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Hot-Dry-Rock Resource Investigation in Changbai Mountain, China

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ABSTRACT

Changbai mountain is located in Jilin province, Northeast China. This is an active volcano and the most recent volcanic eruption happened in the 13th century. But the most powerful eruption happened in the year 1024 AD. This eruption is considered to be one of most powerful two volcanic eruptions in the last 2000 years in the world. Between 2002-2006, some volcanic tremor events were recorded by the monitoring system.

Geothermal resource is abundant in Changbai mountain. Surveys revealed that there are more than 200 hot springs distributed in this area. Water temperature has reached 87ºC. The beautiful geothermal landscapes attract plenty of visitors every year. On the west side of Changbai mountain, six geothermal wells have been drilled. During more than 10 years of production, all springs disappeared in this area. On the north side of the mountain, where there are more hot springs and higher water temperature, there is no geothermal well because of protective measures. So the geothermal landscape is still wonderful.

In order to make efficient use of geothermal resources, and protect the geothermal landscape of Changbai mountain, a project of Hot-Dry-Rock investigation has been started recently. Since 2012, several kinds of geophysical prospecting methods have been used in this area to research the geothermal resource. Some information indicated that there are two magma chambers located at the north side of Tianchi Crater of Changbai mountain. The smaller magma chamber is about 5～7 kilometres deep, and the bigger one is about 15～20 kilometres deep from the surface. These show good prospecting potential for Enhanced Geothermal Systems.

1. INTRODUCTION

The Changbai Mountain is located in the east of Northeast China. The area is about 1300 kilometres long from north to south, and about 400 kilometres wide. In this area, forest vegetation coverage is high, and ecological environment is very good. This area is also the source of three important rivers in northeast China-Songhua River, Tumen River and Yalu River.

The Changbai Tianchi Volcano is located in southeast of Jilin province. It is a dormant volcano, and the most recent eruption was in 1702. The volcanic cone gathered water, and formed a landscape famous in China – the Changbai Tianchi Volcanic Lake. The volcanic lake is 2189.1 meters high, 4400 meters from north to south, and 3370 meters east to west. The water surface area is 9.82 km^2. The average depth of the lake is about 204 meters, and the deepest is about 373 meters. The total storage capacity is about 2 billion cubic meters.

Around the Changbai Tianchi Volcano, there are more than 200 hot springs. Most of them are located at the north side of Tianchi Volcano. Fewer are located at west and south side (east side is Korea, DPR). The highest hot spring temperature is 87ºC.

2. THE GEOLOGIC FEATURE OF CHANGBAI TIANCHI VOLCANO

2.1 Volcanic activity of Changbai Tianchi Volcano

There have been about 50 volcanic events since the late Cenozoic era. Especially since the Holocene, the volcanic activity was more Intense. 10 volcanic eruptions occurred during this period. The most powerful volcanic eruption occurred during the year 1199-1201. It is called by many scientists “the biggest volcanic eruption during the past 2000 years”. This volcanic activity formed a grand canyon on the north side of the Changbai Tianchi Volcano, and also, the volcanic lake. The hot springs are considered to be controlled by this volcanic activity. Volcanic ash from this volcano eruption was found in Hokkaido, Japan by scientists. The ash was several centimeters thick.

The most recent eruption of Changbai Tianchi Volcano occurred in the year 1702. According to earthquake monitoring data, the frequency and intensity of earthquake activity increased in 2002-2003, but decreased in 2004-2006, And returned to normal after 2006.

2.2 Formation of Changbai Tianchi Volcano

There are several different views on the formation of the Changbai Tianchi Volcano. The current mainstream view is that the Pacific plate subducts from west to east, this causes mantle upwelling along structural weaknesses and formed a mantle plume (magmatic column) beneath the volcano.

The seismic tomography profile of Siping- Changbai Volcano-Japan (Figure 1) shows there are two anomalous geological bodies in this area. One low-temperature high-speed body tilts from the Japan Trench to the west, and another high-temperature low-speed body extends to the deep below the Changbai Tianchi Volcano (Shao Ji 'an et al., 2001).

