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GEOLOGIC AND GEOTHERMAL STRUCTURE OF THE HATCHOBARU FIELD,  
CENTRAL KYUSHU, JAPAN

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ABSTRACT

Recent investigations and explorations in the Hatchobaru geothermal field have confirmed the up-flow of thermal fluids along the high-angles faults. The fluids seem to be flowing up from the basement in the footwall of the faults which form the main reservoirs in the Usa group and the Hohi volcanic rocks. The acid altered zones which extend near the surface act as the cap rock. The main reservoirs are chloride water-dominated and are found along the Kamatsuike sub-fault and Hatchobaru fault. The temperature is estimated to be 240-270°C on the basis of fluid inclusion thermometry and measured temperatures. Furthermore, there is a large possibility of finding high temperature reservoirs of 290-300°C in the Basement.

INTRODUCTION

The Hatchobaru geothermal field is located 6 km northwest of Mt. Kuju, and approximately mid-way between Mt. Aso and Beppu Spa. Kyushu electric Power Co. ( KEPCO ) constructed the 12 MW Otake Power Plant in 1967 and the 55 MW Hatchobaru Power Plant in 1977. The exploration of Hatchobaru field in parallel with that of the Otake field has been carried out since 1949. The geothermal reservoir system, however, has not been defined in detail because of the lack of sufficient data such as well logs and tests. Since the investigation and exploration for the 2nd unit at Hatchobaru were started in 1980, a lot of data on geology, geophysics and hydrogeology have been obtained and the geologic cross section and the reservoir model have been revised.

GEOLOGIC SETTING

The Hatchobaru geothermal field is situated in the southern margin of a long and narrow depression running across north-central Kyushu from east to west, the Beppu-Aso Depression Zone ( Yamasaki and Hayashi, 1975 ). The Otake-Hatchobaru area has the feature of a high gravity anomaly area, which reflects the uplift of dense basement rocks. From Miocene to Pleistocene time volcanic rocks accumulated to a thickness of about 2,000m.

The geological succession of the Otake-Hatchobaru area is divided into four groups in descending order ( Fig. 1 ).

- (1) Kuju volcanic rocks  
( Middle-Upper Pleistocene )
- (2) Hohi volcanic rocks  
( Lower Pleistocene )
- (3) Usa group ( Miocene )
- (4) Basement rocks  
( Paleozoic-Mesozoic )

The Kuju volcanic rocks, characterized by relatively viscous hornblende andesite lavas, form many lava domes. The Hohi volcanic rocks consist of pyroxene andesite lava flows and associated pyroclastics. They are about 800m in thickness and extend at depths reaching below sea level ( Fig. 4 ). The Miocene volcanic rocks, so called, " Usa group ", are composed mainly of altered andesite lava flows and tuff breccias and attain a maximum thickness of more than 800m. The basement rocks penetrated by well HT-5-1 are Cretaceous granitic rocks and Paleozoic metamorphic rocks.

The Basement becomes deeper by step-faulting from south to north, and is depressed over 1,500 m. The Hatchobaru geothermal field forms a small horst, which has a trend of NW-SE. There are main NW faults which control hot springs, fumaroles and altered zones. The Komatsuike sub-fault provides a high angle conduit for the fluid moving from the deep reservoir. Many production and reinjection wells ranging from 1,000m to 2,000m have penetrated the Komatsuike sub-fault in Fig. 2. This fault generally dips 60° to 70° SW with a maximum width of 30m.

HYDROGEOLOGICAL INTERPRETATION

From the interpretation of isotope data, the geothermal fluids of Hatchobaru field are derived almost entirely from local meteoric waters which flow downwards in the south-east part of the field. The meteoric waters which penetrate into the basement are heated, and at the same time they change chemical composition through rock-water equilibria. The heated fluids migrate upward again and are reserved into fracture zones in volcanic rocks of Miocene to early Pleistocene time. The main reservoirs are formed in the per-

