NATIONWIDE GEOTHERMAL EXPLORATION SURVEY PROJECT (2ND STEP) WITH SPECIAL REFERENCE TO THE HAKKODA AREA, JAPAN

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ABSTRACT

Geological, gravimetric and CSAMT surveys in the Hakkoda area, northeast Japan, were carried out. The Quaternary composite volcano systems are defined as the Okiura caldera, southern Hakkoda volcano, Hakkoda caldera and northern Hakkoda volcano in historical order. Hot springs are exclusively associated with the oldest Okiura caldera and youngest northern Hakkoda volcano. However, the Shimoyu hot springs with the highest temperature in the area are significantly distant from them. All the methods consistently indicate that the Shimoyu hydrothermal system is developed along a reverse fault zone, and the heat may be ultimately supplied from the northern Hakkoda volcano.

INTRODUCTION

In 1980, the New Energy Development Organization (NEDO) began an assessment of prospective geothermal areas all over Japan, using a newly developed uniform methodology: radar image, gravity and Curie point surveys. This program, called the "Nationwide Geothermal Exploration Survey Project (1st step)," was completed in 1983 and provided a new map showing prospective geothermal fields in Japan. However, because the results mainly depended upon remote sensing techniques, the map is rather hypothetical and additional ground surveys are required to confirm its utility. The "Nationwide Geothermal Exploration Survey Project (2nd step)" has been designed to operate between 1984 and 1986 as a follow-up survey of the 1st step project. In this program, four representative areas were chosen from the prospective areas on the map (Figure 1), and several methods of ground surveys were employed. Here, we shall introduce the outline as well as the preliminary results of this project with special reference to the Hakkoda area, although it is not yet completed.

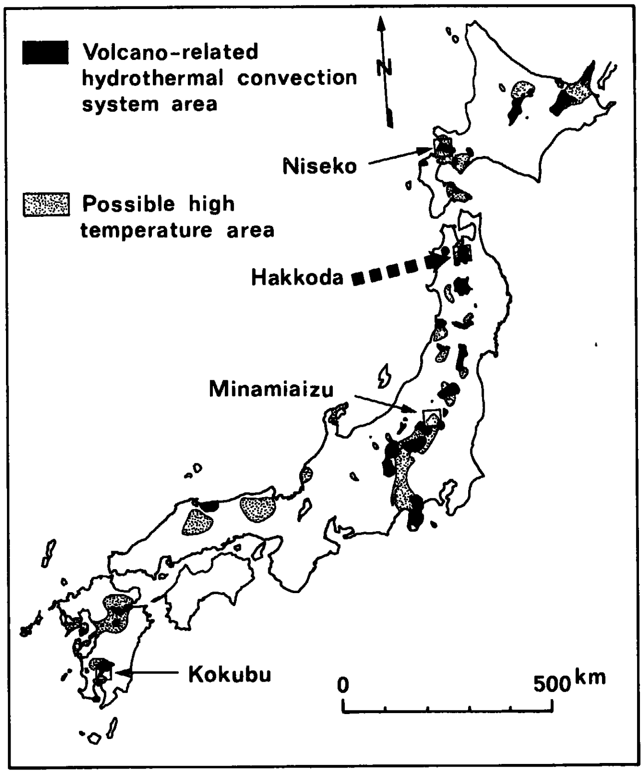

Figure 1. Simplified map of the prospective geothermal fields in Japan and four representative areas in the 2nd step project

