Antarctic Research, Vol. 5, No. 1, 11~20, June 1994

Deep electrical conductivity structure in the Great Wall Station area, Fildes Peninsula, West Antarctica

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Received March 1, 1994

Abstract MT measured in Great Wall Station area shows that the electrical conductivity major axis of the Wind Valley Fault is 110°NE and the crustal thickness in the Fildes Peninsula is about 22.3 km. The crust contains four main resistivity layers with their thicknesses being 1.3 km, 6.7 km, 1.2 km and 13.1 km respectively. The upper crustal thickness is 9.2 km and the lower crustal thickness is 13.1 km.

Key words Fildes Peninsula, magnetotelluric deep sounding, electrical conductivity structure

1 Introduction

The solid geophysics study in Antarctica, such as gravity, magnetism, electricity and seismology is of great importance. It helps us to understand the crust structure and distribution of mineral resources in Antarctica, disintegration of Gondwana land, relative movement of continent plates, Antarctic drift and geodynamics.

Since the founding of Great Wall Station, the Chinese Antarctic Research Expedition has been studying on the magnetism, palaeomagnetism, gravity, seismology and geotherm there. Recently, more and more geophysicists of the world are engaged in the Antarctic researches. They have established many stations to do geophysical observation. Ashcroft (1972) pointed out that the crust thickness of the South Shetland Islands is about 23km, the velocities of seismic wave are 5.5~6 km/s in the upper crust and 6.5~6.9 km/s in the lower crust separately. But until now, little report has been made on the magnetotelluric sounding in West Antarctica. In the middle of December, 1992, we made magnetotelluric sounding measurements on three sites nearby Great Wall Station, obtaining the low frequency ranging from 1 sec. to 4096 sec.

This paper is to discuss the deep electrical conductivity structure, the Moho depth of Fildes Peninsula, and the relationship between the Fildes Peninsula and the adjacent South Pacific Ocean in the crust thickness.

2 Geological setting and field work

The Fildes Peninsula (62°10′~62°14′S, 58°53′~59°01′W) lies at the southern tip of King George Island and covers an area of 35 km^2. It is a hilly land with an elevation of 200 m. The Fildes Peninsula is almost deposited by the volcanic rocks from Jurassic to

Tertiany periods. The volcanic rocks are classified into volcanic conduit facies, subvolcanic facies, eruptive facies, effusive facies and volcaco-sedimentary facies, sidmentary rocks can be seen only in a few areas, belonging to the lacustrine facies. The volcanics in the study area are divided into two units, i.e. (from the lower to upper) the Great Wall Formation and the Fossil Formation (Li *et al.*, 1992) and each formation is further subdivided ascendingly into two members: the Jasper Hill Member and the Agate Beach Member in the Great Wall Formation, the Fossil Hill Member and the Block Hill Member in the Fossil Formation. The basal parts of the Jasper Hill Member and the Agate Beach Member are composed of agglomerates and volcanic breccias, the Fossil Hill Member is the pyroclastic-sedimentary rocks with plant fossil and the Block Hill Member is the agglomerates of the crater facies. The Fossil Hill Member is in discordance with the Great Wall Formation, showing a great sedimentary hiatus between them.

The MT sites are located on both sides of the Wind Valley Fault to the west of Great Wall Station. The distances between A_1(62°12′48″S, 58°57′44″W) and A_2(62°12′46″S, 58°57′49″W), between A_2 and A_3(62°13′03″S, 58°57′48″W), and between A_1 and A_3 are 100, 550 and 500 m respectively (Fig. 1.).