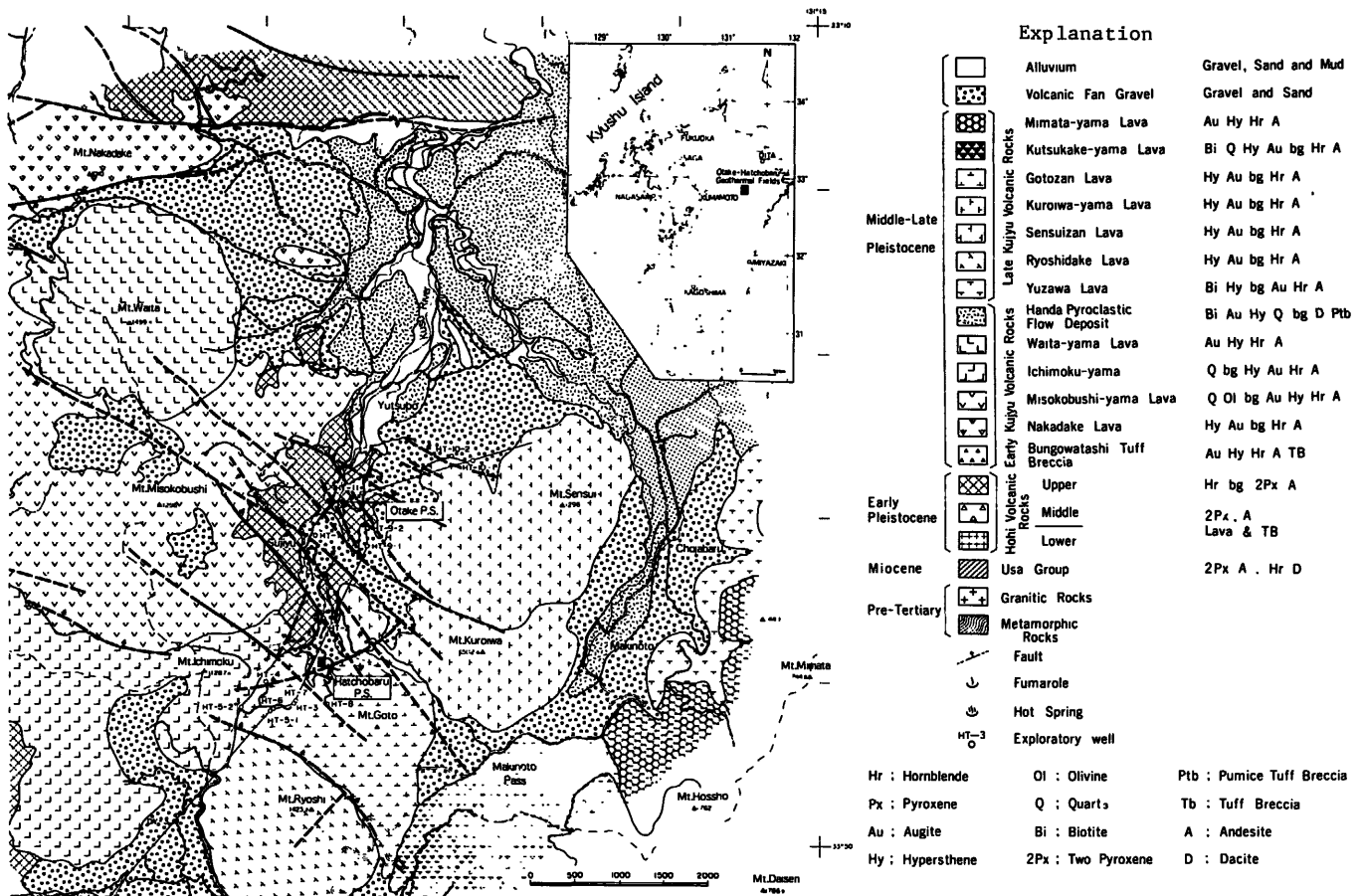


FIGURE 1. GEOLOGIC MAP OF THE OTAKE-HATCHOBARU GEOTHERMAL AREA (modified from Matsumoto, 1983)

meable zones of the NW-SE trending Komatsuie sub-fault and the Hatchobaru fault. Strongly altered zones which have been formed along the faults are composed mainly of cristobalite-quartz, kaolinite-pyrophyllite and anhydrite. They play the role of permeability barrier, because of the minerals formed in fractured and pore spaces. This is also inferred from the high  $Hg^+$  concentration in cuttings collected from the fault zone by drilling. For instance, the well HT-8 which penetrated the thick impermeable layer of the altered zone along the Komatsuie sub-fault had very little discharge of geothermal fluids. The isothermal lines in Fig. 5 undergo a sudden change near the faults and become deep on the hanging walls of faults. Consequently, there is a possibility of different hydrothermal flows with the fault in between. Lost-circulation zones in Hatchobaru wells frequently occur near faults, especially in the foot wall of faults ( Fig.3 ). Thus, it is assumed that geothermal fluids are flowing up from the basement on the lower part of fault planes and the reservoir is formed there.

