AE HYPOCENTER DISTRIBUTION COMPARED WITH DETAILED GRAVITY DATA AND RESISTIVITY IN THE HATCHOBARU GEOTHERMAL FIELD

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ABSTRACT

In the Hatchobaru geothermal field, located in the central part of Kyushu, Japan, we have been carrying out AE (acoustic emission) observation using boreholes in a 6-station network since December 1996. Over a thousand AE and several AE swarms were observed over a ten-month period.

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

AE data is effective for estimating faults. 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 from AE data.

1.0 INTRODUCTION

The Hatchobaru geothermal field is located as shown in Figure 1 in the central part of northern Kyushu, and the 12.5 MW Hatchobaru geothermal power plant is 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 fiactures connected with geothermal fluid flow is examined in this study.

2.0 OBSERVATION

The structure of the observation system is shown in Figure 2. Observation stations measure the 3 components - N-S, E-W, and U-D movement - at six stations which are shown in Figure 3. Observation data are transmitted after amplification to avoid the

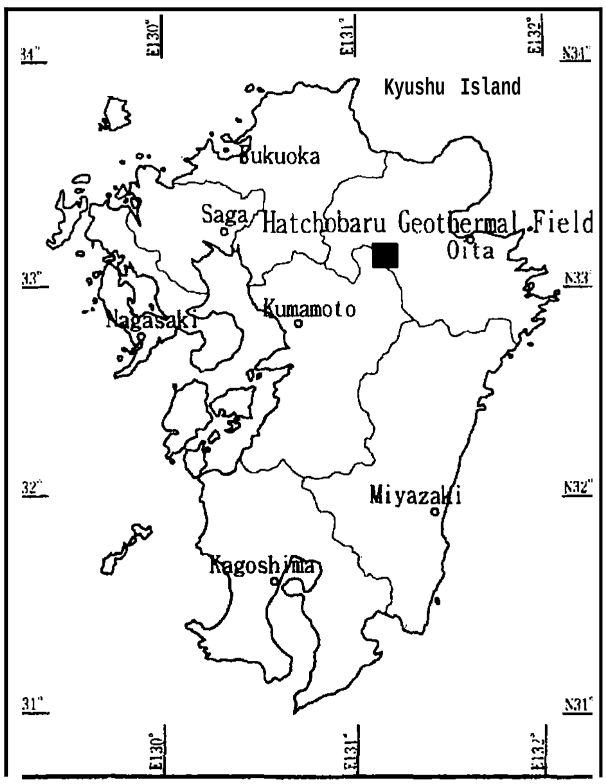

Figure 1. Location of the Hatchobaru geothermal field.

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 Recorded data are *analyzed* with MEPAS (micro-earthquake data processing and analysis system) (New Energy and Industrial Technology Development Organization, 1992).

3.0 OBSERVATION RESULTS

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

3.1 *AE* Hypocenter Distribution

A map of AE hypocenters observed from December 1996 to September 1997 is shown in Figure 4. In the ground plan on the upper left of Figure 4, hypocenters are concentrated northeast of the Hatchobaru power plant surrounded by ST-1, ST-3 and ST-5, and north of ST-3. The concentrated AE source region northeast of the Hatchobaru power plant is distributed about -1 km above sea level, as shown by the north-south section on the upper right *of* Figure 4. The source region north of ST-3 shows a tendency to become deeper to the north in the cross section. Figure *5* shows the daily AE frequency. Several AE swarms were observed over a ten-month period.

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 possiblefor AE swarms occurring temporally and

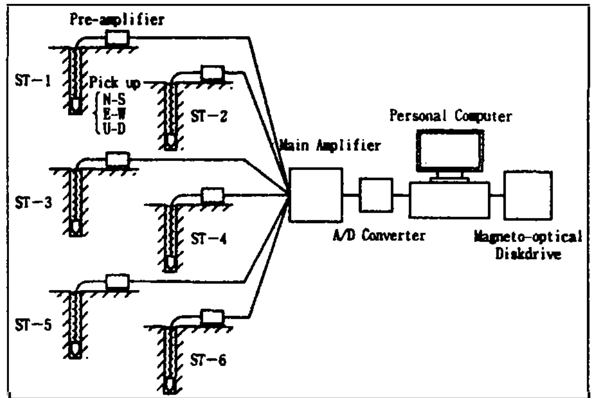

Figure 2. Structure of the observation system.

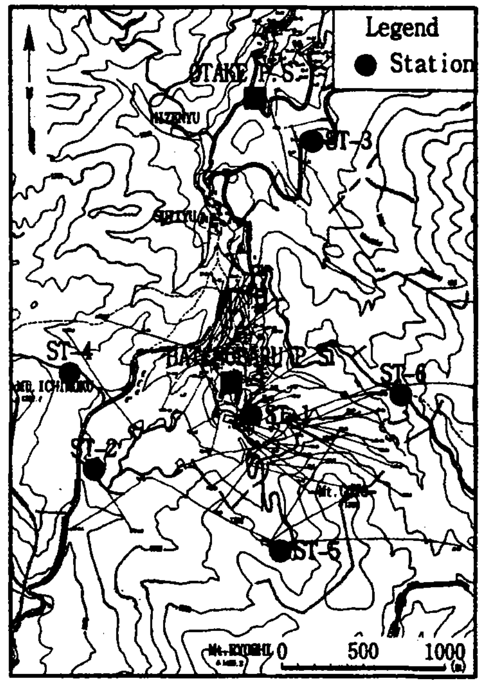

Figure 3. Location of the stations.

