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GROUND TEMPERATURE AND ROCK THERMOPHYSICAL PROPERTIES IN FILDES PENINSULA

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Abstract During 1985—1986, 1986—1987, and 1988—1989 expeditions on Fildes Peninsula the ground temperature was measured. A total number of 218 ground temperature data were obtained. The thermal conductivity measurements were made on 121 rock samples collected during expedition. This article gives a brief analysis and summarization of these data.

Key words Ground temperature, Fildes Peninsula, Temperature probe, Rock thermal conductivity, Hydrothermal process.

1. Introduction

The Fildes Peninsula is located on the south-western corner of the King George Island with an area of about 60 km^2. During antarctic summers of 1985—1986, 1986—1987, and 1988—1989, Drs. Liu Xiaohan and Zhen Xianshen, members of the Chinese Antarctic Expedition Team, conducted geological expeditions on this peninsula, respectively. At the same time, they made ground temperature measurements using a minute temperature-measuring device developed in the Geothermal Lab of the Institute of Geology, Academia Sinica. A total number of 218 ground temperature data were obtained. The thermal conductivity measurements were made on 121 rock samples collected during expeditions. For comparison and analysis purpose we also collected information from the "Great Wall" Meteorological Station and the State Meteorological Bureau. The authors convey their sincere thanks to them. This article gives a brief analysis and summarization of these data.

2. A Minute Portable Digital Temperature Measuring Device

This device consists of two parts: measuring instrument and a temperature-sensing probe (Fig. 1):

(1) The measuring instrument is a minute portable multimeter of 3 1/2 digits. Its dimensions are 14×8×2.7 cm, with a weight of about 235g.

(2) The temperature sensor is a needle probe of 3 mm in diameter and about 20 cm long. A semiconductor-thermister as a temperature sensor is mounted in the needle probe. A 9 cm long synthetic glass handle of 2 cm in diameter is attached to the top of the needle probe from which two electrical wires are extracted. The total weight is 74g.

(3) The performance of the device is stable. The operation is simple. Besides, the device is handy and light with quick temperature display. Its main specifications are as follows:

Temperature sensor: semiconductor thermistor

Temperature range: —15°C — 15°C

Measuring method: digital display

Accuracy: 0.1°C

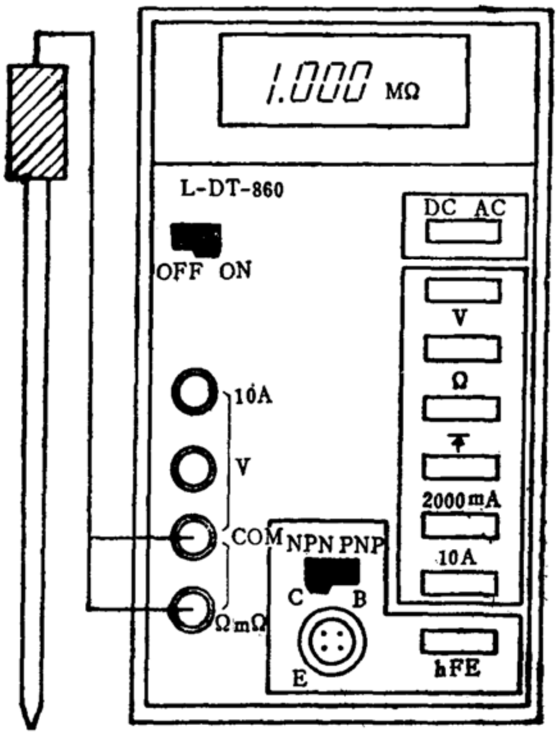

Fig. 1 Sketch of a minute digital temperature-measuring device.

Dimensions: 14 × 8 × 2.7 cm
Total weight: 309 g.

3. Characteristics of Ground Temperature

In sum the ground temperature was measured at 218 sites on the Fildes Peninsula with the measurement depth of 10—20 cm. Fig. 2 is a location map showing the measuring sites. In addition, the ground temperature data were collected from an interval of 0—1.6 m in the Great Wall Meteorological Station (Tab. 1), and from an interval of 0—3 m in three localities of different latitudes from the State Meteorological Bureau (Tab. 2).