Acid altered zones which consist of alunite + kaolinite + quartz + pyrite are widely distributed and have a thickness of 200-500m in the near surface ( Hayashi et al., 1968 ). The altered

zones appear to function as a local cap, which at the same time prevent meteoric water from penetrating to the deep. In Hatchobaru, the acid altered layer becomes deeper and thicker southward from the Komatsuie sub-fault zone in Fig. 5 conjunction with the isothermal lines. The permeabilities of the Hatchobaru reservoir rocks sampled in well HT-4 are usually quite low, less than  $10^{-3}$  darcies. Moreover, no distinct relationship between permeability and porosity is found, This suggest that fluid flows in the reservoir rocks are largely through fractures.

#### GEOCHEMICAL INTERPRETATION

The geothermal fluids from producing wells are characterised by water-dominated type ( chloride type ). The reservoirs along the Komatsuie sub-fault and Hatchobaru fault are considered to be isolated chemically. In the deeper zones, the fluids change progressively to  $SO_4$ ,  $Cl-SO_4$ ,  $HCO_3 - SO_4$  type and Cl type. For instance, it is clear that well H-18 which penetrated the Komatsuie sub-fault at a depth of 800m encountered a  $HCO_3 - SO_4$  type reservoir in the hanging wall of the fault, and a Cl type