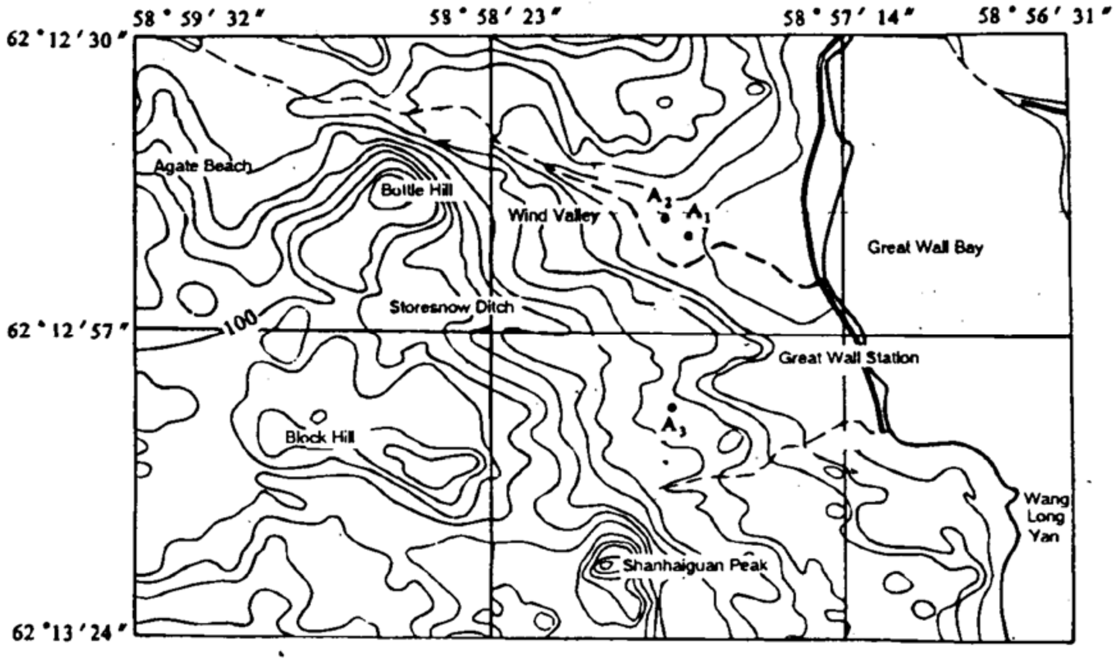


Fig. 1. The locations of the MT sites in the Fildes Peninsula.

The magnetotelluric measurement system MMS-02 was made by METRONIX Company, Germany. The technical data are:

Period range: 2.5～4069 s

Dynamic range: ±38 db

Sensitivity: 16 μV/km for electric field device (probe distance is 50 m) and 2 v/nT · Hz for Trixial Induction Coil Magnetometer

Noise: < μV

Temperature drift: < 5 μV/℃

Operating temperature range: −20 ～ +60℃

The sample interval of MMS-02 is divided into 6 grades: 1s, 2s, 4s, 8s, 16s and 32s respectively. We can choose the sample interval freely and check up the electromangnetic signals during field work.

In Antarctica for MT observation, the instrument must be portable, stable function and good anti-disturbances. The MT sites should be chosen under the following conditions: (1)pick out flat ground, (2) far away from power and radio stations and generating equipment, (3) keep away from river. Selecting a good MT site is a key step for getting high quality data. The four electric field probes are setted with center symmetry. The directions of the E sensor and H sensor are measured by the forest compass and the distances of the probes are measured by measuring rope. The cable were fixed with stones to avoid wind disturbances. The electrode holes are about 30 cm in depth. Four hours later the measurements were started. The magnetometer has three orthogonal sensor components which are mounded on a central fastener and enclosed in a cylindrical plastic case. To aviod the magnetometer shock and keep the temperature stable inside of the magnetometer-housing, two-thirds of the plastic case must be put into the ground. After the installation of the MT equipment, turn on the power switch, set off the compensations of electrodes and low frequency magnetometers, enter date, time, filtercode, start-date and start-time, and insert cassettes. When start-date and start-time are reached, recording will start.