Depending upon different latitudes, the variations of the crustal surface temperatures range from −6.5°C (Antarctica) to +35°C (Equator). Table. 3 gives variation curves of average air temperature and ground temperature with depths in four meteorological stations at different latitudes measured in 1985. It was estimated that the energy provided by the Earth's external source (solar radiation) is about 4 orders of magnitude higher than that served from the Earth's interior (heat flow at depths) corresponding to 10^{-2} versus 10^{-6}cal/cm^2 sec. (Frolov, H.M., 1976).

The sunshine has different effects on the ground temperature on Fildes Peninsula. Fig. 3 shows that the ground temperature at the same spot may vary with seasons. If we compare the average winter temperature with the summer one, we can see that the temperature variation is dramatic at zero depth; (−4.47°C — 1.87°C); whereas that for a depth of 1.6 m becomes much smaller (0.1°C — 1.33°C). Besides, at an interval of 1.6 m ground temperature increases with depths in winter and decreases in summer.

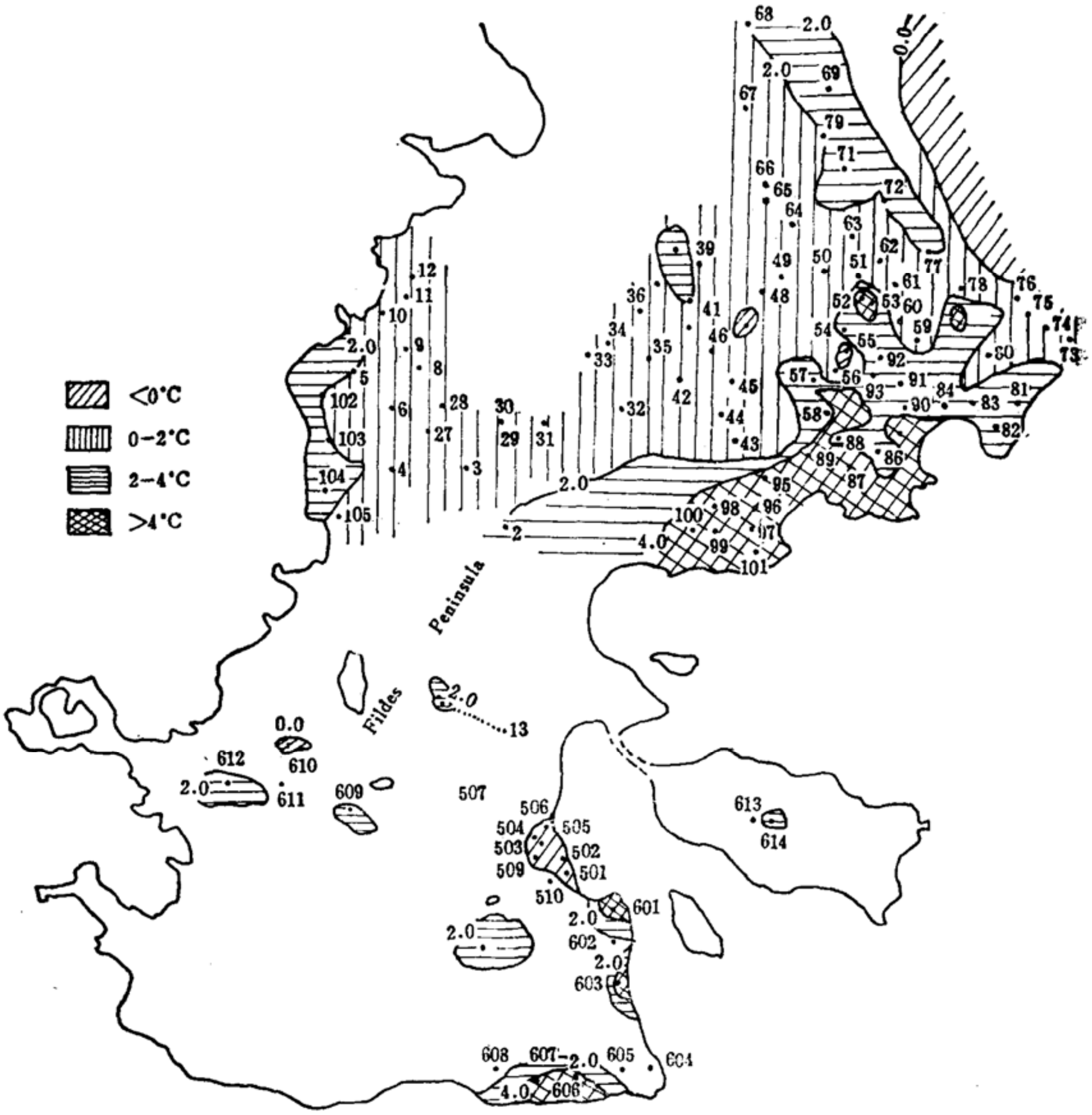

Fig. 2 Location map of temperature-measuring sites and ground surface isotherms.

It clearly shows an increasing trend of the ground temperature from two earth poles to the equator. Furthermore, it indicates that within a depth interval of 1 m the ground temperatures increase with depths near the poles, whereas they decrease with depths at the equator.