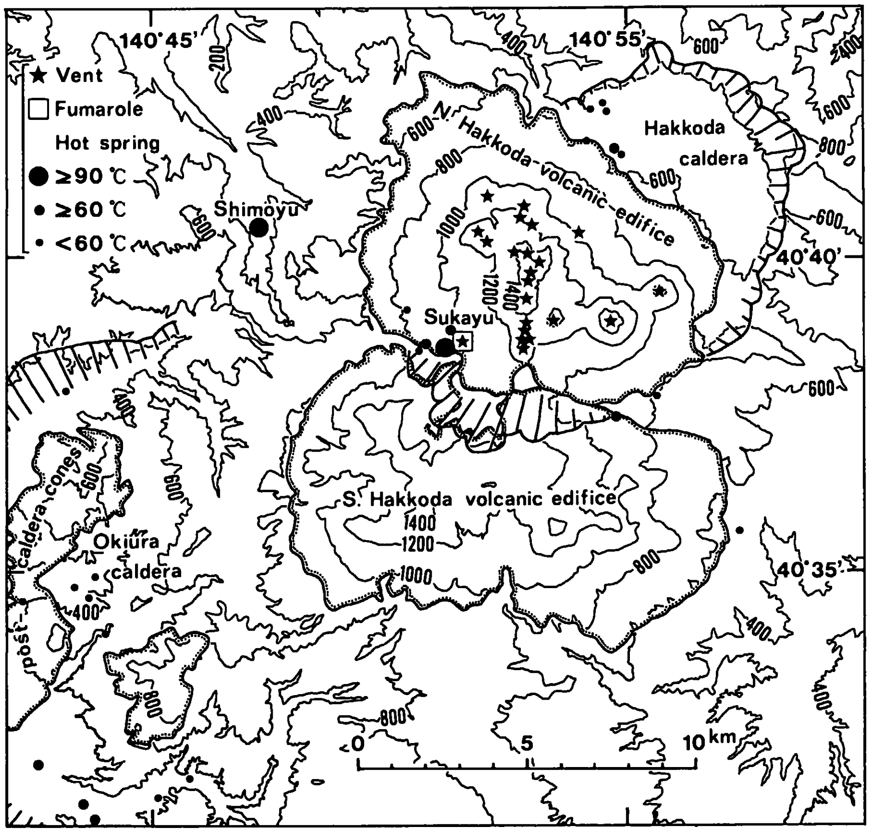

Figure 2.
Map showing the topography, volcanoes and geothermal manifestations of the Hakkoda area. The area is precisely the same as that in Figures 3 through 5.

EXPLORATION GEOLOGY

The Miocene Series in the Hakkoda area has been intensively surveyed with regard to exploration for Kuroko ore deposits, but the Quaternary volcanoes have been less well investigated. Therefore, comprehensive geological and petrological surveys of the Quaternary volcanoes were designed in this program, including a field survey, radioactive datings, and petrological analyses. Preliminary results are summarized here.

Outline of Geology

Figure 2 shows the outline of topography, volcanoes and major geothermal manifestations in the studied area. Figure 3 shows the geologic map partly simplified from results of this survey. It is in the same area as Figure 2. Four composite volcano systems can be identified (in historical order) as the Okiura caldera, southern Hakkoda volcano, Hakkoda caldera and northern Hakkoda volcano. Their basement units consist of the Miocene and Pliocene Series. The Miocene Series contains altered pumice tuff, altered lava (dacite-basalt) and shale, which are collectively called the Green Tuff. The Pliocene Series is composed of the Mitsumori Andesite and Tobe Tuff. They, respectively, are related with pre-caldera and caldera-forming activity of the Pliocene Ikarigaseki caldera in the southwest vicinity of the Okiura caldera (Muraoka, Yamaguchi and Hase, 1983). The Okiura caldera has been discovered recently through Landsat reconnaissance and field surveys (Muraoka and Hase, 1981). The caldera is a semicircular depression of 15 km diameter. Effusives of the Okiura caldera consist of the Aoni Tuff in the caldera-forming stage and the Kenashiyama Dacite in the post-caldera stage. Intracaldera Aoni Tuff is mainly composed of dacitic pumice tuff units derived from the multiple subaqueous pyroclastic flows under a lacustrine environment. The formation age previously had been considered to be Miocene, but Muraoka and Hase (1981) pointed out that it is early Pleistocene from the viewpoints of stratigraphy and K-Ar dating. Maximum thickness of the intracaldera Aoni Tuff recently has been demonstrated to be up to 1300 m by another drilling project of NEDO (1983). Eruption volume of the Aoni Tuff may thus be more than 100 km^3. The Kenashiyama Dacite is the post-caldera domes made of dacite lava whose arrangement is characteristically annular within the caldera floor. Muraoka and Hase (1981) suggested based upon these features that the Okiura caldera is a Valles-type caldera. There remains the puzzling problem with the Okiura caldera that the topography and structure of the caldera are recognized only in the west half of a presumably circular shape.