In normal conditions, the sample intervals are 1s, 4s and 16s respectively. The fieldwork period is around 4～6 days in each sounding site. Usually the distance of the two electrodes (N-S or E-W) is 50 m. Due to the limitation of the geographic condition in the survey area, the distance of electrodes is 50 m in A_1 and A_3, but only 30 m in A_2. The sample intervals in site A_1 are 1s, 4s, 16s and the analysis period range is 2.5～1024s. The sample intervals in site A_2 amd A_3 are 1s, 4s and the analysis period range is

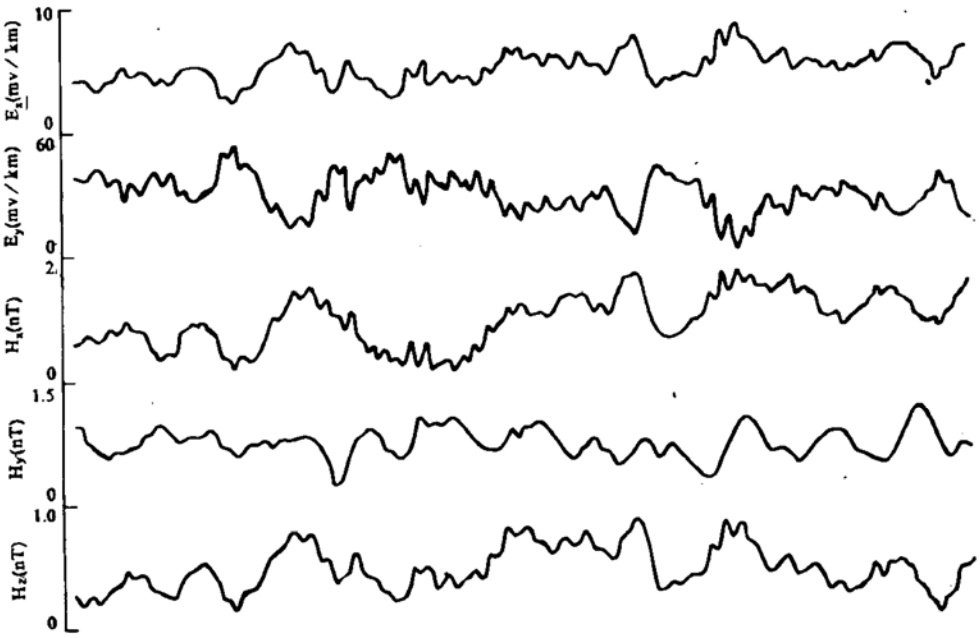


Fig. 2. MT records in site A_3(SP=1s).

2. 5～256s.

Figure 2 shows the five components of natural electromagnetic field records in site A_1 with the sample interval of 1s. E_x and E_y are the NS and EW electrical field components respectively, H_x, H_y and H_z are the NS, EW, vertical magnetic field components respectively.

Three geomagnetic components have good correspondences, and especially the vertical component H_z has the same amplitude as the horizontal components H_x and H_y. It shows that it is influenced by the high electrical conductivity sea water in outland and the complex geological structure in peninsula. E_y amplitude is much greater than E_x amplitude. It shows that the underground current in EW direction is also greater than that in NS direction in Fildes Peninsula. It shows the trend of the electrical conductivity structure seems to be the same as that of the geological fault.

When comparing the MT data with the geomagnetic pulsation data at Great Wall Station, performed by Institute of Geophysics, Academica Sinica, we confirmed that our MT data are reliable, for the two groups of data mentioned above are equivalent in both grade and shape.

3 Data processing

3. 1 Calculation of sounding curves

Generally, one dimensional geological structure is rarely seen. But, two dimensional geological structure is often met. Usually the resistivities are changeable along with depth Z and strike Y.

The MT data processing includes the spectral analysis of signals in time domain, calculating the elements of impedance tensor in measured direction and the major axis of electric conductivity structure for underground medium, calculating the elements of impedance tensor and apparent resistivity in major axis.

Firstly, we selected the data from anologue playback waveform charts, complying with the rules of big signal intensity and high signal-to-noise ratio.

