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EXPLORATION UNDERGROUND STRUCTURE BY AE OBSERVATION IN THE HATCHOBARU GEOTHERMAL AREA, JAPAN

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ABSTRACT

We have been carrying out AE (acoustic emission) observation since 1995 in the Hatchobaru geothermal area, Kyushu, Japan. The AE observation started using borehole-in a 3-station network and 9-station network completed in 1997. Over a thousand AE and several AE swarms were observed a year by this network.

We tried to estimate the underground structure such as location of faults and fracture-rich zones by calculating the hypocenter, determining the AE source mechanism and AE attenuation. Comparing the AE data with detailed gravity and resistivity data, we find that most of the hypocenters of AE swarms are located in the low-gravity anomaly zone. The strikes of faults estimated by AE mechanical analysis agree with isogal and isoresistivity contours.

AE data are effective for estimating high permeable zone. Some high permeability wells were located near estimated faults in the AE swarm areas. Particularly in low resistivity zones, it is sometimes difficult to locate faults from magnetotelluric data but can be rather effective form AE data.

1. INTRODUCTION

The Hatchobaru geothermal field is located as shown in Figure 1 in the central part of Kyushu, and the 122.5 MW Hatchobaru and Otake geothermal power plant are operating there. Microearthquake observation for the purpose of environmental monitoring has continued since 1977, and several hundred hypocenters are determined in this area every year. In this study, AE refers to microearthquakes as well as earthquakes of much smaller energy. An AE observation net for detailed observation of AE occurring around the Hatchobaru geothermal power plant has been constructed, and a method for estimating from AE analysis the geothermal reservoir location and the fractures connected with geothermal fluid flow is examined in this study

2. OBSERVATION

The location of the stations is shown in Figure 2. 3 stations were installed in 1995 and 3 stations were added in 1996 and 1997. The structure of the observation system is shown in Figure 3. Observation stations measure the 3 components - N-S, E-W, and U-D movement - at 9 stations. Observation data are transmitted after amplification to avoid the noise arising during transmission and the decline of the S/N ratio due to the decline of the wave shape. Further amplification and filtering are done with the main amplifier, and after A/D transformation, the observation data are recorded on a hard disk. This network consists two local networks, Hatchobaru area, which has 6 stations, and Otke area, which has 3 stations. Both local networks are connected by communication cable for synchronizing recording data. AE hypocenter and focal mechanism are analyzed with MEPAS (micro-earthquake data processing and analysis system) (New Energy and Industrial Technology Development Organization, 1992).

3. OBSERVATION RESULTS

AE hypocenter, focal mechanism analysis and AE attenuation analysis were carried out using interpreted first motion data for the P wave and S wave of AE with an S-P time of less than 3 seconds,

3.1 AE Hypocenter Distribution

Maps of AE hypocenters observed from December 1996 to December 1998 are shown in Figure 4. In the ground plan on the upper of figure, hypocenters are concentrated northeast of the Hatchobaru power plant surrounded by ST-5, ST-8 and ST-9. The concentrated AE source region is distributed about -1 km above sea level, as shown by the section on the lower of figure. The daily AE frequency from December 1996 to December 1998 is shown in Figure 5. Usually up to 5 AE were observed a day and several AE swarms were observed a year.

3.2 Fault Plane Solution Analysis

Because an earthquake wave heads for the observation point from the diagonally lower position of the hypocenter, the vertical component of the radiation pattern of the P-wave first motion is interpreted as compression (up) and dilation (down). A double couple model and a quadrant type are assumed for the source process in this study. The quadrant type is bounded by two nodal planes. One of the two nodal planes shows the direction of the fracture that is involved in the AE occurrence. Normal faults, reverse faults, and strike slip faults are estimated from focal mechanism analysis (Utsu, 1987). Many observation stations are necessary to be extremely accurate concerning the nodal plane because, with few observation stations, it is not possible to set the nodal plane precisely.

