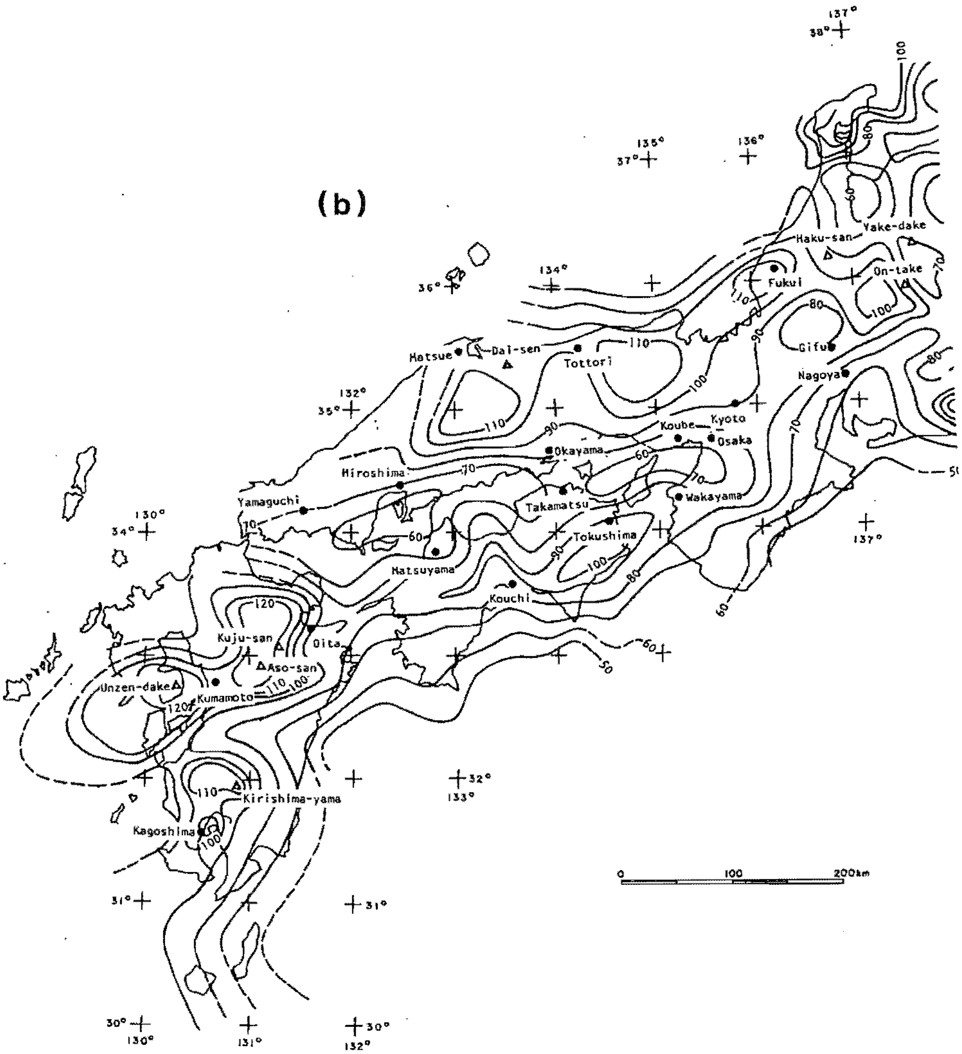

Fig.1 Heat flow map estimated from the Curie depth map, assuming constant heat flow with increasing depth and temperature gradient of (435°C)/(Curie depth) and thermal conductivity of 2 W/m·K in the shallow zone on the whole area. Contour interval is 10 mW/m^2. (a) East Japan (b) West Japan.