The southern and northern Hakkoda volcanoes are composite volcanoes close to each other, and similar in size. Both are multiple andesitic stratovolcanoes. The Hakkoda caldera is located in the north of the northern Hakkoda volcano, but the southern rim has not been identified. With respect to topography, the edifice of the southern Hakkoda volcano is more dissected than that of the northern Hakkoda volcano, and therefore it seems that the former is somewhat older than the latter. Previous workers have considered that both volcanoes are younger than the Hakkoda caldera. However, Muraoka, Yamaguchi and Nakazawa (1983) drew attention to the fact that the

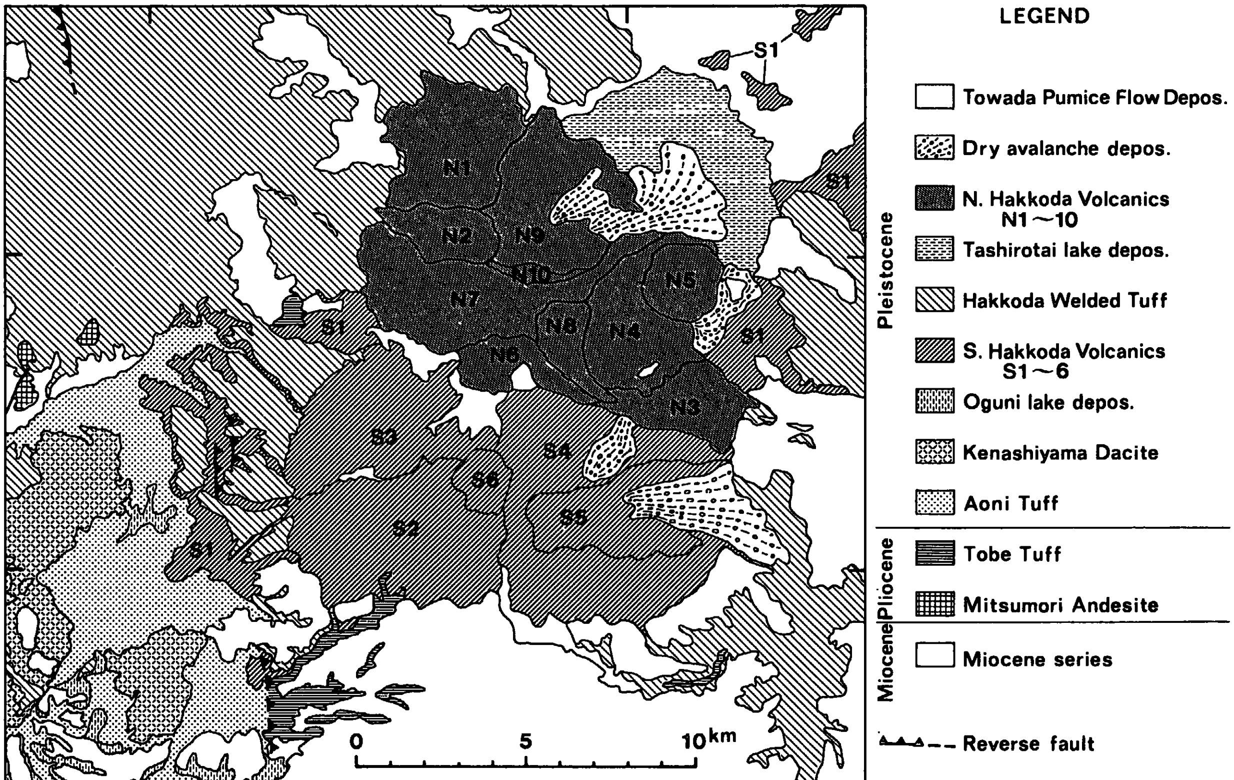

Figure 3.
Geologic map of the Hakkoda area

Hakkoda Welded Tuff, products of Hakkoda caldera generation, overlies the southern Hakkoda volcano but is overlain by the northern Hakkoda volcano. This conclusion has been supported in this project by the lines of stratigraphic evidence. Conclusively, it may be established that the southern and northern Hakkoda volcanoes reveal the pre-caldera (somma) volcano and post-caldera cones of the Hakkoda caldera, respectively. In other words, they also compose a single Hakkoda caldera system in a broad sense.