After the data processing, we obtained the sounding curves ρ_{xy}, ρ_{yx} that are perpendicular to each other, and the sounding curves of major axis direction after rotating some angles. We also calculated the effective apparent resistivity ρ_{ef}, effective phase φ_{ef} and arithmetic average apparent resistivity ρ_{az}, arithmetic average phase φ_{az}

$$Z_{ef}=\sqrt{Z_{xy}Z_{yx}-Z_{xx}X_{yy}} \tag{1}$$

$$Z_{az}=(Z_{xy}-Z_{yx})/2 \tag{2}$$

$$\rho_{ef}=0.2T|Z_{ef}|^2 \tag{3}$$

$$\rho_{az}=0.2T|Z_{az}|^2 \tag{4}$$

Figure 3 shows the apparent resistivities ρ_{xy}, ρ_{yx}, ρ_{ef}, ρ_{az} and apparent phases φ_{xy}, φ_{yx}, φ_{ef}, φ_{az} in site A_1. In the figure, the magnitude of the apparent resistivity ρ_{xy} is generally great, reaching 10^4～10^5 Ωm, but the magnitude of ρ_{yx} is only 10^2～10^3 Ωm.

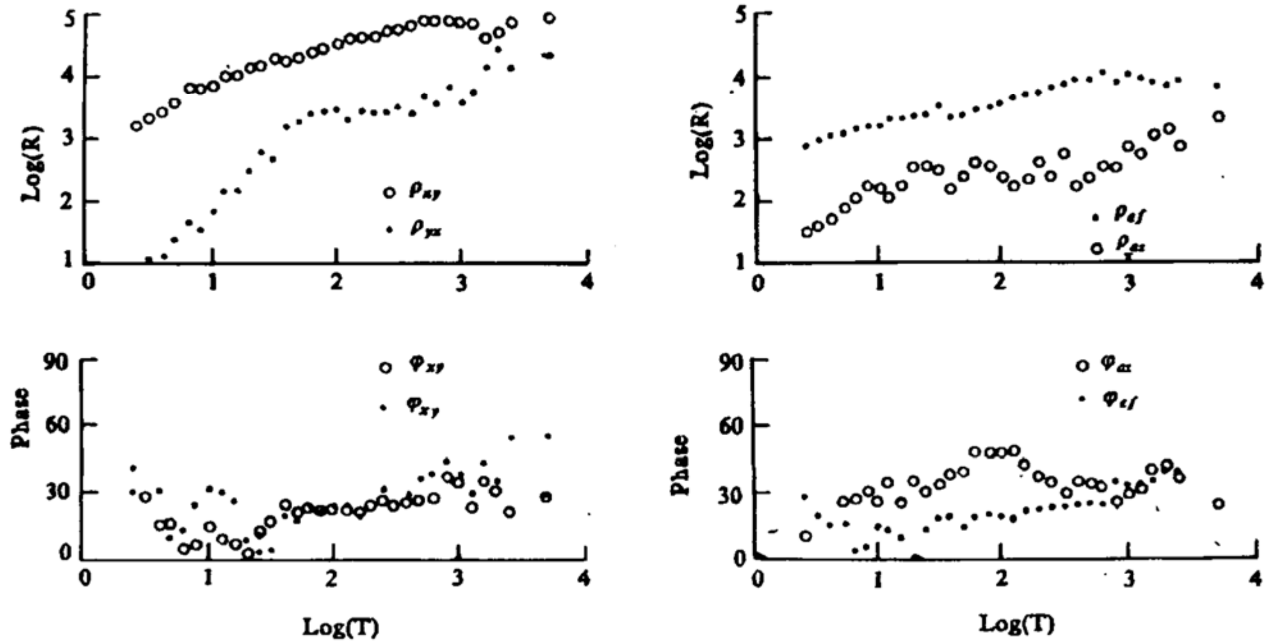


Fig. 3. The apparent resistivity and apparent phase in site A_1.