FRACTURE MAPPING IN FRACTURED RESERVOIR ON JMC'S GEOTHERMAL DEVELOPMENT

SATO, Ko, Japan Metals and Chemicals Co.,Ltd. 24-Ukai, Takizawa, Iwate 020-01,Japan

Japan Metals and Chemicals Co.,Ltd.(JMC) and its related company have three geothermal power plants, that is, Matsukawa (22MWe), Kakkonda (Takinoue) Unit 1 (50MWe) and Mori (50MWe), and are currently developing Kakkonda Unit 2. JMC is also concerned with developing of La Primavera, Mexico and San Kampaeng, Thailand. These geothermal fields are all characterized by fractured reservoir consisting of open fractures in compact and hard rocks.

To evaluate fractured reservoir, JMC has accepted a combination method of fracture mapping as follows:

1) Detection of each individual fracture around borehole
2) Survey on extension of fractures
3) Recognition of fracture pattern

DETECTION OF EACH INDIVIDUAL FRACTURE AROUND BOREHOLE

Lost circulation of mud water during drilling indicates permeable zone around borehole, but does not show the portion of individual fracture. Lost circulation occurs not only encounter fractures but loss of pressure balance between formation pressure and wellbore pressure. In this case, JMC has adopted PTS (pressure, temperature and spinner) logging during well production after drilling to determine the portion of individual fracture.

PTS logging, however, cannot indicate the orientation (dip and strike) of fracture. So that, another logging is now in progress to detect the fracture orientation. For example, the dip meter and borehole televiewer surveys have carried out in 690 - 1,290 m and 1,020 - 1150 m in depth of KT-208 (Kakkonda test well-208) by Schlumberger Japan Inc. and Geological Survey of Japan, respectively. The measurement by dip meter makes clear the dip and dip direction of fractures around borehole in spite of having a limitation of logging temperature (below 177°C). The orientation of fractures is also measured by borehole televiewer under water injection to cool borehole.

SURVEY ON EXTENSION OF FRACTURES

To know the extension of fracture, new surveys have been tried by JMC in addition to conventional surveys including tracer test and pressure interference test.

An extensive multi-offset VSP (Vertical Seismic Profiling techniques) was carried out at Mori geothermal field in 1985 to map the extent of production fractures and to determine the existence of any similar fractures.

- Energy source. a Mertz model 13 shear wave vibrator being rotated 90 degrees to determine shear wave anisotropy
- Geophone . 3 component high temperature and 4-channel recording system at a 1ms sampling rate at every 20 m by SSL inc.
- Analysis . tomographic inversion and identification of VSP reflectors by LBL (Majer *et al.*, 1986).

At first, the parameter that we could map is the difference in the S-wave velocity as a function of source position, because gimbled geophones were not used and the well wes deviated. Fig.1 shows a pixel map of the differences in S-wave velocity by the tomographic inversion from two orientations of the offset 4 vibrator. The quite differences in the SH and SV in Fig.1 are consistent with the geological anisotropy such as caldera wall and boundaries of formation.

Secondly, VSP deep reflection results show that the evidence of reflectors are probably just the wall of caldera and layering within the caldera. Because the caldera is shaped like a funnel, the waves obtained from VSP reflection are reflected at the opposite wall.

Finally, we have tried the reprocessing of surface seismic reflection in light of the information gained from the VSP results. That is to say, the VSP data on the general velocity structure enable refined velocity models for the surface seismic reflection reprocessing. Fig.2 shows the extension map of fractures integrated by tomographic/VSP, VSP deep reflection and surface seismic reflection in the northern part of Mori geothermal field.

Moreover, the acceleration-sensitive long-distance AE measurements have carried out during build up test and hydraulic fracturing as a new survey to determine the extent of production fractures. The details of AE measurements are discussed in separate paper of this symposium by Takanohashi *et al.*(1988).

RECOGNITION OF FRACTURE PATTERN

The above mentioned method for fracture detection is mainly based upon geophysical techniques, and is visible as records of measurements including logging chert, reflection record and AE sources. These records, however, indicate the data within restricted measuring areas, that is, the data based on signals between sonde and sources.