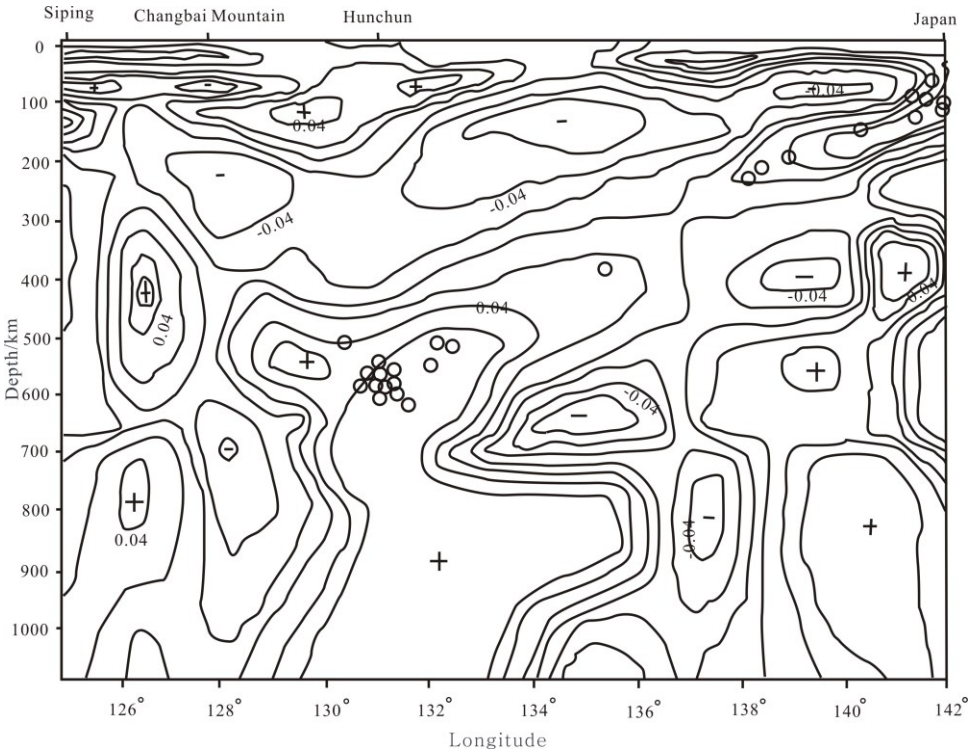

Figure 2: Seismic tomography profile of Siping- Tianchi Volcano-Japan

On the basis of analyzing previous data, Wei Haiquan (2007) studied the magmatic column of Changbai Volcano, and simulated its rising process (Figure 2). The magmatic column is a magma aggregate arranged in layers, which extends down about 1000 kilometers. Vertically, the column can be divided into crust, upper mantle and lower mantle – three segments. Several high-temperature low-speed bodies exist in the crust. This study shows that there is a large and deep high temperature column under the Changbai Volcano. Some high temperature cystic bodies are buried in the shallow part (about 5-10 km depth). These may be the shallow magma chambers or hot dry rock bodies of Changbai Volcano.