It is considered that AE occurring in the same fracture show the same focal mechanisms. It is considered possible for AE swarms occurring temporally and spatially close together to show the same focal mechanisms. Following focal mechanism analysis used 6 –station's data from December 1996 to September 1997. For the purpose of increasing apparent observation station numbers, selected clear P-wave first motions in AE swarms during the observation period are superimposed on the equal area projection to determine the nodal plane. The focal mechanisms show a normal fault type and a strike-slip type, as shown in Figure 6. AE which show a type intermediates between a normal fault, a reverse fault and a strike-slip type are recognized. The focal mechanisms in the Hatchobaru geothermal field show both compression and tension in the east-west direction, and indicate a field where tension and compression are repeating in the same direction. Results of fault plane solution analysis are shown in Figure 7. These estimated faults were put together from nodal planes extending in a northwest-southeast, northeast-southwest and east-west direction.

3.3 AE Attenuation analysis

It is considered that AE waveform attenuation at fracture-rich zone greater than surrounding area. We try to estimate a degree of AE attenuation, Q (quality factor), was calculated following Ehara (1984) using S/P method (Moriya, 1976). 9-station's data from September 1997 to December 1997 was used for this analysis. Observed Q, which means AE path's Q, is calculated by the ratio of P wave and S wave spectrum. A time window of each spectrum is same as S-P time.

Figure 8 shows the results of Q block model. This model consists of 18 blocks and 2 layers. Each block's Q is inverted from observed Q. A number on each block shows Q and A number of parenthesis shows addition of each travel-time of AE paths in second. No AE passed the block number 7,9,16 and 18 then there are no Q of these blocks.

The upper layer Q is lower than lower layer. At the upper layer, the block number 8, which locate production and reinjection zone of Otake geothermal power plant, shows lowest Q. Otke geothermal reservoir locate from 400 m to 700 m above sea level and shows mushroom-shaped thermal profile (Taguchi et al, 1985). This lowest Q is considered to reflect Otake geothermal reservoir. At the lower layer, block number 14 shows relative low Q than surrounding block. This block locates reinjection and a part of production zone of Hatchobaru power plant. Hatchobaru geothermal reservoir locates from -500 m to 400 m above sea level (Matsumoto et al, 1989) that is higher than Otake geothermal reservoir. This relative low Q is considered to reflect Hatchobaru geothermal reservoir. From above results, relative AE attenuation is possible to reflect geothermal reservoir at the Hatchobaru geothermal field. We will make detailed block model by adding another period AE data to compare the Q (AE attenuation) distribution and gravity and resistivity at this area.

4. DISCUSSION

Existing investigation data were compared with the faults estimated by focal mechanism analysis, and characteristics were discussed. The existing investigation data consisted of detailed gravity data and resistivity data. Compiled maps are shown in Figures 9 to 11. A Bouguer anomaly and estimated faults are shown in Figure 9. The Bouguer anomaly iso-gravity contours extend in a northwest-southwest direction from the Makinoto pass to Hizenyu. A low-gravity anomaly is recognized around the Hatchobaru power plant, and a high-gravity anomaly is recognized around Mt.Kuroiwa. The gravity change is gentle in the eastnortheast-westsouthwest direction from Mt.Kuroiwa to ST-5 and the Hatchobaru power plant. In addition, iso-gravity contours run in a north-south direction around ST-9 from Sujiyu, and a high-gravity anomaly is recognized north of Mt.Ichimoku. The faults estimated by AE analysis follow the iso-gravity contours. Most of the faults estimated by AE analysis run northwest-southeast like the fault marked *A*. This northwest-southeast direction is the same as that of the iso-gravity contours around Yutsubo and Hatchobaru. The estimated fault marked *B*, which runs in a north-south direction, is close to the iso-gravity contours. Moreover, the iso-gravity contours run in an east-west direction around ST-5, and the estimated fault marked *C* also runs in the same direction.