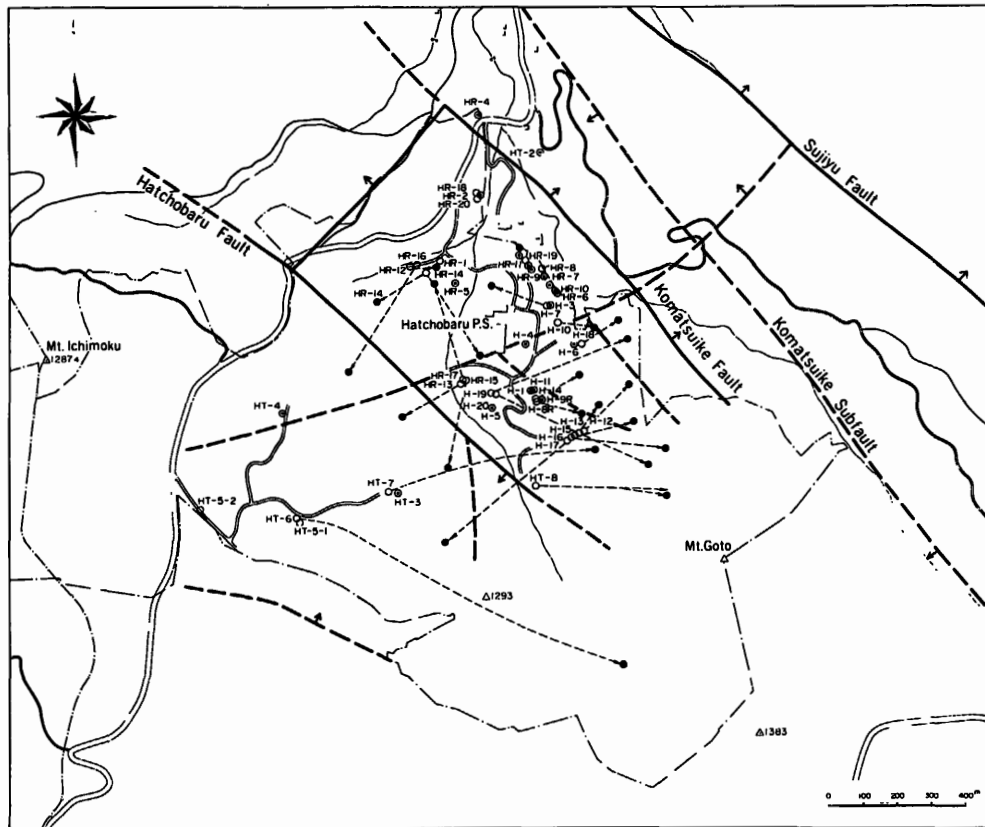


FIGURE 2. LOCATION MAP OF WELLS

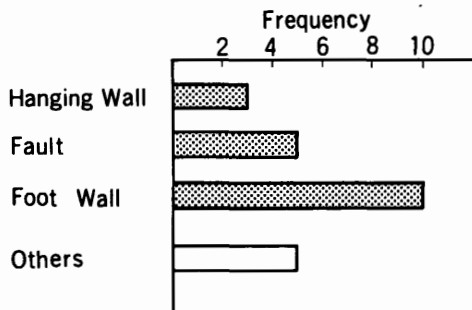


FIGURE 3. FREQUENCY DISTRIBUTION OF LOST - CIRCULATIONS OF THE HATCHOBARU WELLS

The number of lost-circulations are of up to 100m distance from faults

in the foot wall.  $C1/B$  ratio gives information about the nature of the rocks contacting the hot water. Low  $C1/B$  ratios for the fluids discharged from 2,200m of well HT-5-1 indicate the reaction of water with the schist of the basement. The fluids from the reservoirs in the Hohi volcanic rocks and Usa group show  $C1/B$  ratios of 20-30, meanwhile the fluids in the basement show 11-17. From the distribution of  $C1/B$  ratios in Hatchobaru well waters, the lowest ratios in producing zone are found at northern foot of Mt.Goto. The feature of contour map of the  $C1/B$  ratios is quite similar

to that of silica temperature ( $T_{SiO_2}$ ), i.e, the lowest part of  $C1/B$  ratios correspond to the highest part ( $>290^{\circ}C$ ) of  $T_{SiO_2}$ . According to the above data, it is assumed that the north-eastern part of Mt. Goto is the upflow area over the center of heating which has a higher flow potential and a possible maximum temperature of  $290-300^{\circ}C$ .

#### GEOPHYSICAL INTERPRETATION

Extensive geophysical data for the Hatchobaru field and its periphery are available. The most useful measurements are the Schlumberger soundings and magneto telluric surveys. The Schlumberger soundings provide the detailed and unambiguous features of the altered zones and the shallow reservoirs in Hatchobaru. Fig. 6-a shows iso-resistivity map of the low-resistivity layer. The low resistivities occur in the north-eastern part of the field. The very lowest resistivities ( $2 \text{ ohm-m}$ ) form a fan opening to the northeast. On the other hand, to the southwest the resistivities gradually increase. The main producing wells are located in the low-resistivity area ( up to  $6 \text{ ohm-m}$  ). Fig.6-b shows an iso-contour map of the elevation of the top of electrical basement which indicates weakly altered zones of Hohi volcanic rocks and Usa group. The top of this layer becomes

