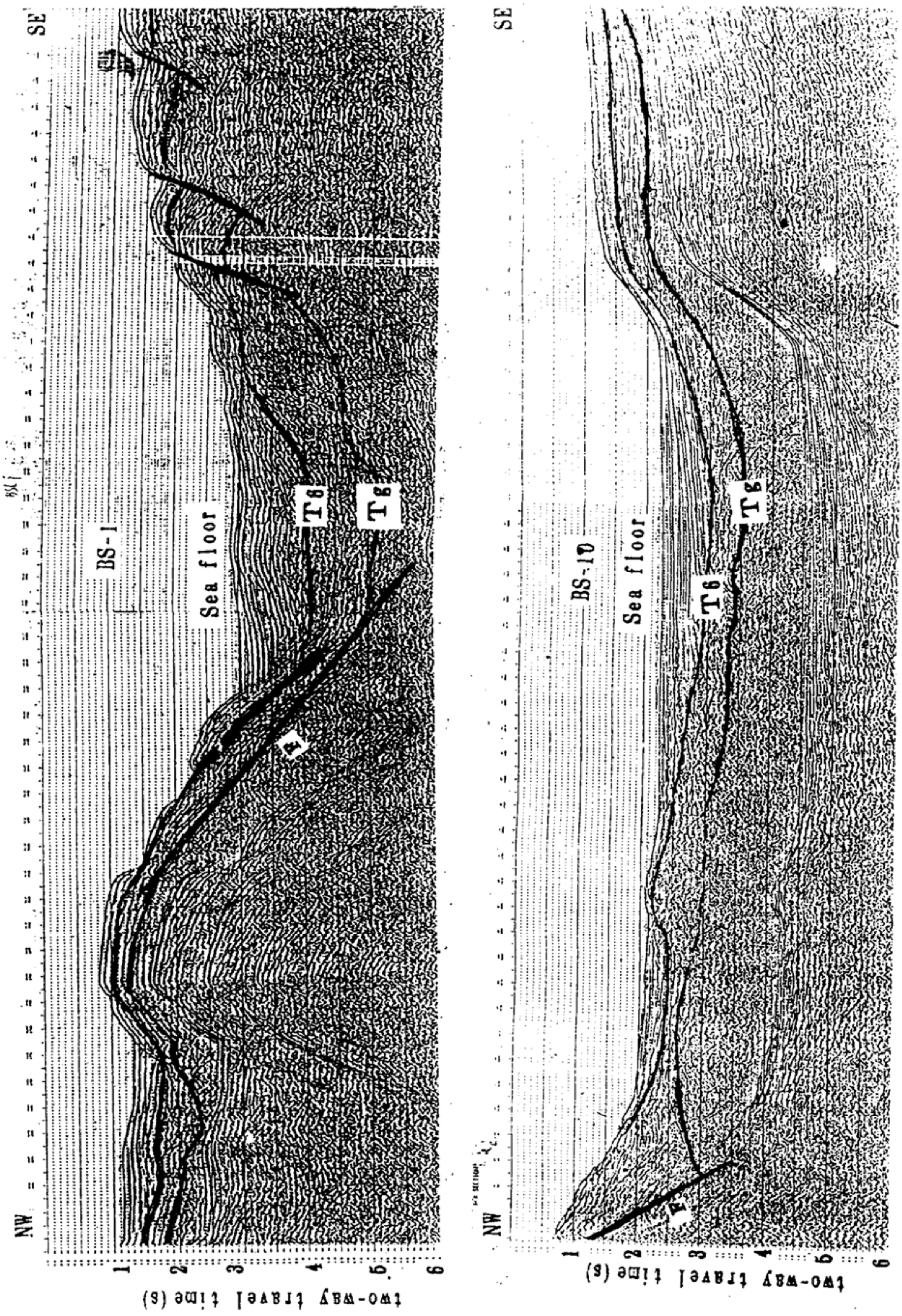

Fig. 5. The seismic profiles of BS-1 and BS-10.