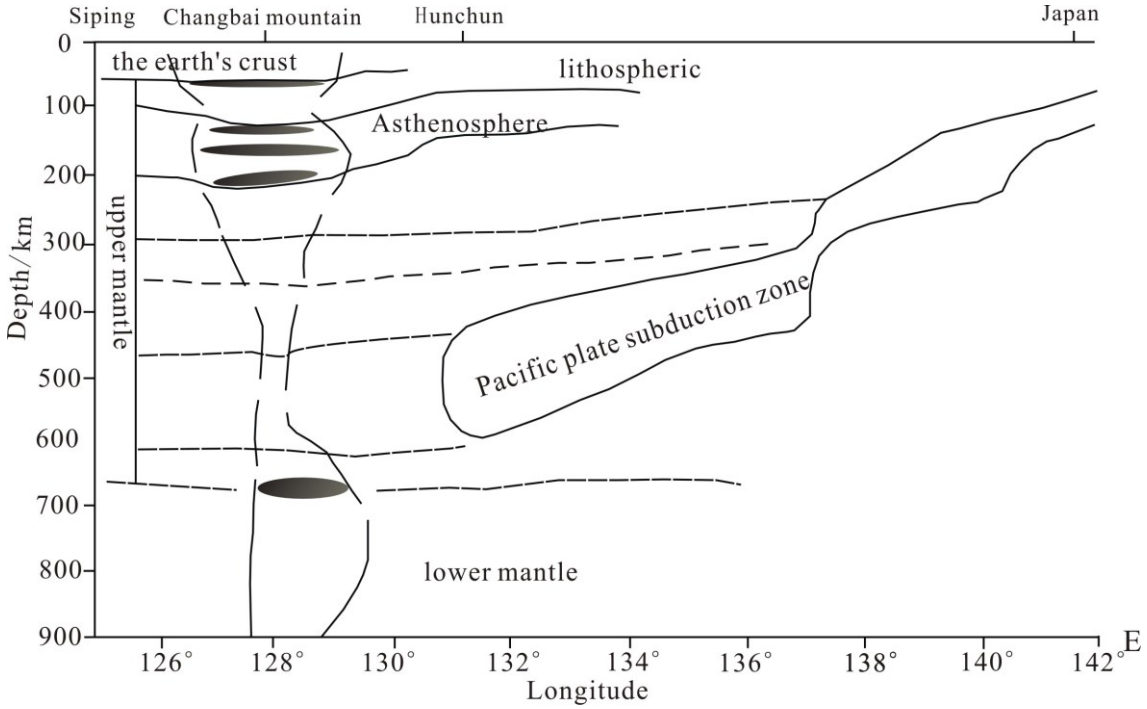

Figure 2: Schematic diagram of magma column structure of Changbai Volcano

3. HOT SPRINGS AROUND THE CHANGBAI TIANCHI VOLCANO

Frequent volcanic activity and high temperature cystic bodies in the shallow part of crust provide an abundant source of heat for this area. Plenty of hot springs formed around the volcano. Here is a brief introduction to the hot springs in the north, west and south of the Changbai Tianchi Volcano.

3.1 North side-Tianchi hot spring

Tianchi hot spring is located on the north slope of Changbai Tianchi Volcano. It consists of three adjacent hot spring groups. There are about 180 hot springs altogether. Water temperature is 30-87ºC. Tianchi hot spring is located in the central scenic area of Changbai Tianchi Volcano. The geothermal landscape attracts a large number of tourists every day, and some tourists like to cook eggs with the hot water (Figure 3 and Figure4).

Figure 3: Hot spring landscape

Figure4: Cooking eggs

To protect the ecological environment, there is no borehole in this area. Some hot water is collected and transported down the mountain by pipeline.

3.2 West side-Jinjiang hot spring and Xianrenqiao hot spring

Jinjiang hot spring is located on the west slope of Changbai Tianchi Volcano. There are 15 hot springs altogether, which are exposed on both sides of the riverbed of the upper Jinjiang river. The highest water temperature is about 60ºC. In this area, there is also no borehole. Hot water is collected and transported down the mountain just as is in Tianchi hot spring.

Xianrenqiao hot spring is about 30 kilometers to the west slope of Changbai Tianchi Volcano. There are 7 hot springs emerged from the area in the early stages. The highest water temperature is about 55ºC. By the year 2000, 6 geothermal wells have been drilled. The depth of the wells between 31-100 meters. The highest well temperature is 57^{o} C, and total production of the 6 wells is 2200 m^3/d. As the wells continued to pump, all the springs disappeared.

3.3 South side-Shibadaogou hot spring

Shibadaogou hot spring is about 40 kilometers to the south slope of Changbai Tianchi Volcano. There are 3 hot springs in this area, and the water temperature is about 39^{o} C. The water flow is 132m^3/d, and hot water is used here for bathing and convalescence.

4. INVESTIGATION AND PRELIMINARY RESULTS OF HOT-DRY-ROCK RESOURCE

4.1 Geophysical survey in Changbai Tianchi Volcano

Geophysical surveys in Changbai Tianchi Volcano have been done many times in many years. The results have some difference, but not by much. Only the most recent geophysical survey and results are cited here for analysis. Geophysical survey was carried out from 2012 to 2014, using magnetotelluric survey by the Institute of Geophysical and Geochemical Exploration of China Geological Survey. From June to October 2012, a total of 42 points and 103 kilometers of magnetotelluric survey were arranged. The survey line from south to north crosses Tianchi Crater. According to the results of two-dimensional inversion, it is found that the low-resistivity anomalous body at the northern end of the survey line has an upward trend. In October 2014, 9 magnetotelluric measuring points were added to the northern end of the original survey line. So the total survey line consists of 51 measuring points, 127 kilometers long (Figure 5).