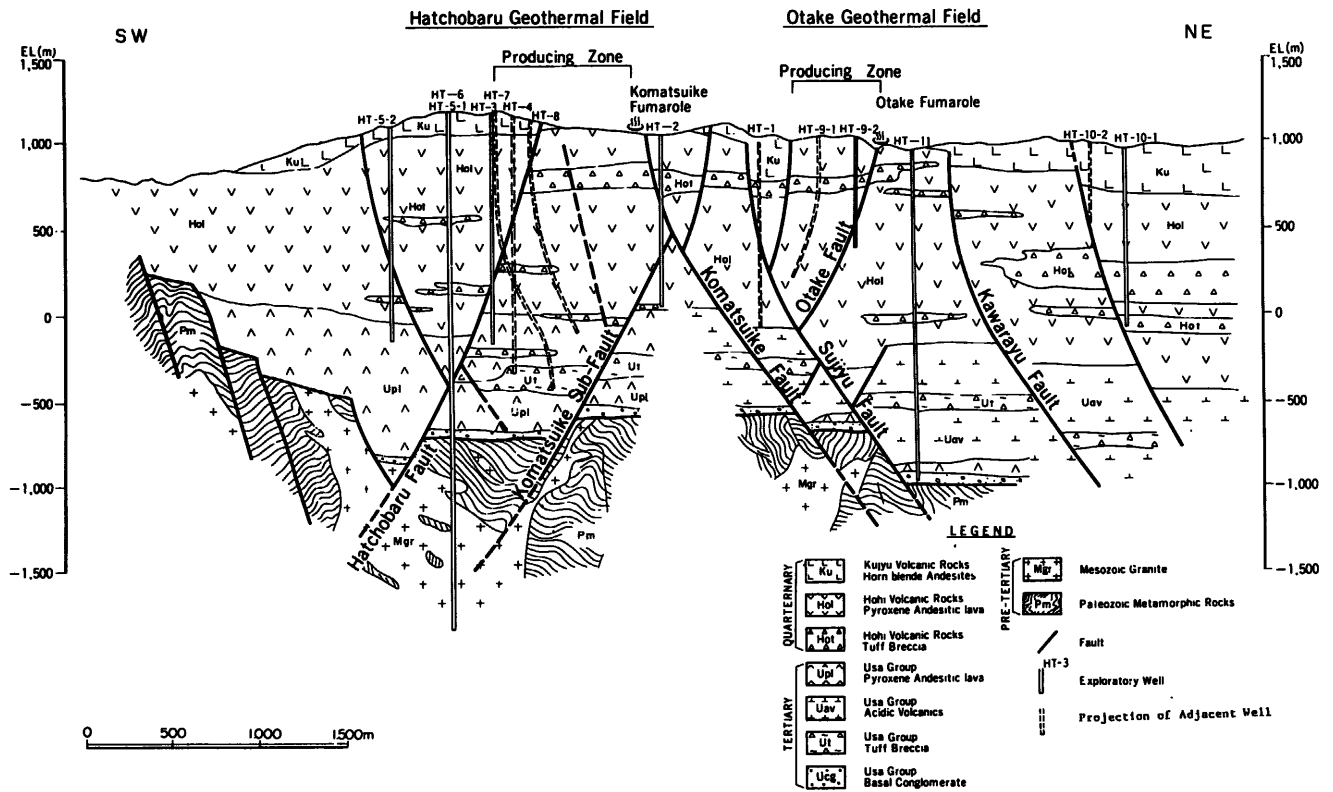


FIGURE 4. THE GEOLOGIC CROSS SECTION OF THE OTAKE-HATCHOBARU GEOTHERMAL AREA

deeper south-westward parallel to the Komatsuike sub-fault and Hatchobaru fault. Furthermore, it is observed that the low-resistivity layer thickens to the southwest and at the western extremity of the field, near Mt. Ichimoku, the layer starts to decrease in thickness. The distribution of the low-resistivity layer well reflects the depth and thickness of the acid altered zone. The main geothermal reservoirs of Hatchobaru are located in the electrical basement. The thermal fluids tend to concentrate in the horst structure of the electrical basement.

GEOHERMAL SYSTEM

Fig. 5 shows a model of the geothermal system of the Otake-Hatchobaru area. A flow paths, as deduced from geologic structure and temperature distribution are illustrated in the figure. The pre-Tertiary basement at Hatchobaru field is depressed over 1,500m, as clarified by wells HT-5-1 and HT-6. It was presumed that the high gravity anomaly was caused by the uplift of the basement (Kamata, 1968). Furthermore, the obscure in high gravity anomaly seems to have close relation with the geothermal activity in the subsurface. This fact suggests that the horst in the depression zone

is favourable to hydrothermal systems, because thermal fluids tend to migrate upward through the fracture zones along the horst, caused by block faulting, and concentrate at the highest place of the local structure of the basement rocks and/or low-permeable rocks.

The geothermal fluids of Hatchobaru field are derived almost entirely from local meteoric waters, flowing down along the faults and high angle fracture networks in the south-east part of the field. Apparently the meteoric waters which penetrate into the basement are heated up to about 300°C by a heat source related to Quaternary volcanism. At the same time, the heated fluids become Cl type solution. It migrates upward through the permeable zones on faults such as Komatsuike sub-fault and Hatchobaru fault, and occur mainly on the lower part of the fault planes in the Usa group and Hohi volcanic rocks. The reservoir temperature in the present producing area is estimated to be 240-270°C on the basis of the homogenized temperatures of fluid inclusions in vein minerals and by measured temperatures. The minimum filling temperatures from the inclusions agree well with the equilibrium temperature estimated from the measured temperatures (Taguchi, 1982). The acid altered zone which extends to

