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CRUSTAL TEMPERATURE AND GEOTHERMAL SYSTEMS IN THE NORTHEASTERN PART OF CHINA

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ABSTRACT

Cenozoic basaltic rocks are distributed widely in the northeastern part of China. However, active geothermal systems are very rare except that of Changbaishan volcano at the border of China and North Korea where high temperature hot spring activities exist. In this paper, we firstly clarified the crust and upper mantle temperature based on the heat flow data. As a result, it is shown that the crustal temperature is not high enough to generate basaltic magma in the crust. The basaltic magmas generate only in the upper mantle. This is the reason why the geothermal systems generally do not develop in the Cenozoic basaltic region of the northeastern part of China. The reconnaissance geophysical and geochemical surveys were conducted around the hot spring activities at the flank of Changbaishan volcano. As a result, a preliminary conceptual thermal model with supply of magmatic fluid is constructed. The hot spring activities at Changbaishan volcano may relate to another type of magmatic activity (silicic trachyte magma) in the Quaternary.

1. INTRODUCTION

Cenozoic basaltic rocks are distributed widely in the northeastern part of China (Fig.1). Generally, basaltic magma rises quickly to the surface and has its heat dissipated due to cooling of the volcanic products, whereas silicic magma, due to its higher viscosity, is likely to lodge in the upper crust and thus act as a heat source of substantial duration (Rybach,1981). As expected, geothermal systems are also very rare in the Cenozoic basaltic region of the northeastern part of China. However, there is an active hot spring field on Changbaishan volcano at the border of China and North Korea. The high temperature (about 80°C) hot spring activities at the northern flank of Changbaishan volcano show the relatively higher heat discharge rate as about 20MW. The heat source of such active hot spring activities is very interesting for the study of geothermal systems in basaltic volcanism. We conducted reconnaissance geophysical and geochemical surveys and presented a preliminary conceptual thermal model with supply of magmatic fluid discharged from recent shallow silicic (trachyte) magma (Liu,1996).

2. HEAT FLOW AND THE CRUST-UPPER MANTLE TEMPERATURE IN THE NORTHEASTERN PART OF CHINA

Recently the heat flow distribution in the northeastern part of China was clarified (Jin et al.,1997). Although there is no heat flow stations near Changbaishan volcano, we can roughly estimate the heat flow value around Changbaishan volcano from the heat flow map. As a result, it is estimated at about 50 mW/m^2, that is, the heat flow is normal to slightly low. The crustal temperatures along the east-west cross section of the northeastern part of China (A-A' in Fig.1) calculated assuming two-dimensional steady state heat conduction show about 600 to 800°C near the Moho discontinuity (about 30 to 40km deep, Fig.2). Generally, it means that there is no possibility to generate basaltic melt in the crust around Changbaishan volcano. We estimated further the one–dimensional steady state mantle temperature based on the above two-dimensional steady state temperature. As a result, it is shown that basaltic melt generates in the depth deeper than 150 km, which means that generally it is very difficult to develop active geothermal systems around Changbaishan volcano.

3. AN ACTIVE GEOTHERMAL SYSTEM ON CHANGBAISHAN VOLCANO

There are several hot spring activities around Changbaishan volcano. Most of them are low temperature hot springs. The most active hot spring activity around Changbaishan volcano, which is called Changbai hot springs, is at the northern flank of the volcano (Fig.3). There are many hot water discharges along the river which is flowed out of the crater lake (called Tianchi) at an elevation of about 2200m. The maximum temperature exceeds 80°C and the total flow rate is about 6500 t/day (75 kg/sec) with the mean temperature of 60°C. Therefore the heat discharge rate from the hot springs water is estimated at about 20 MW as a reference temperature of 0°C. The hot spring activities are limited to the narrow area at an elevation of about 1850m.