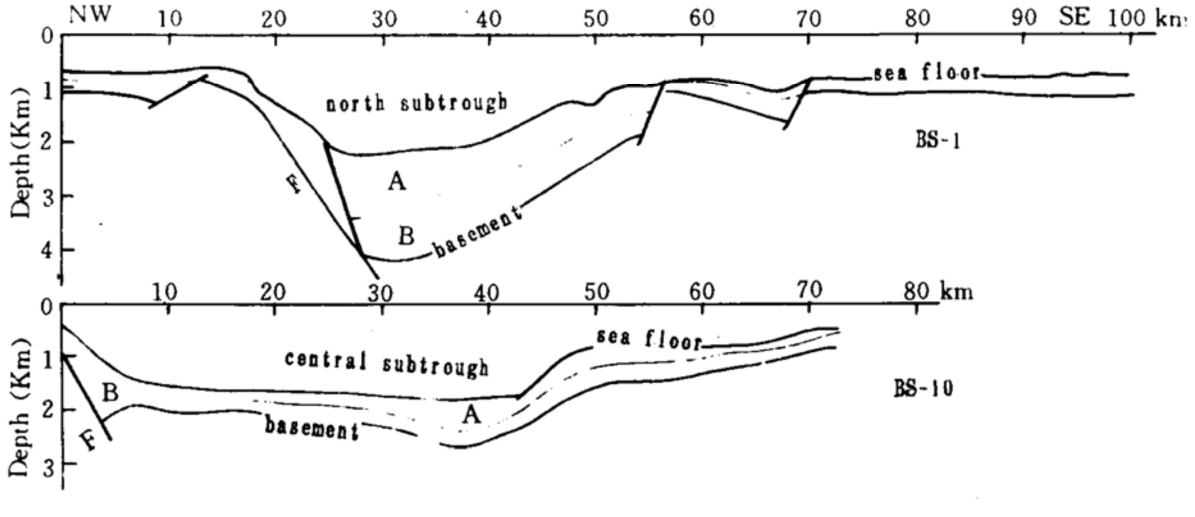

Fig. 6. The interpreted section cross the Bransfield Strait. The location is shown in Fig. 2. A — The sedimentary sequence of second rifting phase; B — The sedimentary sequence of first rifting phase.

Antarctic Peninsula) firstly faulted to become a half-graben on the surface. The sediments deposited in the half-graben can be subdivided into two sequences; the lower sequence (first rifting phase forementioned) and upper sequence(second rifting phase) . Thus, obviously, the tectonic evolution of the Bransfield Trough had undergone two periods. In the first rifting phase, the volcanic arc faulted and a small half-graben was formed on the surface. The clastic sediment from the eroding arc and volcanic material were deposited in the half-graben . In the second rifting phase, the half-graben widened when subducted angle became bigger, and the South Shetland Islands arc moved towards the Shetland plate between the Shackleton and Hero fracture zone. Since the water depth in the graben became deeper, the sediment deposited in the widened half-graben is bathyal deposit.

The exposed geological phenomenon of the Antarctic Peninsula indicated that a magnatic arc moved onwards at least in the Triassic (Andres *et al.* , 1993; Anderson *et al.* , 1990; Rex, 1976; Pankhurst, 1982; Storey and Gattett, 1985; Larter and Barker, 1991). Studies of marine magnetic anomalies have revealed a series of collisions between ridge-crest section of Antarctic-phoenix plate boundary and the trench at the Pacific margin during the Cenozoic (Herron and Tuckholke, 1976; Barker, 1982). The first ridge-crest-trench collision took place about 50 Ma ago at the portion of the margin adjacent to the South Alexander Island(Birkenmajer, 1992). The second collision occurred in the west of the Smith Island during the Pliocene (Later and Barker, 1991) . In the northwest of the South Shetland trench, the Shetland Plate (Birkenmajer , 1992). continuously subducted under the South Shetland Islands . About 4 Ma ago, the subduction rate slowed (Gamboa and Maldonadw, 1990) , and the South Shetland Islands moved northwestwards as the subducted oceanic lithosphere dropped down.

