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THE FAULT SYSTEM AND GEOLOGICAL STRUCTURE OF THE OGUNI GEOTHERMAL FIELD, CENTRAL KYUSHU IN JAPAN

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ABSTRACT

The Oguni geothermal field lies in a large basin referred to as the Beppu-Kuju Subsidence Zone, and is located on the northwestern boundary of the Kuju Uplift Belt, and the southwest rim of the Shishimuta Subsidence Belt. Many faults and fracture systems were inferred to be present along the steep slope of the basement on the margin of the Kuju Uplift Belt with a strike thought to be NW-SE. The Takenoyu Fault runs through the central part of the Oguni field, and is thought as the representative fault that strikes NW-SE trend. The Takenoyu fault has vertical offset of over 400 meters. It's appeared that there is high-angle reverse fault in the north of the Takenoyu Fault by geologic correlation of the wells. A pair of these faults forms a local horst structure. These faults form a nearly vertical zone of high permeability with several hundreds meters wide as the geothermal reservoir. The *in situ* stress field estimated by the drilling induced tensile fracture data in the Oguni field approximately conforms to seismogenic-stress and general tectonic stress in the central Kyushu. The direction of the principal geological structure in the Oguni field is also in accordance with that of maximum compressive stress ($\sigma 1$).

1. INTRODUCTION

The Oguni geothermal field is located in the central Kyushu, southwest Japan. The Oguni geothermal field extends to both the Kumamoto and the Oita Prefectures along the west foot of Mt. Waita (elevation 1500 m), the western-most volcano of the northwest trending Kuju volcanoes. The elevation of the study area is 700 to 900 meters above sea level (ASL). Electric Power Development Co., Ltd. (EPDC) has been developing the Oguni geothermal power station. The Oguni field is a part of the Hohi region, which has one of the highest geothermal potentials in Japan. Within the region, there are three geothermal power stations; Hatchobaru (55 MW*2), Otake (12.5 MW) and Takigami (25 MW).

Geothermal investigations at the Oguni field have been conducted since the 1950s by the local government of Kumamoto, the national government and private companies. In particular, Ministry of International Trade and Industry (MITI) surveyed a large area of approximately 200 square kilometers that included the Oguni field, in order to study a potential of large-scale geothermal power development from deep-seated resources (NEDO, 1987). EPDC began explorations at the Oguni field in 1983 after the national survey program (Fujita and Abe, 1988). EPDC conducted a systematic exploration program consisting of various geophysical surveys and the drilling of 23 exploratory wells, including 12 slim core holes and 11 large diameter wells. Using these data and the results of reservoir engineering studies, EPDC planned the Oguni geothermal development.

This paper presents the fault system and geological structure of the Oguni field delineated by various geothermal surveys and well drillings.

2. GEOLOGICAL SETTING

2.1 Geological Setting

Based on the regional gravity map, the Oguni field lies in a large basin referred to as the Beppu-Kuju Subsidence Zone (BKSZ) as shown in Fig.1. The BKSZ is characterized by large-scale andesitic volcanism associated with north-south extension since the early Pliocene (Abe *et al.*, 1995, Yamada *et al.*, 2000). The continuous extension, subsidence and volcanic activities influence the local geologic structure. The Oguni field lies on the northwestern boundary of the Kuju Uplift Belt, which was probably caused by magmatic intrusion associated with the Kuju volcanoes, and the southwest rim of the Shishimuta Subsidence Belt, a thick sedimentary basin. Many faults and fracture systems are inferred to be present along the steep slope of the basement on the margin of the basin based on the evidence of drilling.

2.2 Local Geology

The stratigraphy of the Oguni field, in ascending order, consists of the following units: basement composed of Pre-Tertiary granitic and metamorphic rocks, the Pliocene Taio formation of andesitic rocks, the early Pleistocene Shishimuta formation of dacitic pyroclastic rocks lying particularly thick in the Shishimuta Subsidence Belt, the middle Pleistocene (2 to 0.5 Ma) Hohi Volcanic Rocks of pyroxene andesite, the late Pleistocene Kusu Group of sedimentary and dacitic rocks which interfinger with the Hohi Volcanic Rocks, and the late Pleistocene to Holocene Kuju Volcanic Rocks (NEDO, 1987). Among these formations, the Shishimuta formation, the Hohi Volcanic Rocks and the Kusu Group are the most important for the Oguni reservoir system. The first two are brittle and fracture easily. These fractures persist and form a horizontal permeable layer for the reservoir above the steep slope of the basement rocks. The Kusu Group has several impermeable sedimentary layers such as the Nogami Mudstone, and plays a role as cap rock above the reservoir. Some hydrothermally altered and impermeable layers of the Hohi and the Kuju Volcanic Rocks also play the same role (Yamada *et al*., 2000).