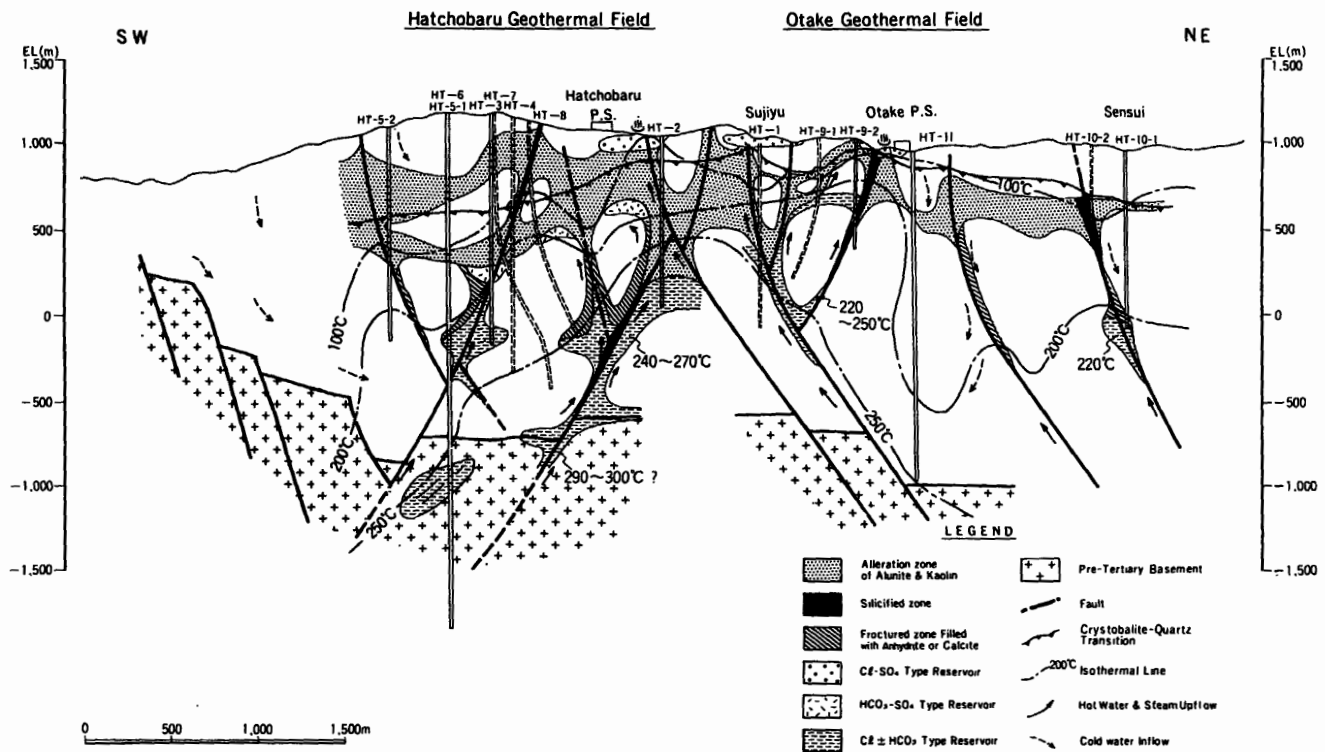


FIGURE 5. A MODEL OF GEOTHERMAL SYSTEM OF THE OTAKE-HATCHOBARU GEOTHERMAL AREA

the near surface plays the role of a cap rock and prevents meteoric water from penetrating to the deeper zones. According to the chemical data, it is assumed that the reservoirs in and under the altered zone are relatively small in extent and are of water-dominated type ( $\text{HCO}_3\text{-SO}_4$  type) and are vapour-dominated in some cases. Steam and gas escaping from the deep zones through the cap rock may form  $\text{SO}_4$  type reservoirs with low chloride contents and low pH values.

Although the deep well HT-5-1 did not encounter a highly permeable zone in the basement, there is a high possibility of finding high-temperature reservoir of 290-300°C, when the center of convection upflow in the area on the north-eastern part of Mt. Goto, is exploited.