3. 2 Static correction

Near-surface inhomogeneous structure (topographic relief or near-surface resistivity anomaly) causes apparent resistivity curve shift, which is called the static shift effect. This effect can lead to errors in inverted models. The static shift apparent resistivity data are not independent for 1-D interpretation, the layer parameters fit the following formula:

$$D_s^2/\rho_s = D^2/\rho \tag{5}$$

here D and ρ are the true layer depth and the resistivity respectively. D_s and ρ_s are the static shifted layer depth and resistivity. D_s and ρ_s are greater than D and ρ when static shift effect increases apparent resistivities. Conversely, D_s and ρ_s are smaller than D and ρ when static shift effect decreases apparent resistivities.

The apparent resistivity curves show that ρ_{xy} is much greater than ρ_{yx}, because MT sites are located at Wind Valley Fault where the geological structure is of Early Tertiary volcanic rocks with high resistivity (Liu and Zheng, 1988). The apparent resistivity curves are shifting upwards due to the influence of near surface high resistivity. To avoid misinterpretation, we have corrected the resistivity curves downwards before 1-D invertion.

3. 3 1-D invertion and 2-D model

We selected the static corrected average apparent resistivity curves ρ_{az} as the interpretation curves. The 1-D inversion results were given in Table 1, where ρ is layered resistivity and H is layered thickness. Fig. 4 shows the apparent resistivity curves.

Table 1. 1-D invert results (unit: ρ, Ωm; H, km)

site \ parameters	1		2		3		4		5	
	ρ	H	ρ	H	ρ	H	ρ	H	ρ	
1	54	1.30	380	6.3	44	1.30	1020	13.4	2050	
2	76	1.48	630	7.0	40	1.13	1160	14.0	2060	
3	27	1.20	610	5.9	42	1.05	1130	12.9	1830	

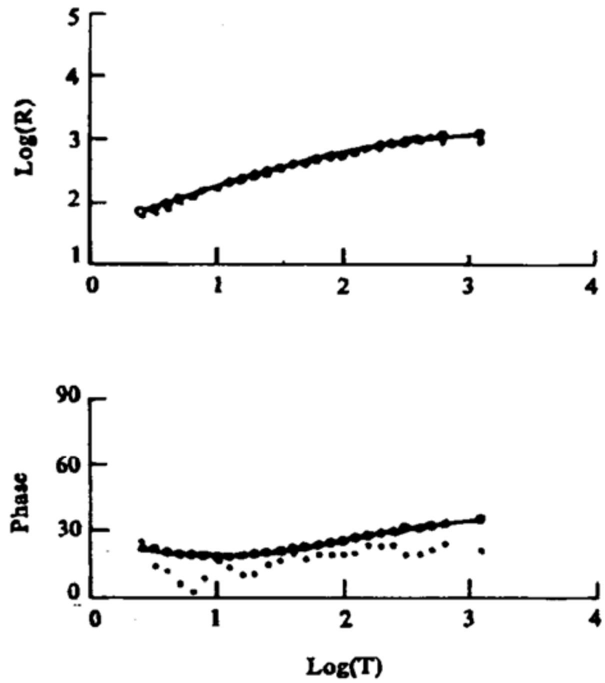


Fig. 4. Observed and calculated apparent resistivity curves in site A_3.
• observed ρ_{xy} curve;
◦ calculated ρ_{xy} curve

