FRACTURE SYSTEM AND FLUID FLOW IN THE TAKINOUE GEOTHERMAL AREA INFFERED FROM THE MICROEARTHQUAKE STUDY

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1. INTRODUCTION

Recent geothermal exploitation and geophysical and geological investigation at geothermal areas lead to recognize the importance of the fracture system in geothermal reservoir. Fluid flow in rocks plays a central role in geothermal energy recovery. Fractures act as major fluid flow path. Permeability is controlled by fractures and is not homogeneous at all as in the case of porous media. So the mapping and evaluation of chracteristic (for example permeability) is of crucial importance. However few results give us sufficient knowledge on the fracture system, for example three-dimensional configuration of fluid flow path and permeability. In this paper, we discuss fracture system and fluid flow in the Takinoue geothermal area based on our microearthquake data.

2. TAKINOUE GEOTHERMAL AREA

The Takinoue geothermal area is located in the central part of the Hachimantai volcanic region,northern Honshu,Japan (Fig.1). It is known as a hot water dominated system, although the Matsukawa geothermal area,which is only 7km northeast of the Takinoue area, is a vapor dominated system. The Kakkonda geothermal power plant has been in full operation of 50 MW since the end of May, 1978. Most geothermal wells (production and re-injection wells) were drilled by directional drilling method from the five drilling base areas (denoted as A,B,C,D and E in Fig.2 and 3).

Almost all the geothermal fiuid is re-injected into re-injection wells. Occurrence of geothermal fluids is controlled by highly permeable zones provided by fault and fracture system (Sato,1982;Doi et al.,1988).

3. SEISMICITY OF THE TAKINOUE AREA

Fig.1 shows the hypocenter distribution of the Takinoue area for one year period. The hypocenters are determined with the P-arrival times of 8 permanent seismic stations installed around the Takinoue area (Ito and Sugihara,1986). Sold and broken line in Fig.2 and 3 depict the production and re-injection wells, respectively.

Almost all the microearthquakes occuring in the Takinoue area have high peak frequency (40~50Hz) and magnitude is estimated to be about 2.0~-1.0. Microearthqukes are occuring almost continuously in the region covering the production zone and extend to SE direction beyond the production zone.

4. SEISMICITY DURING THE BUILD-UP TEST

SEISMICITY

During the build-up test of June,1985, we installed 10 temporal seismic stations in addition to the 8 permanent stations (Fig.1). During the temporal observatin of 5 days, more than 600 locatable microearthquakes occured in the Takinoue area. The wellhead valves at all production wells were subsequently closed in the test (Niitsuma et al.,1987). The pore pressure around the wells change associated with the valve closure.

In Fig.3, hypocenters during the build-up test are shown. During the build-up test, hypocenters cluster around the production wells at first,then extend to SE direction. Fig.4 shows the space time plot of epicenters for two cross sectins: NW-SE and NE-SW cross section. It is clear from Fig.4 that epicenters migrate beyond the production zone in the NW-SE cross section in the NW to SE direction, whereas in NE-SW cross section epicenters stay wiyhin the production zone.

THREE DIMENSIONAL VELOCITY STRUCTURE

Using the P-arrival time of 8 permanent and 7 temporal stations, we derived three-dimensional P-wave velocity structure. We did not use arrival time data for three temporal stations because of the timing inaccuracy. We used program SIMUL3 by Thurber (1983) for the velocity inversion. As initial velocity model is critically important in velocity inversion, we constructed the initial velocity models based on the the velocity structure from the analysis of the explosion data (Sugihara et al.,1988a) and conducted the inversion process for various initial model.

In Fig.5, obtained velocity structure is shown. Contours in Fig.5 show the P-wave velocity in km/sec. There is low velocity zone extends NW to SE,covering the production area of the Kakkonda power plant. There are high velocity zones north, southeast and southwest side. If we compare these results with geologic structure shown in Fig.6 (Doi et al.,1988), it is clear that high velocity zones correspond to intrusive rocks;Matsuzawa tonalite intrusion, Torigoenotaki dacite and Porphylite intrusion. The low velocity region corresponds very well with the fractured zone in Fig.6.

FOCAL MECHANISM

Focal mechanisms are determined for each event using P-wave polarity of 18 stations(data from three stations are used for focal mechanism analysis) by grid search method (Reasenberg and Oppenheimer,1985) using hypocenter location determined by three dimensional velocity structure. Almost all the focal mechanisms have double couple solution. No non double couple event was found.

5. FRACTURE SYSTEM IN THE TAKINOUE AREA

Kaneshima et al.,(1988) studied shear-wave splitting and found almost uniform alignment of the polarizations of faster split shear-wave in ENE-WSW direction. This may result from th epresence of aligned liquid filled microcracks.