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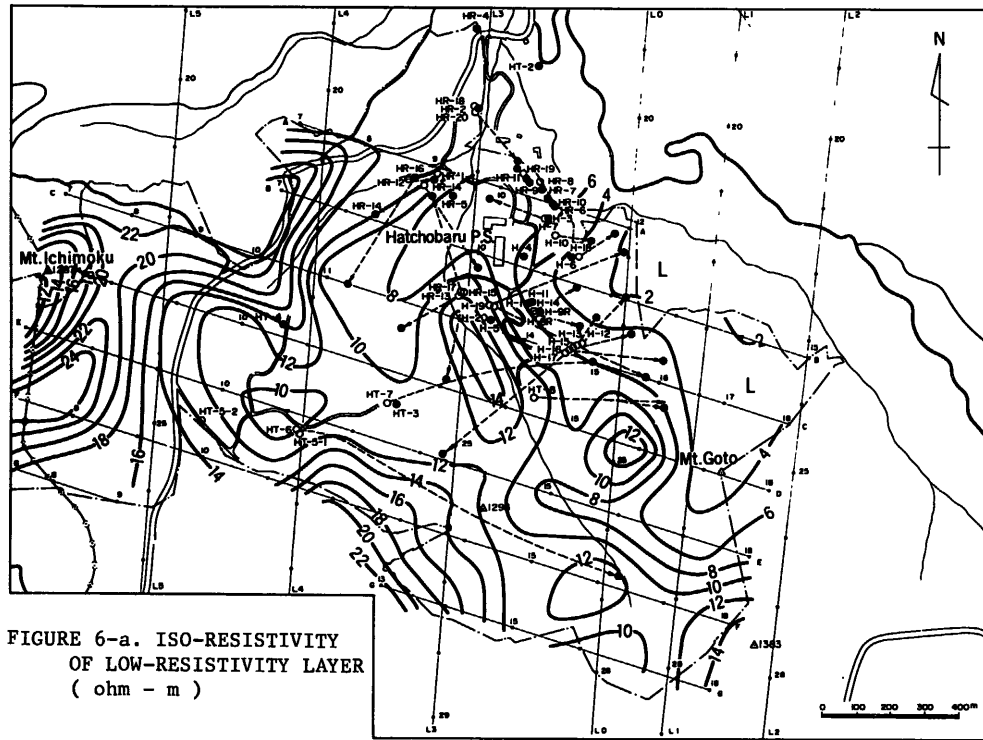


FIGURE 6-a. ISO-RESISTIVITY OF LOW-RESISTIVITY LAYER ( ohm - m )

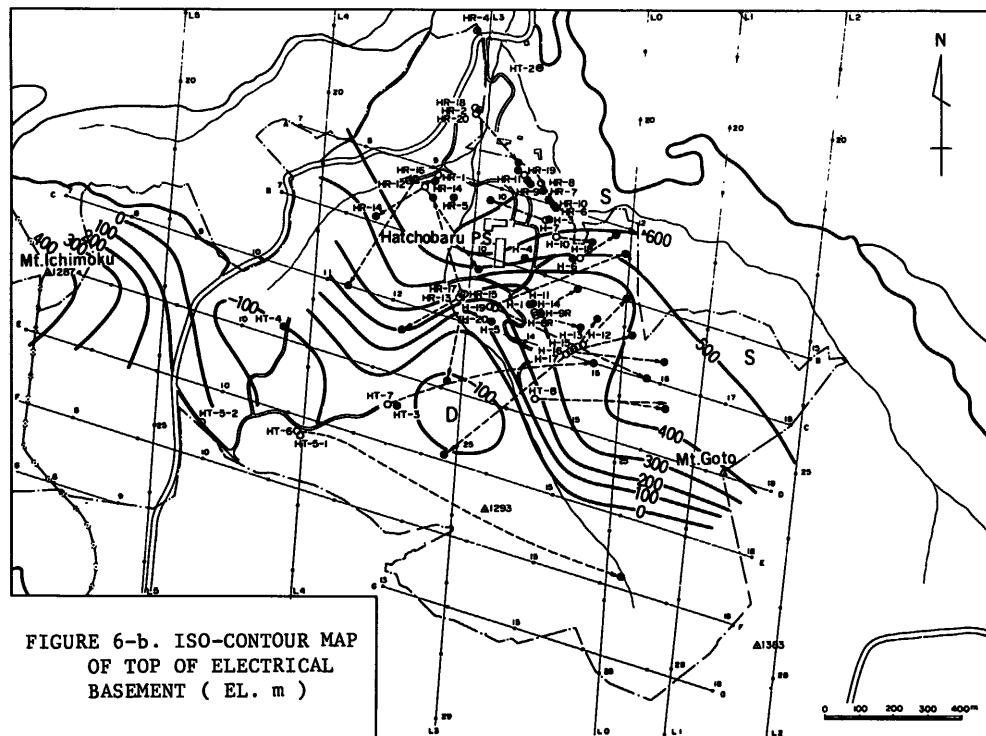


FIGURE 6-b. ISO-CONTOUR MAP OF TOP OF ELECTRICAL BASEMENT ( EL. m )