3.1 Geophysical and Geochemical Reconnaissance Surveys

1m depth ground temperature measurements were conducted along the two mountain roads from an elevation of about 1500m to 2600m (Fig.4). The temperature profile versus elevation is shown in Fig.5. The clear high temperature anomalies (III) are limited near the hot springs at an elevation of about 1850m. Slightly high temperature anomalies (II) are observed near the crater lake and also at the lower elevation side of the hot springs (IV and V). These temperature anomalies reflect the shallow geothermal fluid flow. We also estimated the conductive heat discharge rate (about 3MW) based on the shallow geothermal gradients between 10cm and 20cm deep and the assumed ordinary soil thermal conductivity of 1 W/mK.

Surface temperatures are estimated based on the infrared imagery. Anomalous surface temperatures are observed only around hot springs. The heat discharge rate from the hot ground surface is estimated at about 4.5MW based on the heat balance method (Sekioka and Yuhara, 1974). The value is very similar to that estimated by the near surface ground temperature measurements in the above. Therefore the total heat discharge rate from the hot spring field is about 20 to 25 MW.

The geochemical surveys which include analyses of hot spring waters and gasses, and soil gasses were also conducted along the mountain roads and near hot springs. The anomalous concentrations in soil gasses (CO_2, Hg and Rn) are also detected near the hot springs, near the crater lake and at the lower elevation side of the hot springs, which show the similar distribution pattern as obtained in the 1m depth ground temperature measurements. The chemical equilibrium temperatures were estimated at about 160°C based on the Na-K-Ca geochemical thermometer. Most of the discharged water are of meteoric origin from the stable isotopic analyses. The origin of hot spring gasses are of meteoric or crustal origin from the relation of He, Ar and N_2 as shown in Fig.6.

AMT and Self Potential (SP) surveys were also conducted along the two mountain roads and near hot springs. The AMT surveys show low resistivity (3 to 30 ohm-m) in the shallower part (a few hundreds meter) near hot springs (Fig.7, near the observation points 8 and 9). The SP surveys show positive anomalies near the hot springs. These reflect the existence of geothermal fluids in the shallower depth as a few hundreds meters. However, there is no low resistivity zones in the deeper part (down to about 1.5km deep), which may be related to a heat source.

3.2 Conceptual Model

The followings summarizes the geophysical and geochemical data obtained by this study.

(1). The main hot water discharge area is confined to a narrow zone at an elevation of about 1850m. The lower elevation side of the hot spring field is slightly affected by the shallow underground geothermal fluid flow. The small amount of geothermal fluids are also discharged near the crater lake which is in the central part of the volcano.

(2). The total heat discharge rate from the hot spring field is about 20 to 25MW. The maximum temperature of the discharged water is about 80°C. The estimated chemical equilibrium temperature of the underground reservoir fluid is about 160°C.

(3). There is a zone with a shallow low- resistivity and a positive SP anomaly near the hot spring field which may show the existence of geothermal fluid.

We can include the following important data from the previous studies in order to construct a conceptual thermal model.

(1). The gasses discharged from hot spring water contain those originated from mantle with those from the crust (Shangguan et al.,1996).

(2). Most of the waters discharged at the Chanbai hot spring field are of meteoric origin from the stable isotopic study (Shangguan et al.,1996).

(3). There are many fracture systems on Changbaishan volcano which dominate in the direction of north-south and northeast to southwest. There is another type of fracture system which dominates in the direction of northwest to southeast near the hot spring field. Hot spring discharge points are aligned with this direction (Jin and Zhou,1994).

(4). A trachyte magma chamber is suggested at a relatively shallow depth of 7 to 8 km, compared to typical basaltic magma chambers in the upper mantle. The temperature of the magma in the shallow crust is estimated at 855 to 1075°C from the petrological study (Jin and Zhou,1994).