A residual gravity map compiled with faults estimated by AE analysis is shown in Figure 10. In the residual map the long frequency component is removed from the Bouguer anomaly map. A remarkable low-gravity anomaly extends in a northwest-southeast direction from around Sujiyu to the Makinoto pass, and the estimated fault runs in the same direction. A low-gravity anomaly extends from around the Hatchobaru power plant in a northeast-southwest direction, and most of the hypocenters of the AE swarm are distributed in the low-gravity anomaly zone.

A resistivity map of low resistivity layers, which is compiled with faults estimated by AE analysis, is shown in Figure 10. This figure shows the resistivity distribution of the low resistivity layer in Marquart inversion analysis. The hypocenter distribution of the AE swarm is characteristic in that most hypocenters are located in the especially low resistivity area of the low resistivity layer. It is difficult to apply the electromagnetic method to the exploration of the subsurface where the low resistivity layer is distributed. AE can be observed independently of the resistivity distribution, and the subsurface structure estimated.

AE have occurred in the Hatchobaru geothermal field caused by shearing due to stress concentration on a point where the rock strength is poor. When many cracks appear due to shearing, permeability increases, geothermal fluid flow becomes active, and then the rock alteration proceeds. When the hydrothermal alteration proceeds, the rock resistivity is lowered, and a relative low resistivity zone is formed. A sheared zone becomes relatively low density, and shows a low-gravity anomaly. When the rock strength declines as a result of the hydrothermal alteration, it is hard for rocks to accumulate the distortion energy, so they are sheared again, and many AE occur. The area where the AE swarm northeast of the Hatchobaru power plant is observed is thought to be shearing repeatedly.

In the two areas around ST-5, ST-8, and ST-9 located in the low-gravity anomaly area and around Mt.Ryoshi located in the relative low resistivity area of the low resistivity layer, AE swarms have not been observed, and seismisity is low. Wells drilled in this area don't encounter a large-scale lost circulation zone (Figure 12). The area northeast of the Hatchobaru power plant, where an AE swarm is observed as shown in Figure 4, and which can yield good actual drilling results close to the faults estimated by AE analysis, is considered a good permeable area. The faults estimated by AE analysis are expected to be a promising drilling target.

5. CONCLUSION

The most common AE focal mechanisms are the normal fault type or the strike-slip type. A combination of normal and strike-slip types or of strike-slip and reverse types is seen occasionally. The northwest-southeast, northeast-southwest and east-west faults were estimated from AE analysis of the area northeast of the Hatchobaru power plant. Existing investigation data were compared with the estimated faults by focal mechanism analysis, and characteristics were discussed. The following conclusions are drawn:

(1) Most of the hypocenters of the AE swarms are distributed in the low-gravity anomaly zone and/or relative low resistivity zone.

(2) The faults estimated by AE analysis follow the direction of the iso-gravity contours.

(3) Particularly in low resistivity zones, it is sometimes difficult to locate faults from magnetotelluric data, but this can be done rather effectively from AE data.

(4) Relative AE attenuation is possible to reflect geothermal reservoir at the Hatchobaru geothermal field.

(5) The area northeast of the Hatchobaru power plant, where many AE and AE swarms are observed, is considered to be a good permeable area and is expected to be a promising drilling target.

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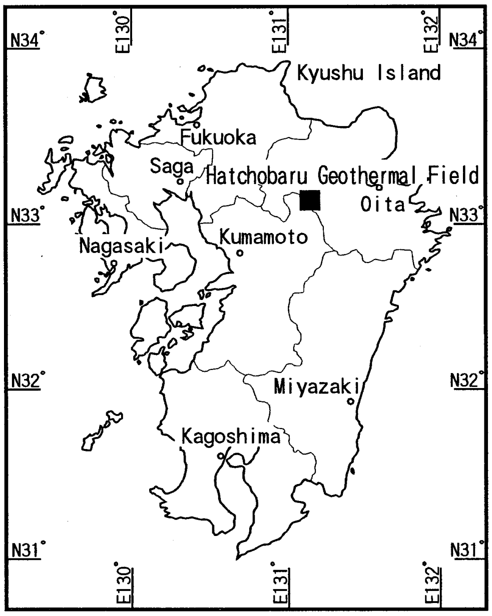