K-Ar Dating

K-Ar dating was carried out on 55 samples mainly taken from the southern and northern Hakkoda volcanoes. The same samples were also analyzed for major chemical components and natural remanent magnetization. Unfortunately, because most of these samples are low-potassium andesite, the argon level is critically low to make precise measurements. No ages have been calculated for many of them. Determined K-Ar ages range from 3.9 to 0.5 Ma on the southern Hakkoda volcanic rocks, 1.0 to 0.8 Ma on the Hakkoda Welded Tuff and 1.0 to 0.3 Ma on the northern Hakkoda volcanic rocks. Although these trends coincide with the stratigraphic sequence in a broad sense, the scattered ranges preclude a precise discussion. It is, however, important that every sample from the northern Hakkoda volcano represents a normal magnetization direction. It indicates that the volcano should be younger than 0.7 Ma in age.

Geothermal Geology

Among the four composite volcano systems, hot springs seem to be associated exclusively with the Okiura caldera and northern Hakkoda volcano (Figure 2). Although the Okiura caldera is oldest among them, the Valles-type origin makes us expect a shallow and long-lived magma chamber beneath the caldera. In contrast, heat potential of the Crater Lake-type caldera seems to depend upon the activity of younger post-caldera cones such as the northern Hakkoda volcano, probably due to a deep and (or) short-lived magma chamber. The northern Hakkoda volcano has no historic records of eruptions, but ash-fall activity is considered to have continued up to a few thousand years ago. Fumarole activity is still recognized in the vicinity of the Sukayu hot springs spa (Figure 2). Hot springs in the surroundings of the northern Hakkoda volcano show the zonal arrangement that the SO_4 fraction and temperature decrease and pH values increase with distance from the volcanic center. Therefore, the heat sources of most of the hot springs can be clearly explained by the two volcano systems.

The apparent exception is the Shimoyu hot springs (Figure 2), which shows neutral pH values but the highest temperature in the studied area. The locality is significantly distant from the northern Hakkoda volcano or other volcanic systems. In this connection, the most important fact is that a reverse fault zone was found in the course of this study south of the Shimoyu hot springs. Each fault exposure is rather small, but they are systematically dipping to the east at 30 to 40 degrees and are generally trending in a north-south direction. The latest fault activity is younger than the southern Hakkoda volcano. These roles seem to be critically important not only to the origin of the