For most continental part of China, the average temperature of superficial rocks is almost always higher than the average air temperature at the locality of the ground surface (see curves 2, 3 and 4 in Fig. 4). This implies that the heat at the ground surface comes not only from solar radiation, but also from heat flux coming upwardly from the deep interior of the Earth. However, the data from the Great Wall Station show a more complicated situation (see curve 1 in Fig. 4) where the annual average temperature of surface rocks (0 m) is slightly lower than the annual average air temperature. This may imply that, in addition to the above-mentioned two factors, the temperature of the surface rocks is also influenced by the cooling effect of the thick ice-cap in Antarctica.

Table 1. Data of monthly mean temperature on the Great Wall Station, Antarctica in 1985.*

Months	Air temperature (°C)	Ground temperature (°C)				Seasonal mean ground temperature (°C)		
		0 m	0.4 m	0.8 m	1.6 m	Seasons	0 m	1.6 m
March	−0.6	−0.6	0.9	1.1	0.9	Autumn	−2.17	0.40
April	−0.7	−1.6	0.1	0.2	0.2			
May	−0.4	−4.3	−0.8	0.1	0.1			
June	−4.5	−4.7	−2.4	−0.8	0.1			
July	−3.2	−4.1	−1.8	−1.0	0.1	Winter	−4.47	0.10
August	−3.9	−4.6	−1.5	−0.8	0.1			
September	−1.8	−2.1	−2.0	−0.7	0.0			
October	−1.6	−1.8	−0.1	0.0	0.1	Spring	−1.90	0.07
November	1.0	0.6	−0.2	0.2	0.1			
December	1.0	0.6	0.2	0.2	0.1			
January	1.5	3.2	3.0	2.1	1.6	Summer	1.87	1.33
February	1.3	1.8	3.2	2.9	2.3			
Annual mean temperature	−1.37	−1.5	0.0	0.29	0.48			

* The temperature data for Jan-Feb. are taken from those for 1986.