Fig. 7 shows the crustal structure crossing the South Shetland Islands, the Bransfield Strait and the Antarctic Peninsula. The crust in the South Shetland Islands is 21 km thick. In the Bransfield Strait the crust is only 12 km thick, but the Moho velocity is 7. 7

km/s. Such an anomaly mantle reflects that there should be a partial melting in the upper mantle under the Bransfield Strait.

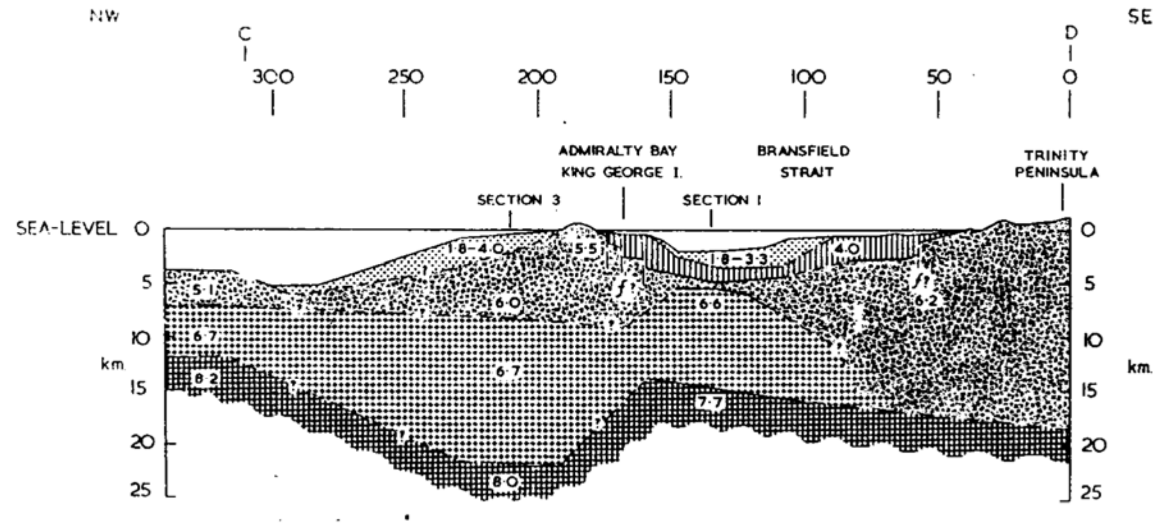

Fig. 7. Generalized cross-section along line C-D. The location is shown in Fig. 2.

Based on the above analysis we can see that the movement of Phoenix plate subducting under the Antarctic Plate dated back to Triassic. The South Shetland Islands and the Antarctic Peninsula connected together and included the volcanic arc. The subduction continued to the Cenozic(Fig. 8a). About 22 Ma ago, the volcanic arc broke into the South Shetland Islands arc and Antarctic Peninsula arc (Birkenmajer, 1992), then a half-graben on the surface of the arc appeared (Fig. 8b). About 4 Ma ago, the phoenix plate between Tula and Hero fracture zones subducted completely and the ridge-crest subducted into the trench. So the Phoenix plate between the Hero and Shacleton fracture zones and the Shetland plate subducted slowly under the South Shetland trench. The subducted oceanic plate dropped down, and the South Shetland Islands arc moved northwestwards. The half-graben between the South Shetland Islands and the Antarctic Peninsula was widened (Fig. 8c).