Summarizing the data obtained from this study and from the previous studies, we propose a following preliminary conceptual thermal model. This model has a magma reservoir in the shallow crust (about 7 to 8 km deep). Magmatic fluids are discharged from the magma reservoir. The discharged magmatic fluids mix with the downgoing meteoric water between the magma chamber and the surface (the depth is assumed to be about 2km in this study). We have a geothermal reservoir with a temperature of about 160°C. Geothermal fluids in the reservoir are discharged towards the surface. The uprising geothermal fluids mix again with the shallower ground water. However, a small part of the reservoir fluids rises upwards and they are discharged in and near the crater lake.

Based on the above concept, the following flow rate in each process is estimated as shown in Fig. 8. If we assume the heat supplied from the magma is the same as the heat discharged at the surface, we can estimate the flow rate of the magmatic fluid. The estimated flow rate of the magmatic fluid is about 5kg/s, assuming that the temperature and pressure of the discharging magmatic fluid are 800°C and 700bar, respectively. The uprising magmatic water mixes with the cold meteoric water in the reservoir. The enthalpy of the reservoir fluid is estimated from the equlibrium temperature and reservoir depth (pressure). If we assume that the heat discharged from the reservoir is the same as the heat discharged from the hot spring field, we can estimate the flow rate discharged from the reservoir. The discharge rate is estimated at about 30kg/s. The discharge rate of water at the surface is estimated at 75kg/s. Then another 45kg/s of the shallower ground water mixes with the geothermal fluid discharged from the reservoir.

In this model the estimated ratio of the magmatic water to the total discharged water is only 6 to 7 %. This result does not contradict with the geochemical observation which shows that the most of the discharged water is of meteoric origin but a small amount of gas originated from the mantle is included. The estimated values in the above are not definite. However we can imagine the underground geothermal system beneath Changbaishan volcano semi-quantitatively. The model shows a possibility of existence of an intermediate temperature geothermal reservoir. If we have caught only small part of the underground fluid flow as hot springs at the surface, then we may detect additional geothermal resources beneath Changbaishan volcano by surveying the much wider and deeper region.

This study shows the existence of an active hydrothermal system beneath a large basaltic polygenetic volcano. As pointed earlier, generally basaltic magma rises more quickly to the surface and has its heat dissipated in cooling of volcanic products, whereas silicic magma, due to its higher viscosity, is likely to lodge in the upper crust and thus act as a heat source of substantial duration (Rybach,1981). The magmatic hydrothermal system clarified in this study may relate to not ordinary basaltic magma but silicic (trachyte) magma. The main volcanic rocks of the volcano are typical olivine basalt.

However, different types of volcanic activity occurred in Quaternary and recently. This may be a reason why an active hydrothermal system develops at Changbaishan volcano.

4. CONCLUSIONS

We conducted reconnaissance geophysical and geochemical surveys on Changbaishan volcano in the northeastern part of China. Based on the data obtained in this study and the previous studies, a preliminary conceptual thermal model was presented as follows: The magmatic water (about 5kg/s) mixes with the meteoric water and forms a geothermal reservoir at a few km depth. The reservoir temperature is about 160°C. The heat and water discharge rates at the surface are about 20MW and about 75kg/s, respectively , and the maximum temperature of the hot spring water is 80°C. This is an example of small magmatic hydrothermal system related to the Quaternary silicic magma, although the main rock type of the volcano is basaltic. The reconnaissance survey is confined to the narrow and shallow areas. Therefore there is a possibility to detect larger geothermal resources by extending geological, geophysical and geochemical surveys.