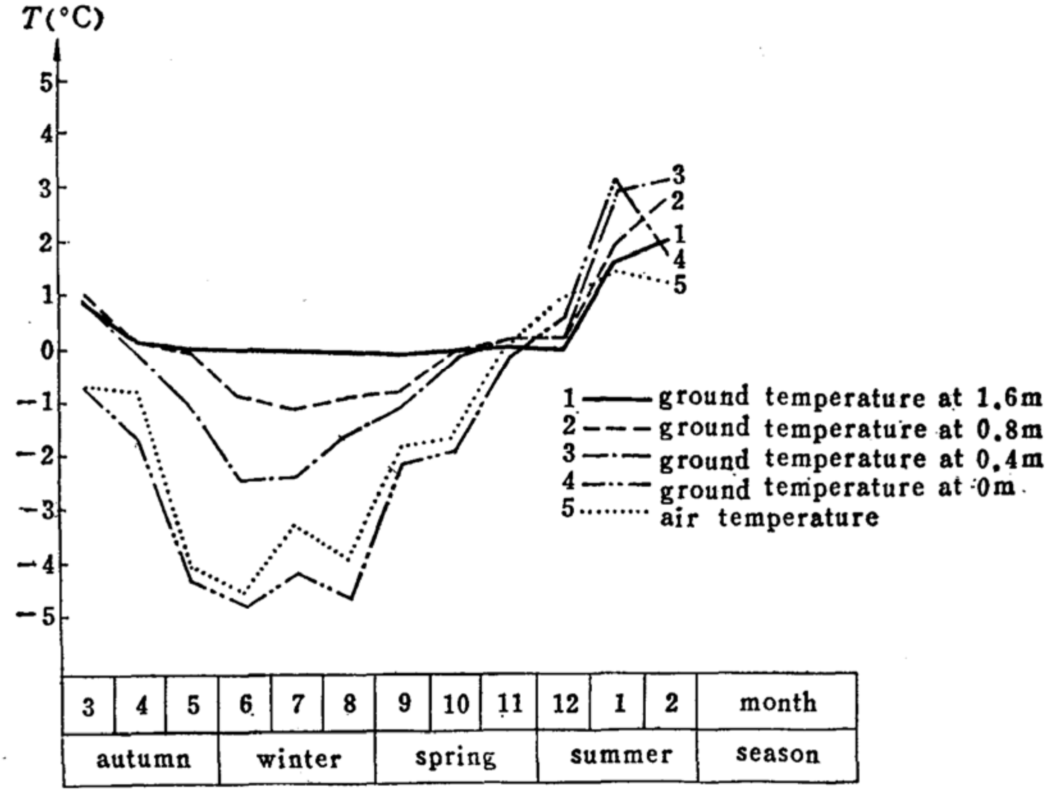

Fig. 3 Curve of monthly average ground temperature variation in Great Wall Station.

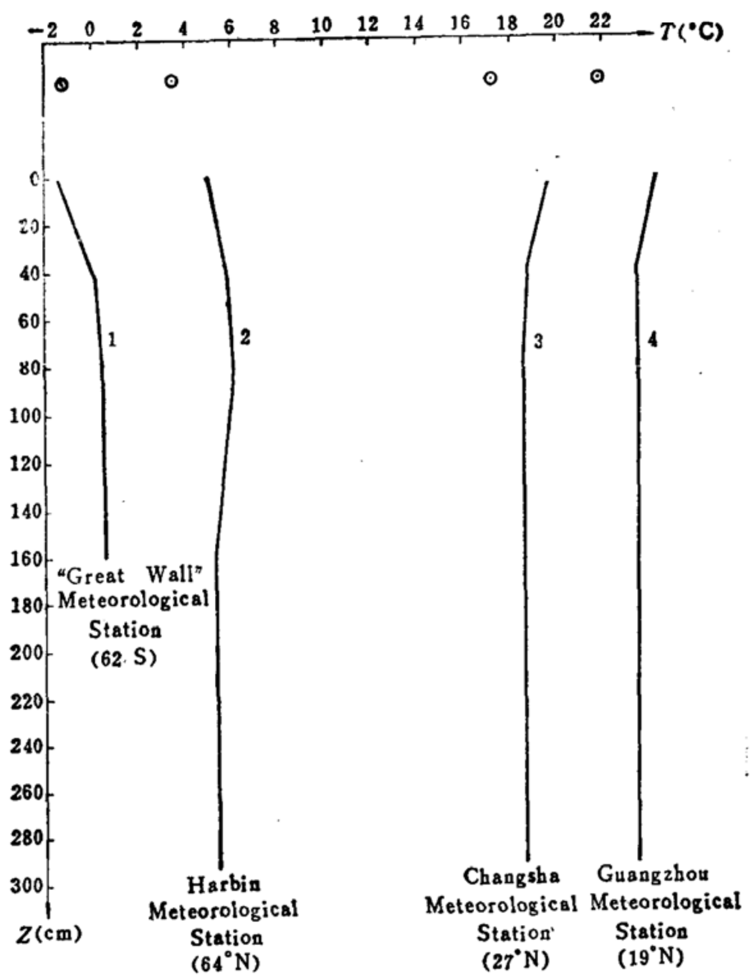

Fig. 4 Variation curves of the average air temperature (0 m) and ground temperature with depths in four meteorological stations at different latitudes.