Figure 1. Location of the Hatchobaru Geothermal Field

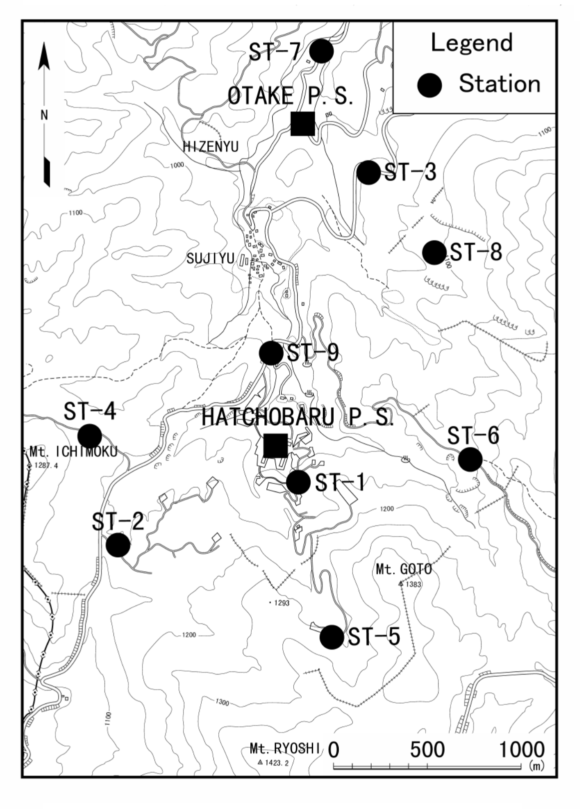

Figure 2. Location of the Stations

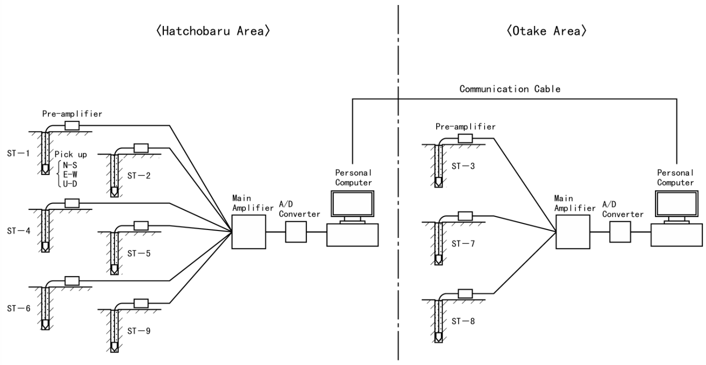

Figure 3. Structure of the Observation System