6 The characteristics of litho-spheric deformation

According to the above analysis we can see that there existed a half-graben in the Bransfield Strait in Cenozoic period, which was formed by basement faulting and faulted block moving along the faulted suface. According to the seismic profiles through the Bransfield Strait we found that the basement faults went down to the upper crust and quickly disappeared. These facts, showing that the faults took place in the upper crust, reveals brittle and the brittle faults occurred under the effect of extensional stress field in

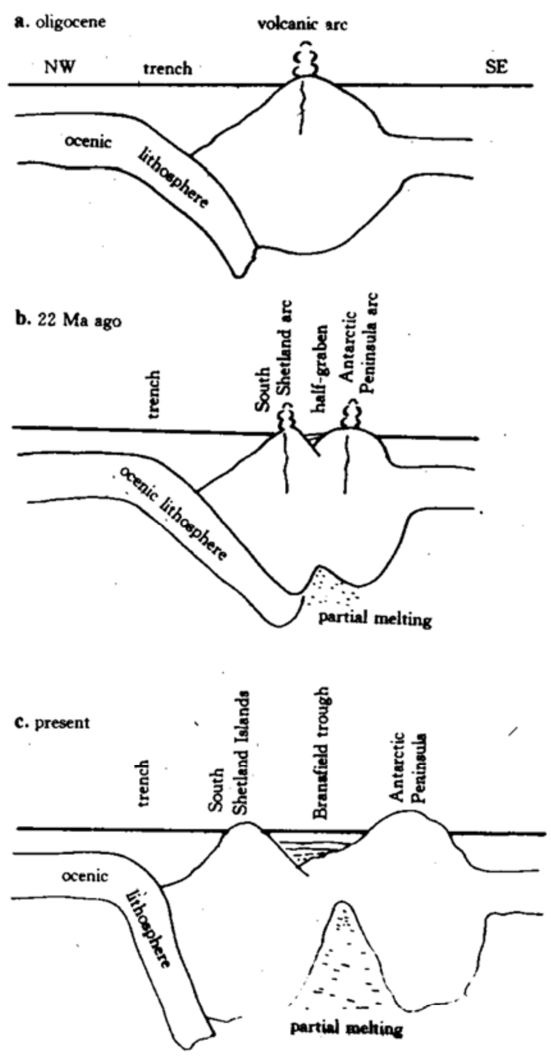

Fig. 8. The tectonical evolution modle of the Bransfield Strait.

upper crust. As shown in Fig. 8 the seismic velocity is 6. 6 km/s with 7～8 km thickness in lower crust there. It reflected that it thinned evenly. The thickness evenly thinned only if the ductile material extended as shear deformation. In this case, we inferred that there was ductile deformation in lower crust under the effect of extensional stress field in the Bransfield Strait. Even though there were no observatory data in lithospheric mantle, the authors found that there existed faults in the upper mantle (Yao *et al.*, 1994) while studying the passive margin of the south China Sea Basin. Therefore, we inferred that there has brittle deformatioin in the lithospheric mantle. The authors have hypothesized a layered-shear model for the lithospheric deformation under the effect of extensional stress field. It can be believed that this model will suit better the lithospheric deformation in the Bransfield Strait area (Fig. 9).

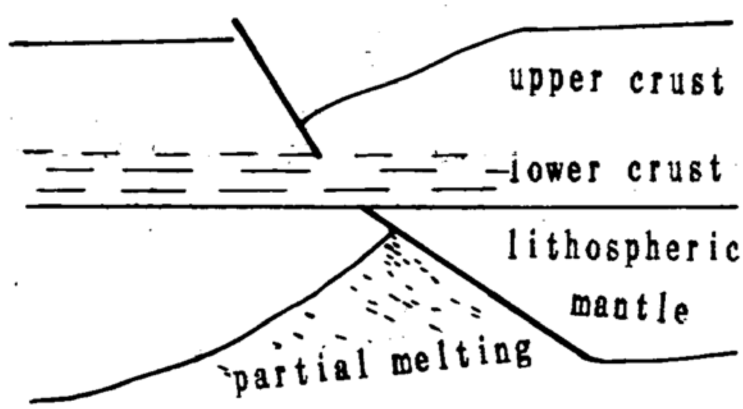

Fig. 9. The layered-shear model.

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