Fig. 2 gives rough distribution features of the ground temperatures on Fildes Peninsula. Based on the ground surface isotherms the area can be divided into four regions: <0°C, 0—2°C, 2—4°C and >4°C regions. The following is a brief description for each of the regions.

Table 2. Data on annual average temperature on meteorological stations at different latitudes in 1985.

Meteorological stations	Latitudes	Air temperature	The ground surface temperature (°C)				
			0 m	0.4 m	0.8 m	1.6 m	3.0 m
Guangzhou Station	19° N	21.62	24.22	23.28	23.33	23.32	23.41
Changsha Station	27° N	16.93	19.54	18.53	18.39	18.52	18.53
Harbin Station	46° N	3.29	4.79	5.58	5.97	5.09	5.33
Great Wall Station	62° S	—1.37	—1.51	0.00	0.29	0.48	

a. Region with $T<0°C$. It is distributed in a scattered way, except for the northwestern corner of the peninsula where the Collins Glacier is located with annual temperature lower than 0°C;

b. Region with $T=0—2°C$. Its location basically coincides with the distribution of Paleocene lavas of Jasper Hill and Agate Beach groups;

c. Region with $T=2—4°C$. This region with relatively high ground temperature is distributed there where stocks and dykes widely developed, such as FLAT TOP pen, HORATIO Stump, BLOCK HILL, Shanhaiguan and Ardley Island etc; whereas dykes are generally concentrated near the ancient volcano eruption centers, intrusive bodies and fault zones.

d. Region with $T>4°C$. The distribution of the region with highest in the peninsula ground temperature coincides with distribution of the youngest (Eocene, Oligocene) volcanic breccia intercalated with lavas in the northern part, northern beach of Ardly Strait and southern corner of the peninsula with widespreadly developed hydrothermal veins. All this indicates that the ground temperature is closely related with the contemporaneous volcanism and accompanying strong hydrothermal activities.

As a summarization it can be pointed out that the distributive features of ground temperature is closely connected with the distribution of stocks, dykes and fault belts, especially with the paleo- and neo-volcanic activities.

4. Rock Thermophysical Properties

Rock thermophysical properties (thermal conductivity, heat capacity and thermal diffusivity) are important parameters for study of thermal structure of the crust and the deep thermal status of the earth.

Most of exposed rocks on the Fildes Peninsula are composed of Tertiary basalts and basalt-andesitic lavas, volcano-clastic rocks and volcano-clastic sedimentary rocks. This volcanic rock suite is characterized with properties of Island-arc type (Liu Xiaohan *et al.*, 1988).

Limited by the sample size (hand specimen), the HY–1 Model Transient Thermal Conductivity Meter of Ring Heat Source Probe Type (Yang Shuzhen *et al.*, 1987) was used for K determination.

Thermal conductivity determination on 121 different type rock samples in total was conducted. Among them there are 90 lava samples, 27 subvolcanic rocks and 4 volcano-clastic sedimentary rocks. All experimental results are shown in Tab. 3 and Fig. 5. Thermal conductivity of calcitized (I–2) and altered basalt (I–3) is relatively high (for example, 2.37 W/mK and 2.68 W/m•K for samples No. 102 and No. AD–11 respectively). Rock thermal conductivity tends to increase with depth, because at shallow depth rocks are usually loose and porous. As go to a greater depth, they becomes denser and harder.