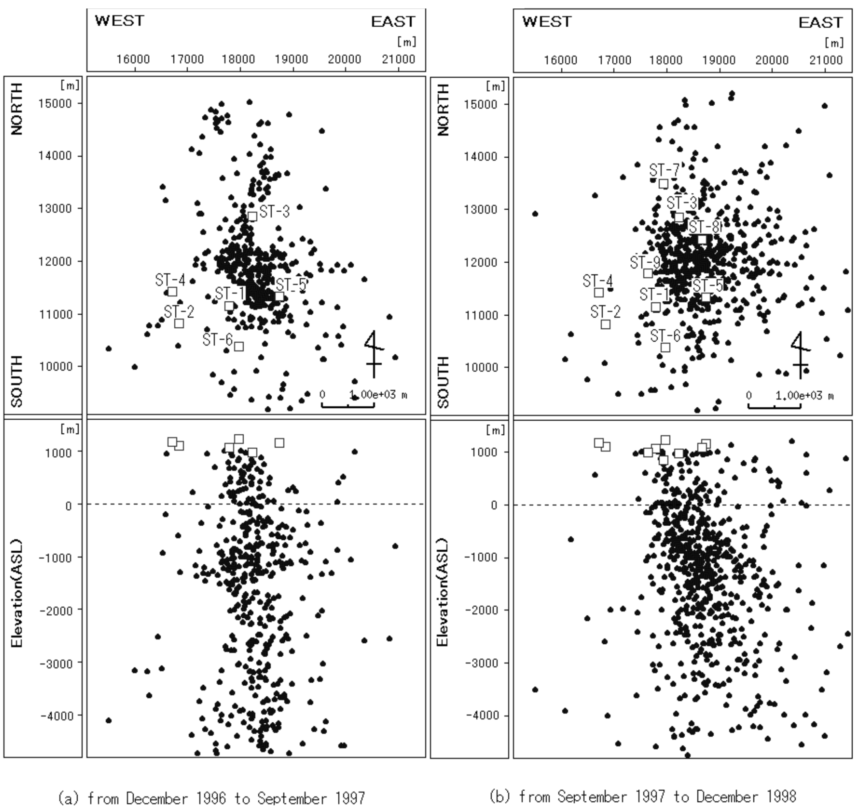

Figure 4. AE Hypocenter Distribution Map

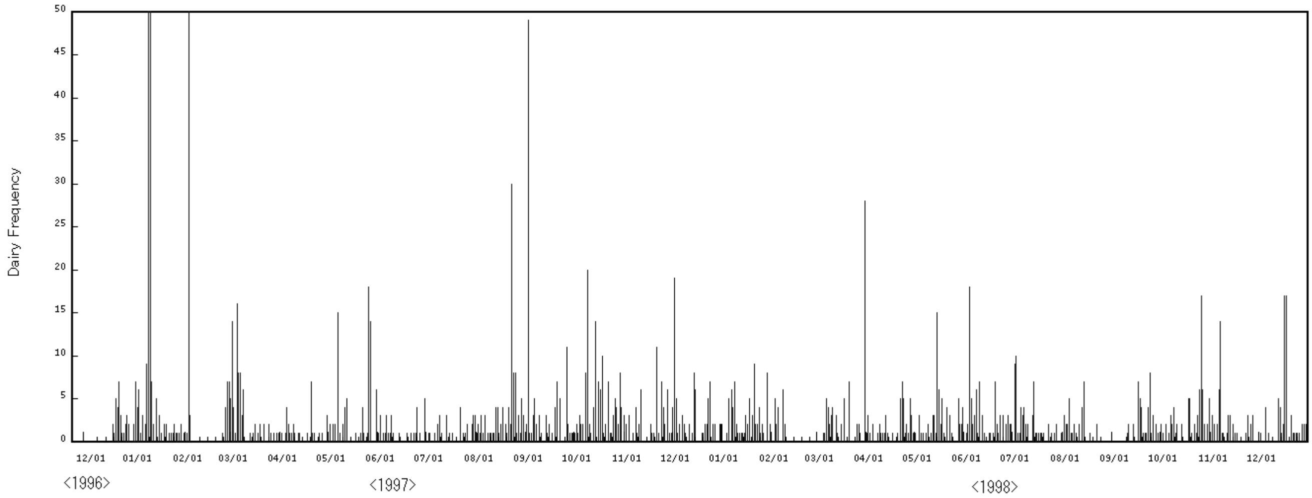

Figure 5. Daily Frequency of AE

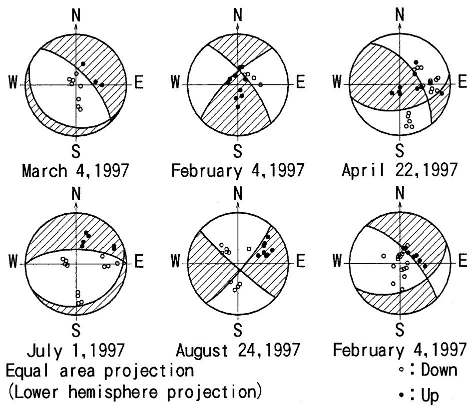

Figure 6. Focal Mechanism

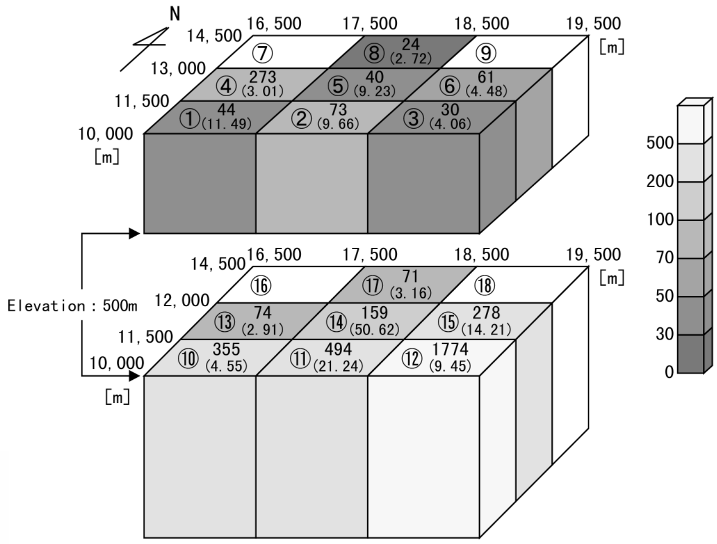