To map the fracture pattern in fractured geothermal reservoir, it is important to estimate the regularity of fracture development by means of geological approach as well as geophysical techniques. Although the geological approach is more subjective and empirical than geophysical approach, it suggests correctly the subsurface fracture pattern which is not visible. For example, Doi *et al.* (1988) present the permeable fracture distribution of the Kakkonda (Takinoue) geothermal reservoir in separate paper of this symposium. Based on this presentation and my geological research of the Kakkonda field, it can be shown the geological development and history of tectonic movement of this area in Fig.3. Fig.3 shows various significances of fracture pattern in geological history. Looking at the fracture direction, it becomes the following estimation given below.

NW-SE and NE-SW trending fractures.

1) These fractures in basement rocks (Pre-Tertiary rocks) were formed by block movement accompanied with the spreading of Japan Sea in early Miocene.
2) These fractures in Tertiary rocks were formed by the uplift of Backbone Range. When the basement moved vertically along the pre-existing faults, the plastic sediments of Miocene caused shear faults of NW-SE and/or NE-SW. The shear faults are affected by the pre-existing faults and are developed in deeper reservoir.

NS and EW trending fractures.

When the uplift of Backbone was large in late Neogene, the σ_1 (maximum compressive stress) increased, resulting in facilitation of open fractures. The open fractures trend mainly NS and/or EW which is the regional stress fields of Japanese Island in this time, and are developed in shallow reservoir.

CONCLUSION

To map the fractures in fractured reservoir, it is important to estimate the regularity of fracture development by geological approach as well as geophysical new techniques such as VSP, AE measurements, dip meter and borehole televiewer.

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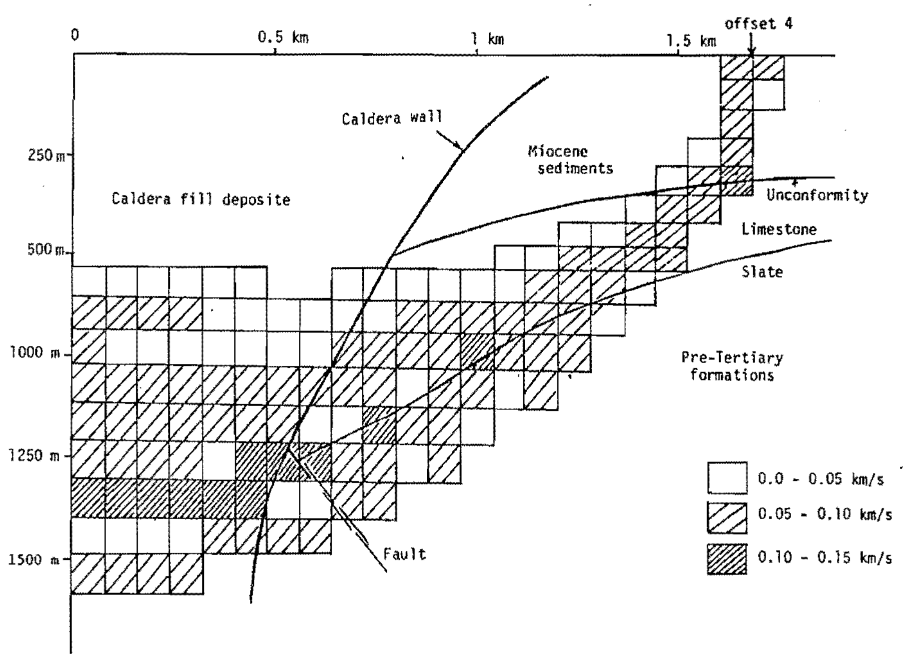

Fig.1 The tomographic inversion result obtained from the VSP offset. Shown are the differences in S-wave velocity from two orientations of the vibrator. Velocity range is from 0.00 to 0.15 km/s.