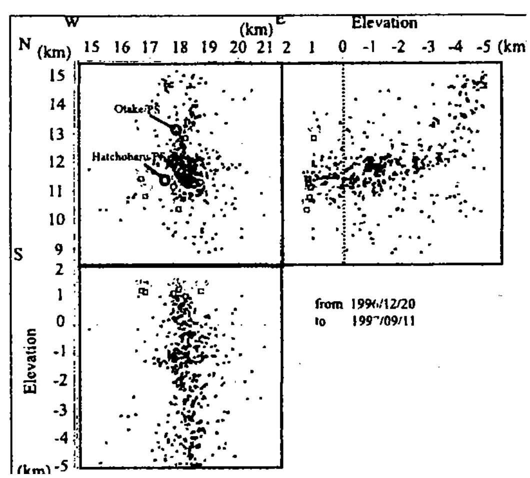

Figure 4. Map of the AE hypocenter distribution

spatially close together to show the same focal mechanisms. 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 intermediate between a normal fault, a reverse fault and a strike-slip type are recognized. The Hikosan Collaborative Research Group (1992) explains the tectonics **of** the "Kuju-Beppu Graben" northwestern part **of** Kyushu island as being due to the north-south compression and the east-west compression stress fields. It considers that that is also the AE energy source in the Hatchobaru area. 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 fi-om nodal planes extending in a northwest-southeast, northeast-southwest and east-west directions.

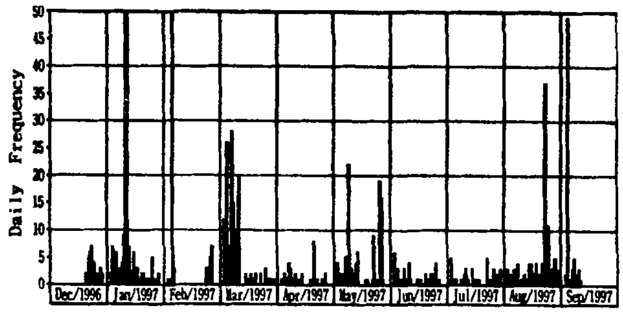

Figure 5. Frequency of AE.

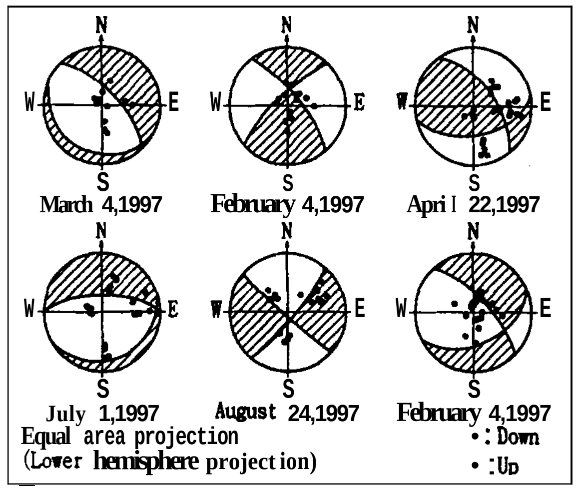

Figure **6**. Focal mechanism.

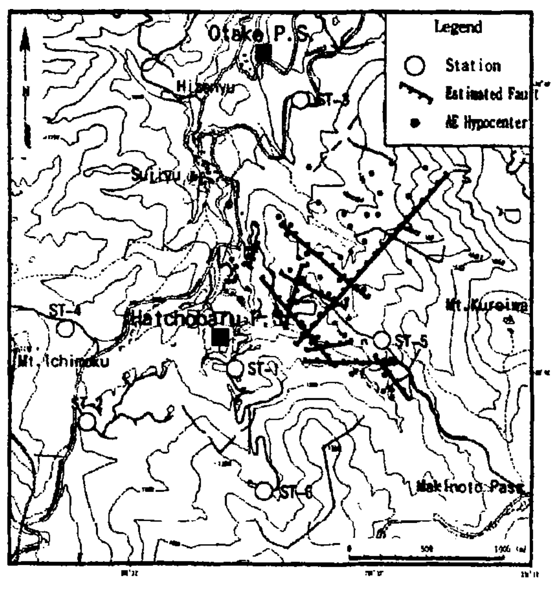

Figure 7. Location of faults estimated by focal mechanism analysis.