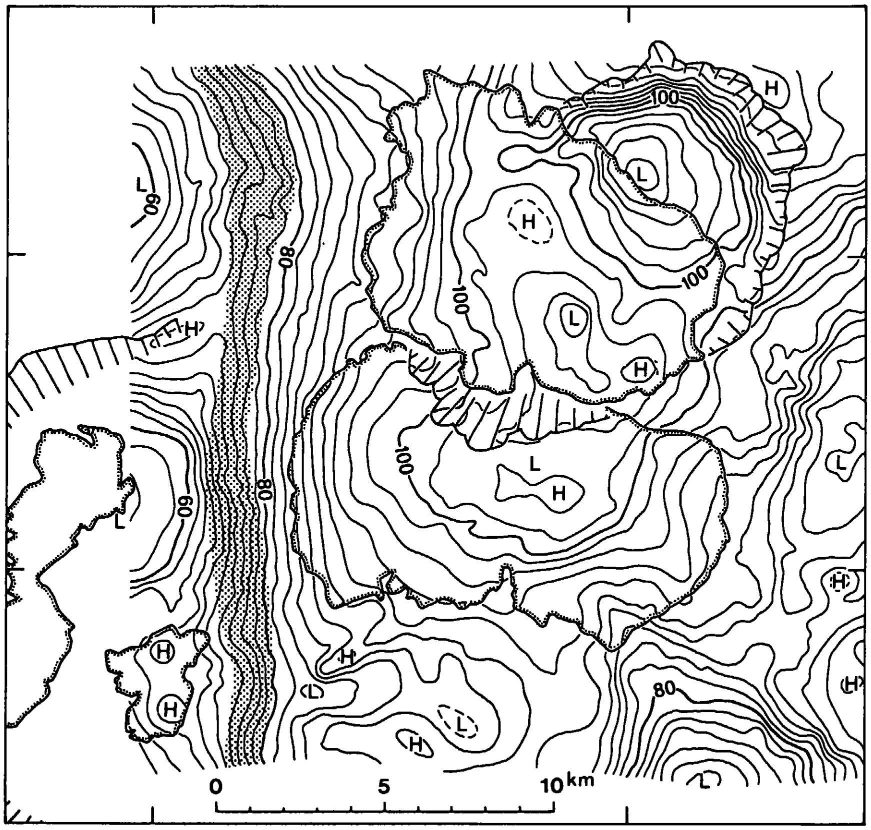

Figure 4.
Bouguer anomaly map of the Hakkoda area. A reduction density of 2.00 g/cm³ was used. The contour interval is 2 mgal. The shaded belt reveals a gravity fault zone.

Shimoyu hot springs but also to the missing east half of the Okiura caldera.

GRAVIMETRIC SURVEY

Because the studied area is almost entirely covered by Quaternary volcanic eruptives, the gravity survey is important to clarify the subsurface relief of the pre-Quaternary units. During the autumn of 1984, NEDO added 713 gravity stations in this area, each time measuring a level of the site. These data were merged with the previous data (1,172 stations in the 1st step survey), and reduced to complete Bouguer gravity values with Bouguer reduction densities of 2.00, 2.30 and 2.50 g/cm^3. These values rather minimize the actual values measured on samples from this terrain. However, because the terrain is dominated by loose volcanic material, sampling bias is significantly large. Therefore, the gravity field reduced using a density of 2.00 g/cm^3 probably better approximates the structure of this area. Figure 4 shows the Bouguer anomaly map reduced at 2.00 g/cm^3.

Bouguer gravity values of Figure 4 range from 57 to 113 mgal, which belong to the highest class in the Japanese Islands. The major gravity feature is that the highest anomaly axis runs along the center of the mapped area in a north-south direction and grades into low anomaly areas to the east and west. This roughly coincides with the topographic axis of the Nasu volcanic zone as well as the uplifted zone of pre-Tertiary basement units. The closed low in the northeast represents the northern part of the Hakkoda caldera subsidence, but the southern part seems to be masked by the post-caldera cones of the northern Hakkoda volcano. The high in the southern Hakkoda volcano is partly due to a topographic high, and partly due to the shallow depth to Tertiary rocks as can be inferred from the exposure of Tertiary rocks (Figure 3). The steep gradient zone found between the Okiura caldera and the southern Hakkoda volcano (Figure 4) is impressively linear trending in a north-south direction. This is clearly consistent with the reverse fault zone mentioned above. This gravity contrast continues to the north of the Okiura caldera, and includes the Shimoyu hot springs area. As a result, two important points can be suggested. One is that the missing east half of the Okiura caldera is involved in the regional uplift zone controlled by the young reverse fault system. Therefore, the east half might have been heavily eroded before coverage by the younger volcanic rocks. The other point is that the Shimoyu hydrothermal system may be developed along the reverse fault zone.

CSAMT SURVEY

The controlled source audiofrequency magnetotelluric (CSAMT) method is a kind of MT method using an artifical source. In order to obtain the apparent resistivity map of the area, NEDO set up 10 transmitter and 266 receiver stations. Transmitter orientation was in a north-south direction. The frequency coverage of the receiver system ranges from 1 to 2,048 Hz. Apparent resistivity maps were made at 2, 16, 128 and 1,024 Hz. Higher frequency maps indicate that the low resistivity anomaly well coincides with the hot springs areas. The map of 2 Hz is shown in Figure 5. Skin depth of the map is theoretically estimated to be about 1 km at 20 ohm m and about 2 km at 40 ohm m.