They further analyzed the delay times between the faster and the slower split shear-waves and found the the region of anomalously large delay times. This region is in the low velocity zone by the three-dimensional velocity inversion. As the delay time between the faster and slower split shear-wave is considered to be caused by the microcacks,the high delay time means the the region trough which the ray pass has high crack density.

The velocity of crustal rocks is controlled by various parameters;pressure,temperature, rock type,crack density,crack aspect ratio, degree of saturation in the cracks etc.. The low v elocity in the Takinoue area is considered due to cracks or fractures saturated with water, because low velocity region corresponds to the region of large delay times of split shear waves and fractured zone estimated by drilling and well test results.

Ito and Sugihara(1988) found that hypocenters seem to migrate from the geothermal wells during the build-up test in 1984. They assumed that pore pressure increase, caused by the valve closure of the production wells, diffuse away from the well along a fracture and triggers microearthquakes. If this assumption works, we might be able to estimate fluid flow paths from the hypocenter distribution and permeability from the migration rate of the hypocenters.

Fig.7 shows an example of the hypocenter migration during the build-up test in 1985.Plane view (upper left),E-W cross section (lower left) and N-S cross section(upper right) are shown. Epicenters are shown with the results of focal mechanism analysis. If we choose the high angle plane out of two nodal planes,those planes are almost in accordance with the line shown by the solid line in the plane view that depict the migration direction.

Fig.4 shows that hypocenters migrate in very anisotropic way;from NW to SE in a large scale. In a small scale however,as shown in Fig.7, fluid flow path inffered from the microearthquakes are not always aligned in this direction.

One of the explanation of this is as follws;small scale fractures,that have rather diversed direction,form an aligned fracture system in accordance with the maximum horizontal stress direction(in Takinoue,NW-SE).

6. CONCLUSION

(1) Hypocenter distribution in the Takinoue geothermal area have close relationship with fracture (crack) and pore pressure distribution. If we assume that effective pressure and stregth decrease in the region with high fracture (crack) density and high pore pressure, then microearthquakes are triggered. In other words, hypocenters of microearthquakes may represent geothermal reservoir in the meaning that high fracture density and high pore pressure is major constituents of geothermal reservoir.

(2) In some cases, hypocenters migrate associated with increase in the pore pressre. In this case, it is possible to estimate fluid flow paths from the hypocenter distribution and permeability from the migration rate.

(3) The observation with a large number of seismic stations enabled us to obtain three-dimensional velocity structure and focal mechanisms for each microearthquake event. Three-dimensional velocity structure is consistent with geologic structure estimated from drilling results. Low velocity region corresponds to the region with high crack density. Combined with hypocenter and low velocity zone, highly cracked (fractured) region is estimated.

One of the nodal planes determined by the focal mechanism analysis may represent plane of existing fractures. Focal mechanism analysis might provide us informations on fracture plane. This is especially useful when enuogh microeartquakes are not obtain to deduce fracture system from hypocenter distribution only.

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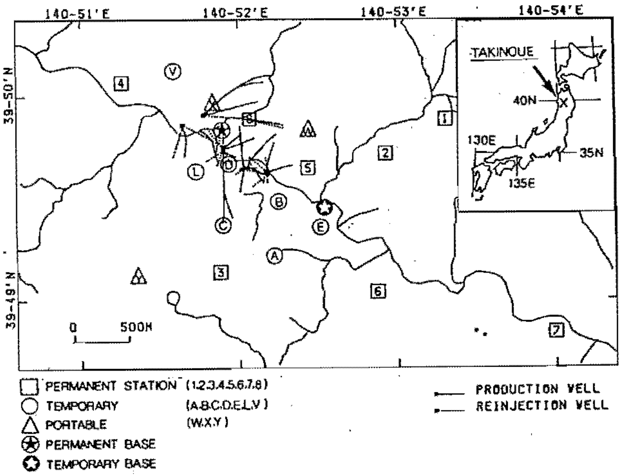
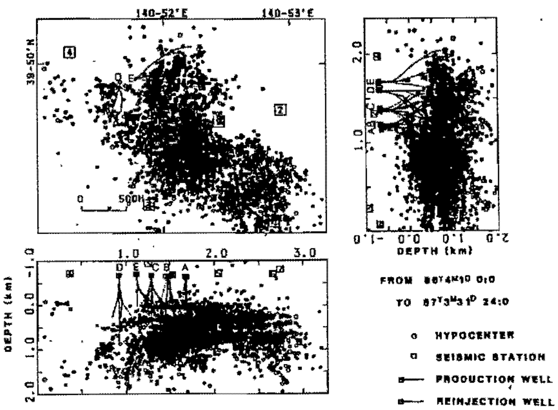


Fig.1 Map showing thw seismic stations and geothermal wells.