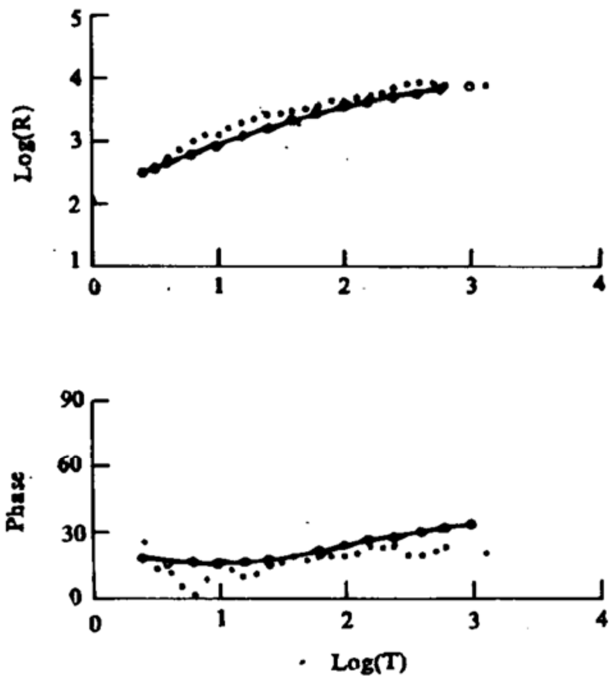


Fig. 5. 2-D results.
• observed ρ_{xy} curve;
◦ 2-D results

According to the 1-D inverted results and the situation of Bransfield Strait and Drake Passage on the sides of the Fildes Peninsula, we constructed 2-D mode (see Table 2). 2-D model program is calculated by use of the finite element algorithm. The 2-D model results well correspond to the MT curves of the three sites as shown in figure 5.

3.4 Electrical conductivity structure strike

The major axis directions of 2-D electrical model agree with the strike and dip of geological structure. These directions in the Fildes Peninsula are 20°and 110 °. We use the tipper to confirm which direction is the strike or dip.

The three geomagnetic components of short-period variations satisfy the relation:

$$H_z = AH_x + BH_y \qquad (6)$$

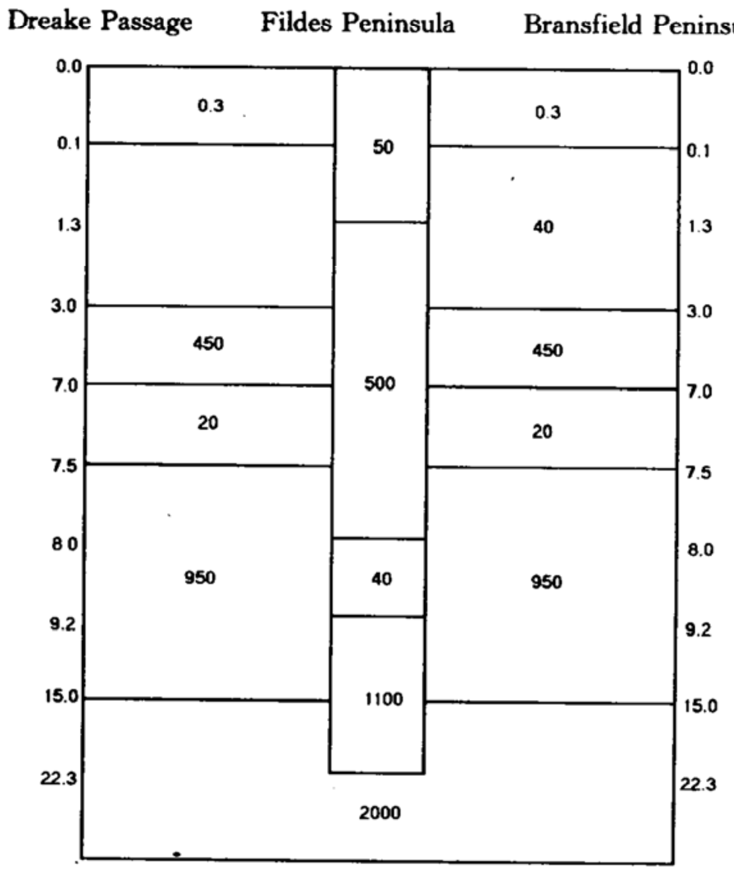
here A and B are called tipper in the frequency domain. *A* and *B* are the functions of rotating angle θ:

$$A(\theta)=A\cos\theta+B\sin\theta \tag{7}$$
$$B(\theta)=-A\sin\theta+B\cos\theta \tag{8}$$