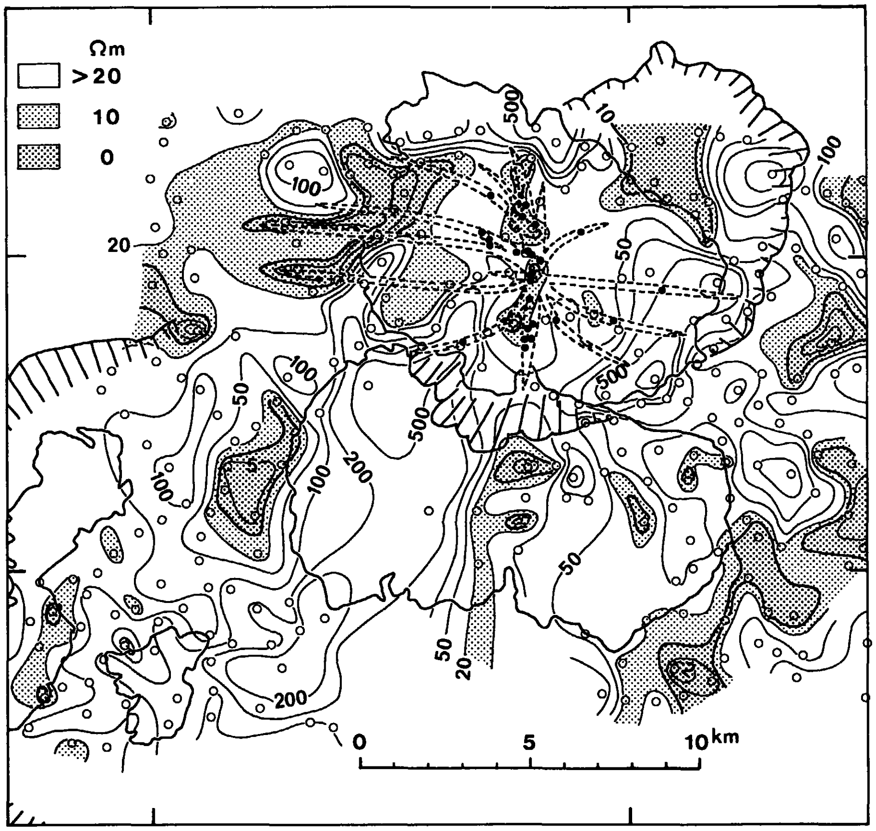

Figure 5.
Apparent resistivity map of the Hakkoda area by the CSAMT method. Frequency range is 2 Hz. Contours are shown by 2, 5, 10, 20, 50, 100, 200 and 500 in ohm m. Broken lines illustrate a radial dike model. Closed circles show vents and open circles show receiver stations.

Generally speaking, low resistivity areas on the map tend to be consistent with the steep gradient zone on the gravity map. For example, a low anomaly is seen along the reverse fault zone, though it is not continuous. In addition, this map seems to enhance the linearity of some low resistivity areas compared with those of the higher frequency maps. Remarkable linearity is found across the center of the northern and southern Hakkoda volcanoes in a north-south direction. It is significantly harmonic with the vent alignments. An east-west trending low is also seen in the vicinity of the Shimoyu hot springs. If the parasite cones and craters (closed circle in Figure 5) can be taken as the indicators of radial dikes beneath the volcano (Nakamura, 1977), a schematic picture of dikes may be drawn on the northern Hakkoda volcano as shown in Figure 5. In this case such a linear low may be ascribed to intrusive-derived hydrothermal activity or an alteration halo.

CONCLUSIONS

The Hakkoda area includes the four Quaternary composite volcano systems; the Okiura caldera, southern Hakkoda volcano, Hakkoda caldera and northern Hakkoda volcano, in historical order. One group of hot springs is associated with the oldest Okiura caldera, because of the long-lived magma chamber characterized by a Valles-type caldera. The other group is zonally distributed in the surroundings of the youngest northern Hakkoda volcano. The exception is the Shimoyu hot springs with the highest temperature in the area. Geological, gravimetric and CSAMT surveys indicate that the Shimoyu hydrothermal system is developed along a reverse fault zone, and their heat sources may be explained by the continuation of possible radial dikes beneath the northern Hakkoda volcano.

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