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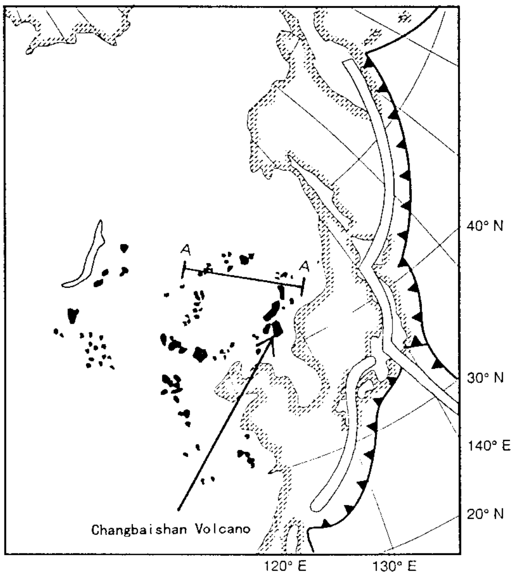

Figure 1. Cenozoic basaltic rocks(black) in the northeastern part of China and Changbaishan volcano (modified from Tatsumi,1995)

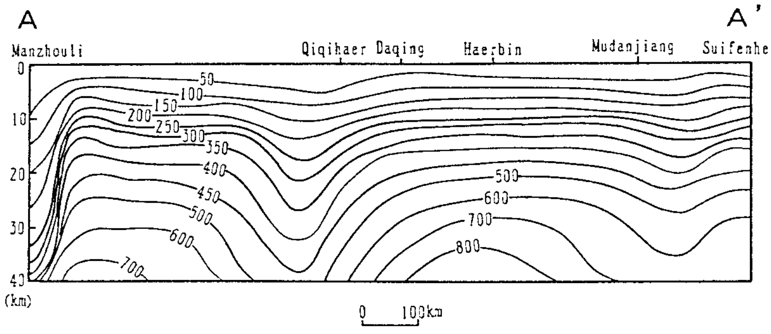

Figure 2. Crustal temperature distribution(degree C) along the line A-A' in Fig.1(Jin et al.,1997)

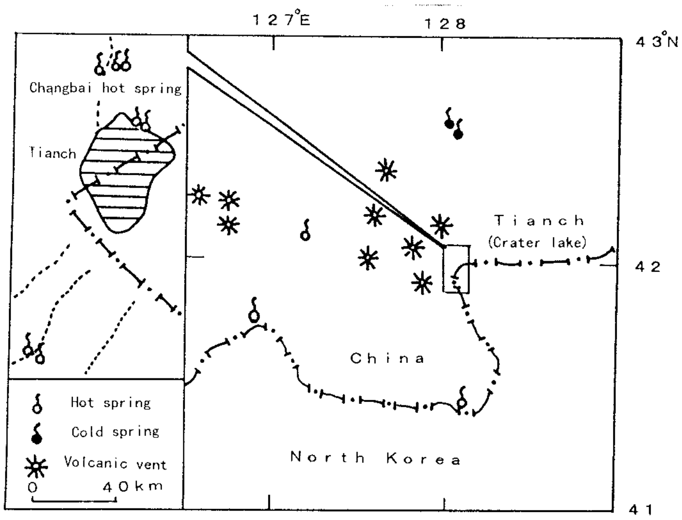

Figure 3. Distributions of hot springs around Changbaishan volcano (modified from Shangguan et al.,1996)