The tipper is very sensitive to the anisotropic medium in horizontal directions in the 2-D medium, the electromagnetic waves can be separated into two linear polarization waves along with the major axis. H_z only appears in E polarization wave (E_y, H_x, H_z) but not in H polarization wave (H_y,E_x,E_z). If Y axis is the direction of strike, then the formula (6) becomes:

$$H_z=AH_x,\ B=0 \tag{9}$$

Table 2. 2-D Modeling drift map



(unit: ρ,Ωm;H,km)

That is to say, the tipper $B=0$, the direction corresponding with the tipper A is the geological dip. In the three dimensional case, neither A nor B is zero, but there is a relative major axis. By rotating the measuring axis so as to minimize the component of B, then A is the relative tipper, and the major axis corresponding with A is perpendicular to the direction of relative strike. After computing the tipper, we obtain that the electric conductivity structure strike in the sounding sites is NE 110°(see Figure 6), which is agreeable with the strike of Wind Valley structure.

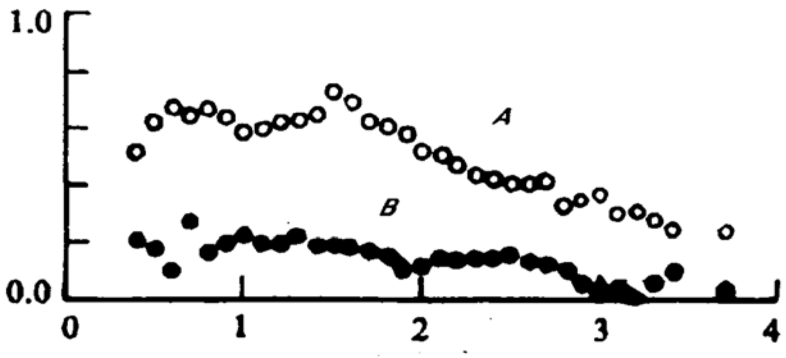


Fig. 6. The tipper A and B in site A_1.

4 Comprehensive interpretation and discussion

The coherence of the impedance tensor is greater than 0.75 in our selected data, so the data are certainly reliable.

4.1 Structure dimension and major structure direction

Figure 7 shows that the polarization ellipticity β are 0～0.4, and 2-D skewness S is greater than 0.5. It indicates that the Fildes Peninsula is a three dimensional structure with obvious two dimensional structure. The major structure direction of Wind Valley Fault is approximately east-west, and the electrical conductivity structure major axis is mainly around NE 110 °, which seems to be in accordance with the real geological situation.

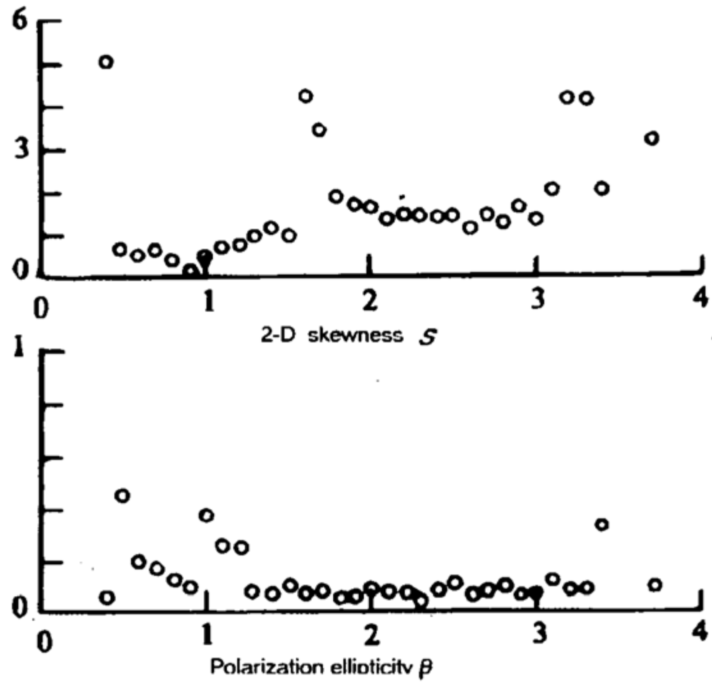


Fig. 7. The ellipticity and skew S in site A_1.