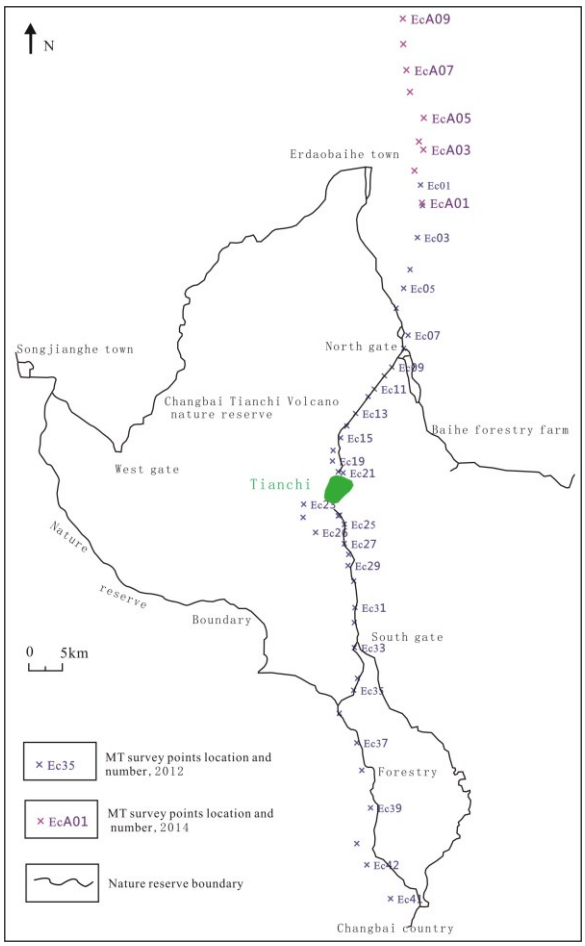

Figure 5: Arrangement of magnetotelluric survey points in Changbai Tianchi Volcano

4.2 Analysis of geophysical survey result

The geophysical survey result shows that there are two possible magma chambers on the north slope of Changbai Tianchi Volcano. One is in the north of Tianchi crater. It is shallow (5-7 km) and rather small, and the characteristic of low resistance abnormal body is obvious. It is connected with the magma channel under Tianchi crater and F5, F6. Another magma chamber is about 45 km north of Tianchi crater. The center of chamber is about 25 km deep. It is bigger and connected with 4 fractures-F7, F8, F9 and F10 (Figure 6).