A comparison of the average thermal conductivity of Tertiary basalts from this peninsula with that for basalt of same age from the upper crust of North China shows that the K value for the former one (1.76 W/m•K) is about 28 percent higher than that for the latter one (1.32 W/m•K). It is mainly due to filling of the pores by calcite and siliceous material and alteration of most basalts on the peninsula. This may imply that the strong hydrothermal circulation might have taken place during paleovolcanic activities. At the same time, it also indicates that the ocean-island basalts are slightly different from the continental basalts in their thermal

Table 3. Mean values of thermal conductivity of volcanic rocks from Fildes Peninsula (W/m K).

Types	Groups	Number	Rock type	Number of samples		$\frac{n}{N}\times 100$ %	Mean thermal conductivity K	Extreme thermal conductivity	
				n	N			K(max)	K(min)
Tuff	I	1	Basalt	27	90	30.10	1.660±0.20	2.164	1.353
		2	Calcitized basalt	4		4.44	2.237±0.19	2.373	1.715
		3	Altered Basalt	4		4.44	2.607±0.10	2.677	1.615
	II	4	Basaltic andesite	22		24.44	1.700±0.15	2.017	1.473
		5	Chloritized basaltic andesite	3		3.33	1.818±0.18	2.026	1.676
		6	Calcitized basaltic andesite	5		5.56	1.919±0.22	2.138	1.612
		7	Altered basaltic andesite	4		4.88	2.083±0.17	2.195	1.853
	III	8	Tuffolava	3		3.33	1.632±0.21	1.849	1.434
		9	Basaltic breccia lava	9		10.00	1.651±0.58	2.600	1.031
		10	Basaltic anglomerate lava	2		2.22	1.814	1.890	1.814
		11	Tuffaceous breccia lava	3		3.33	1.902±0.35	2.160	1.508
		12	Basaltic tuffolava	4		4.44	2.109±0.65	2.693	1.510
Subvolcanic rocks	IV	13	Basaltic glass	1	27	3.70	0.883		
	V	14	Diabase	4		14.82	1.652±0.16	1.984	
		15	Gabbro-diabase	3		11.11	1.720±1.04	1.767	1.537
	VI	16	Trachybasalt	4		14.82	1.760±0.08	2.399	1.688
	VII	17	Basaltic porphyrite	4		14.82	1.473	2.269	1.705
		18	Altered pyroxenite	2		7.71	1.804±0.32	2.029	1.473
	VIII	19	Gabbro	1		3.70	1.594		1.579
		20	Altered gabbro	1		3.70	2.008		
	IX	21	Andesitic porphyrite	3		15.11	1.669	2.136	1.669
		22	Basalt-andesitic-porphyrite	2		7.71	1.728±0.02	1.745	1.711
		23	Altered course-grain porphyr	2		7.71	2.058	2.058	1.790
Volcanoclastic sedimentary rocks	X	24	Tuffaceous sandstone	4	4	100	1.435±0.20	1.571	1.270