4.2 *Conductivity layered structure*

The MT results show that there are 5 resistivity layers in the crust of the Fildes Peninsula.

The first layer has a resistivity of 30～80 Ωm and a thickness of 1.3 km, belonging to the surface sedimentary layer.

The second layer has a resistivity of 250～600 Ωm and a thickness of 6.7 km, belonging to the upper crust.

The third layer, with a resistivity of 30～50 Ωm and a thickness of 1.2 km, is the crust's high conductivity layer that lies in very shallow depth. The top depth of this layer is only 8 km. The cause of formation for the crust's high conductivity layer may be that the change of hornblendite facies become granulite or the dehydration of granitization.

The fourth layer, with a resistivity of 1000～1200 Ωm and a thickness of 13.1 km, belongs to the lower crust. The resistivity of this layer is very different from that of the upper crust, so their lithological characterisitics are different from each other. According to Ashcroft (1972), the lower crust is basalt with the seismic wave velocity of 6.5～6.9 km/s. Therefore the resistivity value is high in this layer.

The fifth layer, with a resistivity of 2000 Ωm or more, is the upper mantle, and the top of this layer is Moho surface. The depth of the Moho surface is 22.3 km. The seismic exploration results (Davey, 1971; Ashcroft, 1972) also show that the crust's depth of South Shetland Island is 23 km, it is in correspondence with the electric structure Moho surface given in this paper.

4.3 *Plate tectonics background*

In general opinions, because of Pacific Ocean Plate downthrust eastward, at least from Middle Jurassic period, Antarctic Peninsula developed into a magmatic arc gradually, the South Shetland Islands that lie in front of the magmatic arc are situated in the edge of subducting plate for a long time and they are built by the volcanic action from the end of Cretaceous period. The Bransfield Strait is considered to be formed by back arc extension, and the South Shetland Islands separated itself from Antarctic Peninsula to move north-westward (Smellie, 1983). In this tectonics background, Fildes Peninsula, together with the King George Island, was affected by pressure stress in NW-SE direction, therefore the structure of Fildes Peninsula is mainly a series of strike slip faults approximately parallel to NW-SE direction. From the two dimensional model of MT, it can be inferred that the crustal thickness of Drake Passage and Bransfield Strait, that lie on both sides of Fildes Peninsula, are about 15 km, thinner than the crustal thickness of South Shetland Islands, and this shows that the crust becomes thinner gradually from the South Shetlands to South Pacific Ocean.

Acknowledgement

We would like to express our appreciation to the State Antarctic Committee of China and Chinese Academy of Sciences for financial supports and to the Ninth Expedition (1992—1993) for helping us to do field observation. We thank Mr. Yang Shaofeng for supplying some data of geomagnetic pulsation in Great Wall Station.

References

Ashcroft, W. A. (1972): Crustal structure of the South Shetland Islands and Bransfield Strait. *Brit. Ant. Sirv. Sci. Dept.*, 66, 1—43.

Davey, F. J. (1971): Marine gravity measurement in Bransfield Strait and adjacent areas. In: Antarctic Geology and Geophysics, ed. by Adie R. J., Oslo: Universitets forlaget, 39—45.

Li Zhaonai, Zheng Xiangshen, Liu Xiaohan, Shang Ruxiang, Jin Qingmin and Wang Bixiang (1992): Volcanic rocks of the Fildes Peninsula, King George Island, West Antarctica. Science Press (in Chinese).

Liu Xiaohan and Zheng Xiangshen (1988): Geology of volcanic rocks on Fildes Peninsula, King George Island, Antarctica. *Antarctic Research* (Chinese Edition), 1(1), 25—33.

Smellie, J. L. (1983): A geochemical overview of subduction related igneous activities in the South Shetland Islands, Lesser Antarctica. In: Antarctic Earth Science, Ed. by Oliver, R. L., Cambridge University Press, 346—352.