4.0 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 **8** to 10. **A** Bouguer anomaly and estimated faults are shown in Figure **8.** The Bouguer anomaly iso-gravity contours extend in **a** northwest-southwest direction fi-om 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 fkom Mt.Kuroiwa to ST-5 and the Hatchobaru power plant. In addition, iso-gravity contours run in a north-south direction around ST-9 fiom 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 **9.** 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.

Tectonics at the island arc system along the Nankai trough is the energy source **of** the AE which 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. Tectonics at the island arc system along the Nankai trough is not the only energy source **of** the repeated AE occurrence because both compression and tension are recognized in the same direction as the AE source mechanism. In the two areas around ST-1, **ST-2,** and ST-3 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 11). The

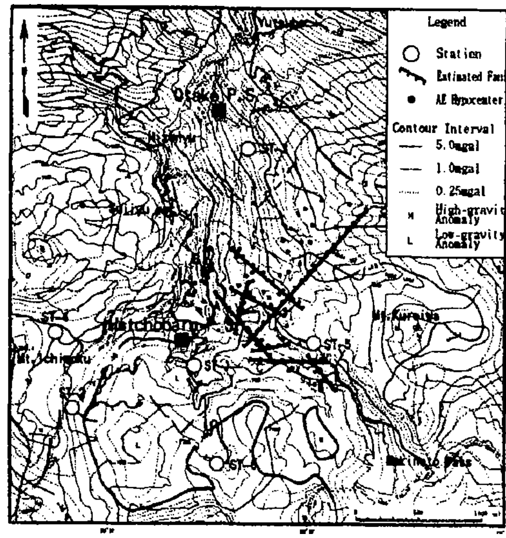

Figure **8.** Bouguer anomaly **map.**

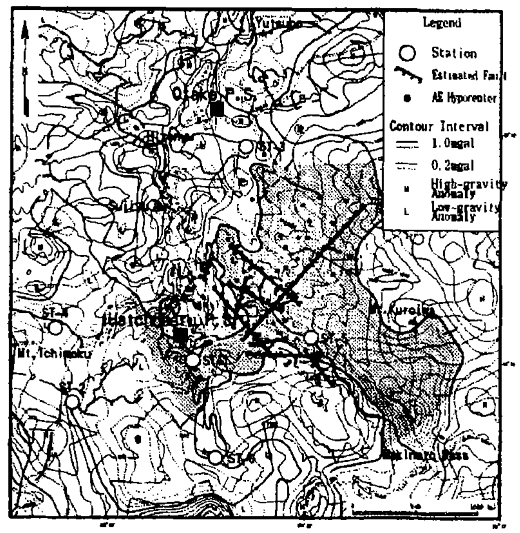

Figure 9. Residual gravity **map.**

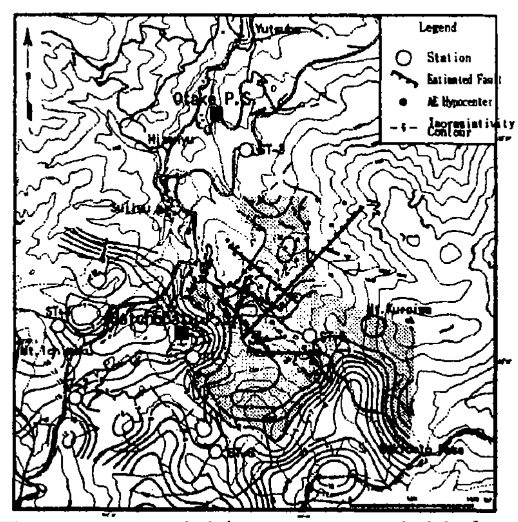

Figure 10. Iso-resistivity map of **low resistivity** layer.

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.

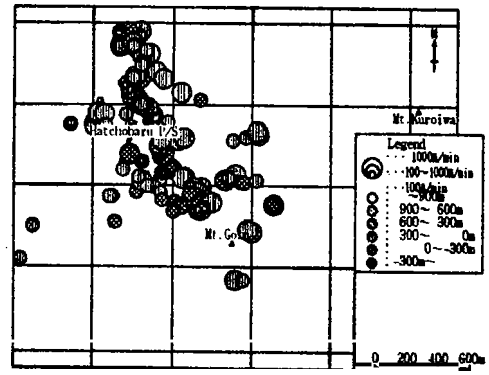

Figure 11. Location **of lost** circulation zone.

5.0 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 fiom 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.**

AE occur in the Hatchobaru geothermal field caused by shearing due to stress concentration on a point where the rock strength is poor. **As** many cracks appear due to the shearing, permeability increases and geothermal fluid flow becomes active, the hydrothermal alteration proceeds and the rock resistivity and density fall. When the rock strength declines as a result of the hydrothermal alteration, it is hard for rocks to accumulate the distortion energy, and they are sheared again. Many AE occur in the area northeast of the Hatchobaru power plant , where AE swarms are observed, and good actual drilling results can be obtained here close to the faults estimated by AE analysis. This is considered to be a good permeable area and is expected to be a promising drilling target.

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