Figure 7. Block Model of AE Attenuation

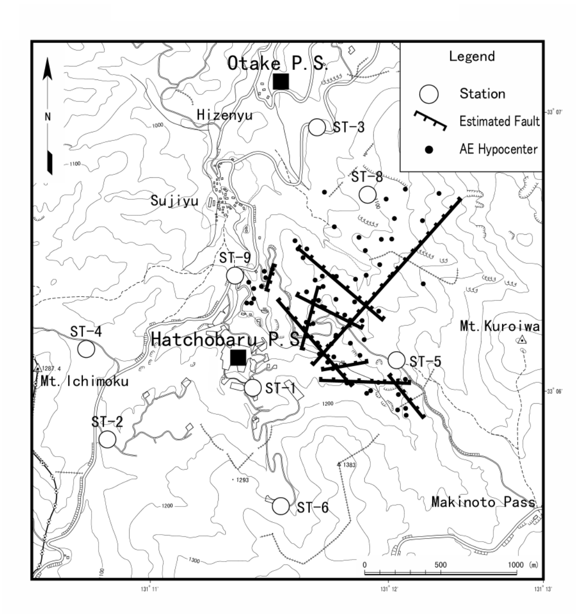

Figure 8 Location of Faults Estiated by Focal Mechanism Analysis

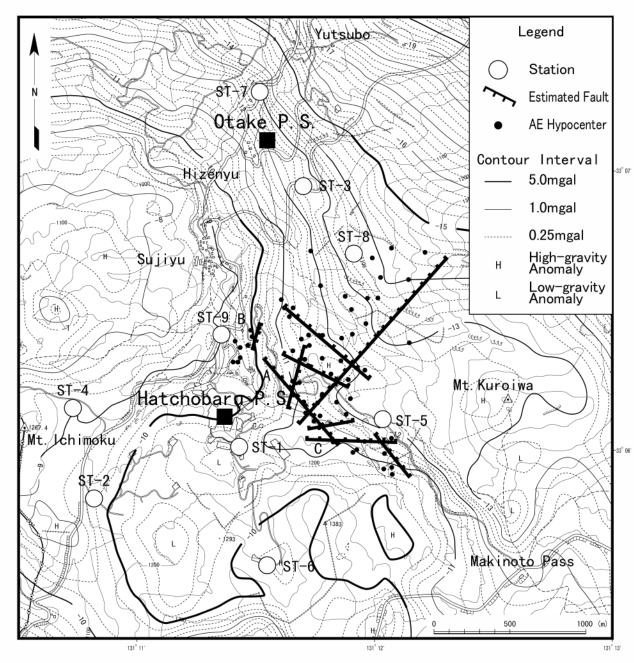

Figure 9 Bouguer Anomaly Map