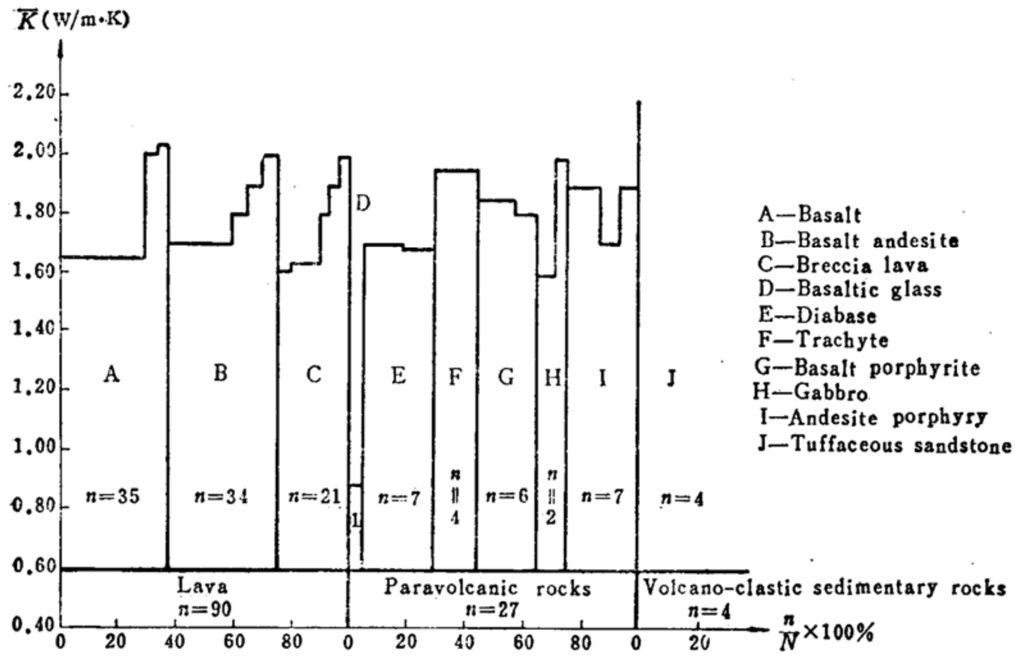

Fig. 5 Statistical distribution of the average thermal conductivities for different rock types.

conductive capacities.

It can be seen from Fig. 5 that there is no prominent difference in average thermal conductivities of lavas and paravolcanic rocks. They are 1.78 ± 0.31 W/m·K and 1.69 ± 0.14 W/mK, respectively. The average thermal conductivity for volcanoclastic sedimentary rocks is 1.44 W/m·K. It seems rather low. All these three types of rocks possess intermediate thermoconductance capacity.

It is worthwhile to have a closer look at the thermo-conductance characteristics of basaltic rocks. The average thermal conductivity K of 27 rock samples equals 1.76±0.20 W/mK ranging from 1.36 W/m·K to 2.68 W/m·K. Most seemingly, the variation of thermal conductivity of basalts is closely related to the existence of bubbles produced during eruptions, filling material in the pores and its positions (upper, middle and lower filling). The thermal conductivity of basalt with bubbles is relatively low (for example, 1.44 W/m·K and 1.37 W/m·K for samples No. 1804 and No. 1806, respectively); meanwhile thermal conductivity of altered and calcitized basalt is higher.

5. Preliminary Results and Discussion

Based on the ground surface temperature data and the analysis of the thermal conductivity determined, the following preliminary results for the geotemperature and the thermophysical properties on the Fildes Peninsula can be derived:

(1) Most part of Fildes Peninsula is an ice- and snow-molten land area during Antarctic summer. The localities with ground temperature below 0°C are scattered around. The predominant ground temperature ranges from 0°C to 2°C.

(2) The localities with elevated temperature between 2 and 4°C are distributed near fault

zones and in dyke swamp zones.

(3) The localities with the highest in the peninsula ground temperature above 4°C are totally coincident with the area of youngest (Eocene and Oligocene) volcanic breccia and lava of crateric phase where hydrothermal veins are widespreadly developed.

(4) The average annual ground surface temperature in the Fildes Peninsula is lower than the average annual air temperature. This may be attributable to the cooling effect due to the thick permanent ice sheet covering the Antarctic Land.

(5) The average thermal conductivity of the Tertiary basalts on the peninsula (1.66 ± 0.20 W/m•K) is about 25 percent higher than that of the contemporaneous basalts in North China (1.32 ± 0.15 w/m•K). This may be due to pore precipitation of silica and calcite and alteration in the Fildes Peninsula's basalts. It means, on the one hand, that during the paleovolcanic processes the strong hydrothermal activities took place on the Peninsula and, on the other hand, the thermophysical properties of basalts of oceanic and continental types are quite different.

(6) The Tertiary volcanic rocks widely spread over the peninsula belong to rocks of medium thermal conductivity with a mean value of 1.69—1.78 W/m•K.

(7) Further investigations are still needed to reply the following questions: Are the high temperature observed in the southern margin of the peninsula indicative for the nearby fault activity ? Is the faulting connected with the stretching of the Blancefildes Rift since Pleistocene, or is it related to the recent volcanic activities on the islands around ?

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