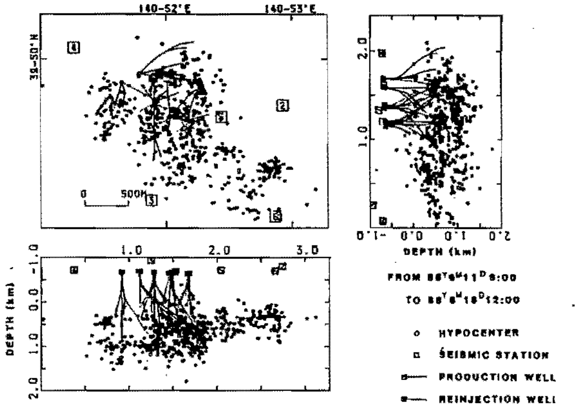


Fig.2 Hypocenter map for 1 year period. Fig.3 Hypocenter map during the build-up test in 1985.

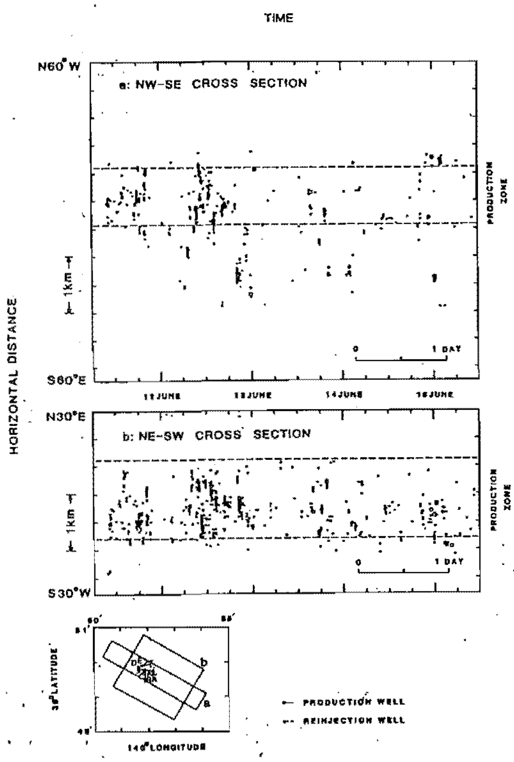


Fig.4 Space time relation of epicenters.

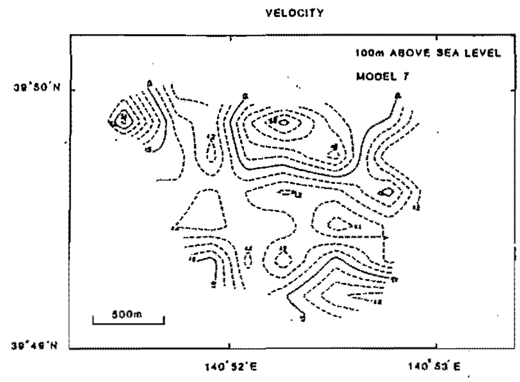


Fig.5 An example of the three-dimensional velocity structure.

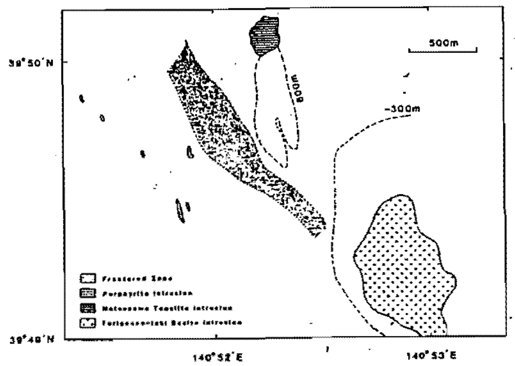


Fig.6 Geological structure of the Takinoue area(simplified from Doiet al.,1988).

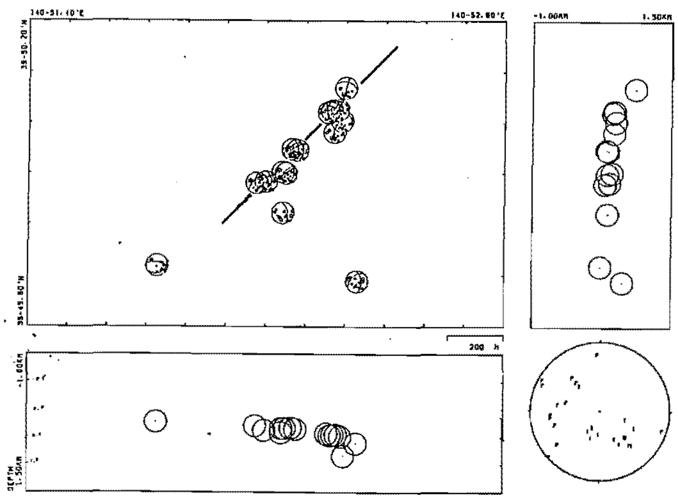


Fig.7 An example of the hypocenter migration.