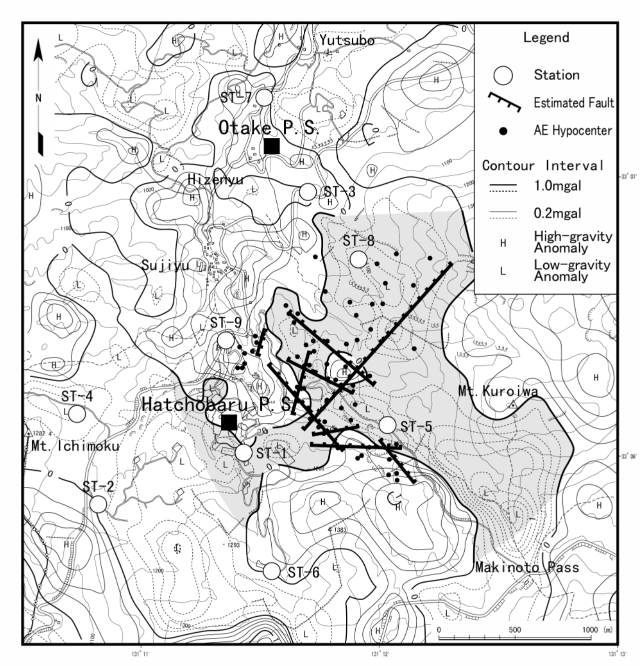

Figure 10 Residual Gravity Map

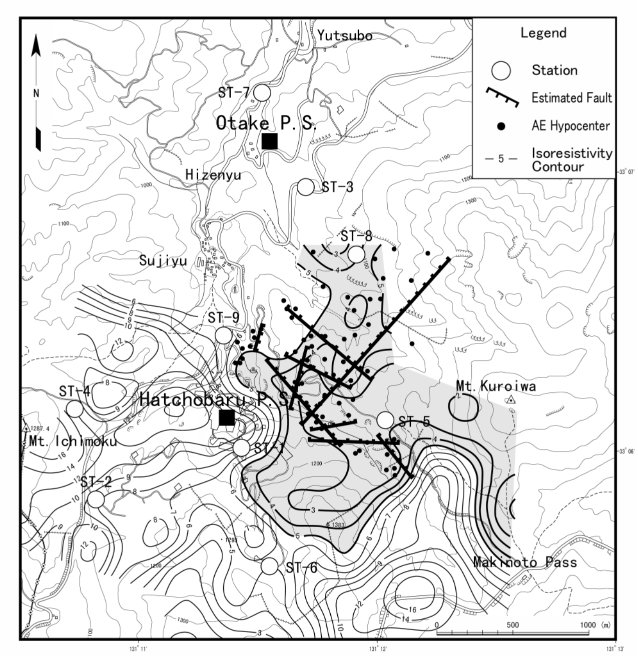

Figure 11 Iso-resistivity Map of Low Resistivity Layer

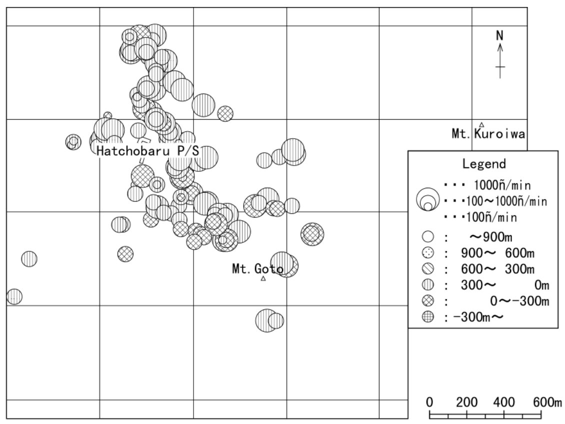

Figure 12 Location of Lost Circulation zone