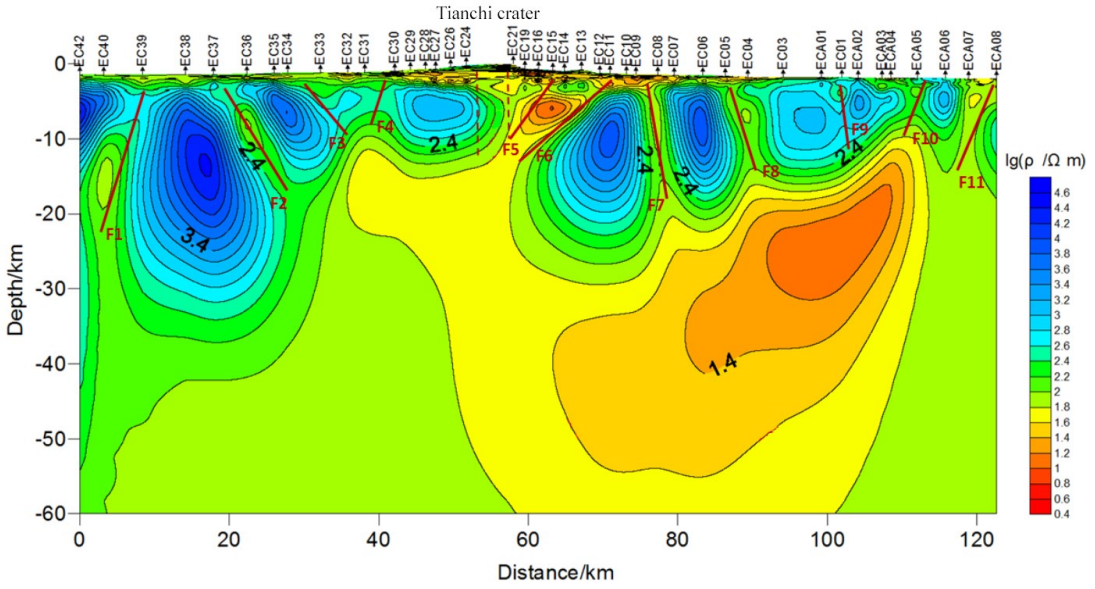

Figure 6: Interpretation results of magnetotelluric survey in Changbai Tianchi Volcano

According to the analysis above, the northern magma chamber of Tianchi crater is relatively shallow, which is the primary choice for the exploration of volcanic hot-dry-rocks. Three suberect low resistance zones (F7, F8, F11) were found. One is near the north gate of the scenic area, and the other two are about 10 and 40 km to the north. The three low resistance zones are directly connected with the low resistance body below. Presumably they are related to magma activities. These are important choices for the exploration of hot-dry-rock resources in Changbai Tianchi Volcano.

5. NEXT TO DO

Good progress has been achieved in geophysical surveys during 2012-2014. The distribution of magma chamber and suberect low resistance zones in Changbai Tianchi Volcano was further understood. But only one line of geophysical survey has been carried out in the north-south direction, and it is difficult to describe the form of the magma chamber accurately. Therefore, it is necessary to carry out further geophysical investigation.

The first is to redeploy another geophysical survey from north to south. The survey line is deployed in the Tianchi crater to the north, across the west side of Erdaobaihe town. The purpose of this work is to verify the geophysical survey work carried out from 2012 to 2014, and hope to find more information (Figure 7).

Then four geophysical lines will be deployed east to west. The purpose is to find out the distribution of the magma chamber in the east-west direction, and make a three-dimensional description of magma chamber buried form. This will provide more accurate basis for dry-hot-rock drilling.

Changbai Tianchi Volcano is a national nature reserve. Any project in this area, including drilling for hot-dry-rocks and later testing and development, must pay attention to the protection of natural resources. So the project site should be located as far as possible outside the nature reserve.

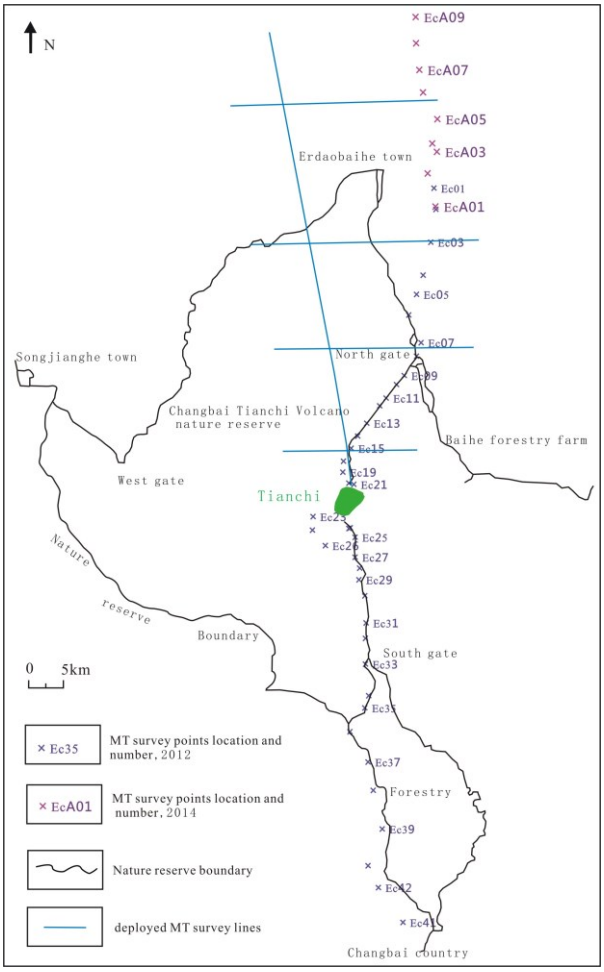

Figure 7: Further magnetotelluric survey line in Changbai Tianchi Volcano

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