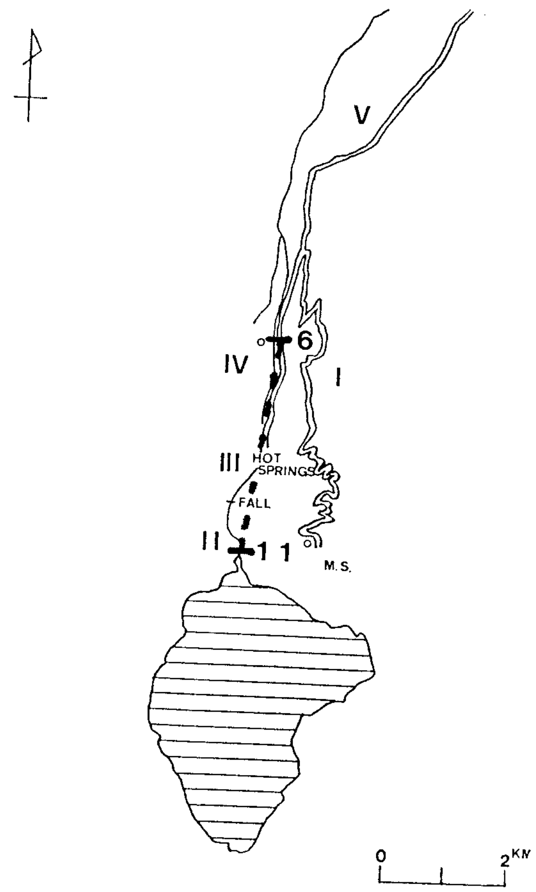

Figure 4. Location map of the geophysical and geochemical measurements. The shaded part shows the location of the Crater lake(called Tianchi). The hot springs are near III.The broken line shows the measurement line by AMT survey(from No.6 to 11).M.S. shows the location of the local meteorological station.

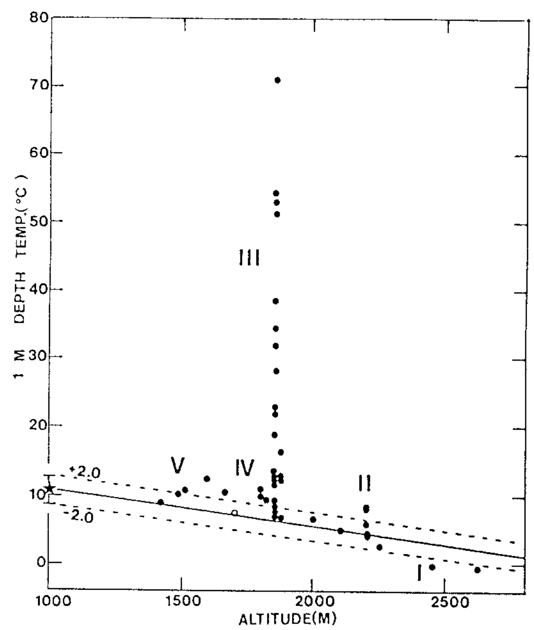

Figure 5. 1m depth temperature versus elevation at the flank of Changbaishan volcano

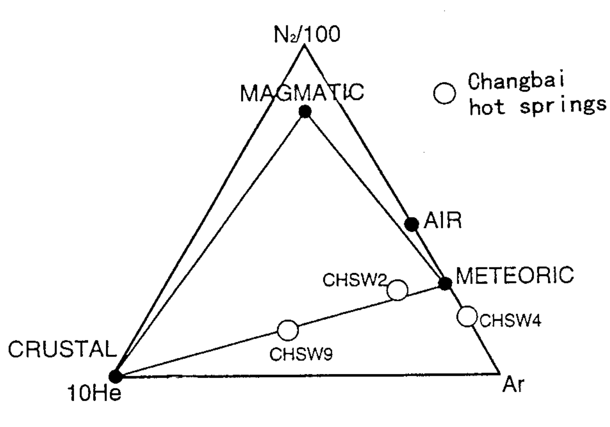

Figure 6. Origin of hot spring gasses from the relation of He, Ar and N_2.

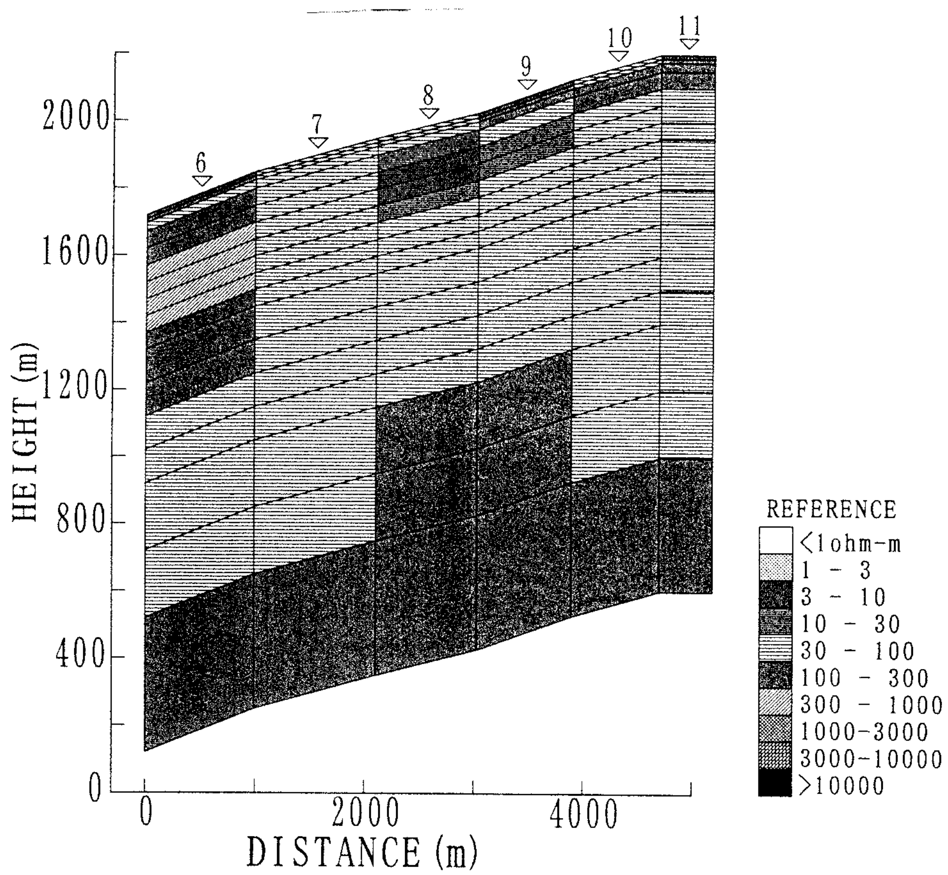

Figure 7. Two-dimensional resistivity structure across the hot spring area at the flank of Changbaishan volcano

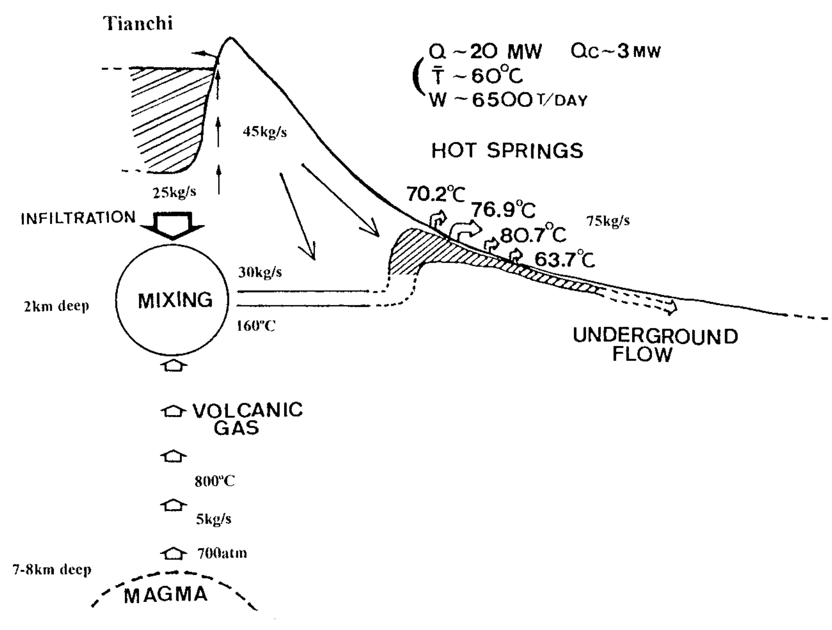

Figure 8. A conceptual thermal model beneath the hot spring area at the flank of Changbaishan volcano