3. FAULT SYSTEM

3.1 Takenoyu Fault

The basement drops off steeply to the northeast, and many faults are presumed to extend with the NW-SE direction at this part of the field; some of these faults were encountered by exploratory wells. A representative fault with the same strike, the Takenoyu Fault runs through the central part of the reservoir system as shown in Fig. 2. This fault is not apparent at the surface; however, several geophysical surveys and the geological sequence indicated by drilling confirms its existence. Several wells were drilled on both sides of the fault. The Shishimuta formation was encountered at a higher elevation on the northern side of the fault with vertical offset of over 400 meters as shown in Fig. 3.

Lost circulation during well drilling occurs in particular nearby the Takenoyu fault. Drilling results also indicate that the Takenoyu Fault is accompanied by parallel faults that form a nearly vertical zone of high permeability with several hundreds meters wide as the geothermal reservoir. Fig. 4 indicates the relationship between lost circulation during drilling and fracture distribution estimated by geophysical and geological surveys. A sketch of typical fracture as boring core is shown in Fig. 5 (Tezuka *et al*., 1995). Total lost circulation occurred at the depth acquired the core during well drilling. According to the observation of the core samples, lots of small fractures aggregate like network, furthermore the gaps are often filled with drusy secondary minerals (e.g., quartz, anhydrite, calcite).

3.2 Horst Structure and Reverse Fault

On the southwest edge of the Shishimuta Subsidence Belt in the north of the Takenoyu Fault, the Shishimuta formation is thick, and its top occurs at the same elevation as on the southern side of the fault as shown in Fig 3. This suggests that a hidden fault runs to the north of the Takenoyu Fault, and that a pair of these faults forms a local horst structure. Fig. 6 shows a north-south schematic cross section of the Oguni geothermal field. Drilling result indicates that many fractures are developed in the horst structure.

The repeated appearances of top boundary of the Shishimuta formation were observed in two re-injection wells (GH-21, GH-23) drilled in the north of the Takenoyu Fault. This suggested the existence of high-angle reverse fault (Tezuka *et al*., 1995). The reverse fault is considered to be also apparent open fracture as shown in Fig. 5 from the drilling data such as lost circulation and weight on bit during drilling.

3.3 Recent Stress Field

Okabe *et al*. (1998) proposed a new method to estimate an *in situ* three-dimensional stress field by using data of drilling-induced tensile fractures (DTF). In the Oguni field, borehole televiewer loggings were carried out in two re-injection wells (GH-21, GH-23) to understand the detailed fracture system (Shimizu and Todaka, 1998). We estimated a contemporary *in situ* three-dimensional stress field by using the DTF data extracted from the two re-injection wells with the method of Okabe *et al.* (1998). The results are shown in Fig. 7. The maximum compressive stress ($\sigma 1$) is WNW-ESE direction, the intermediate compressive stress ($\sigma 2$) is nearly vertical and the minimum compressive stress ($\sigma 3$) is NEN-SWS direction. This stress state corresponds to the strike slip fault type.

4. DISCUSSION

The horst structure in the Oguni geothermal field might have been caused by local uplift and subsidence of the basement before the Kuju volcanic activity (Abe *et al.*, 1995). Kuniyasu (1982) restored the inverted folding associated with uplift and subsidence of the basement through laboratory study, and reported the production of reverse fault in the experiment. Nakano *et al.* (1983) reported the structure of geothermal areas that are characterized by collapse basins and lifted blocks, and the lifted blocks are considered to be tossed blocks abutted with high-angle reverse faults and/or vertical faults. These papers suggest that the horst structure and high-angle reverse fault would be formed in association with local uplift and subsidence of basement at the Oguni field.

On the other hand, the central Kyushu district is situated in the tectonic structure at which the strike slip type and normal type fault system produces the active seismicity (Sudo, 1993). The tension axes strike to the N-S or NW-SE direction, while the compression axes are in the E-W or NE-SW direction (Shimizu *et al.*, 1993). The stress field estimated by the DTF data in the Oguni field approximately conforms to above seismogenic-stress and general tectonic stress in the central Kyushu. The direction of the principal geological structure in the Oguni field is also accordance with that of maximum compressive stress ($\sigma 1$) estimated by the DTF data.

5. CONCLUSION

Geologic correlation of the wells and several geophysical surveys indicate that some parallel faults represented by the Takenoyu Fault form a local horst structure in the Oguni geothermal field. This horst structure would be formed in association with local uplift and subsidence of basement. The direction of this geological structure is in accord with recent stress field in the central Kyushu. The Takenoyu Fault and the horst structure play important roles as the geothermal reservoir in the Oguni field. We need the further detailed study to clarify between the geological structure and the recent stress field to develop the geothermal resources in the Oguni field.

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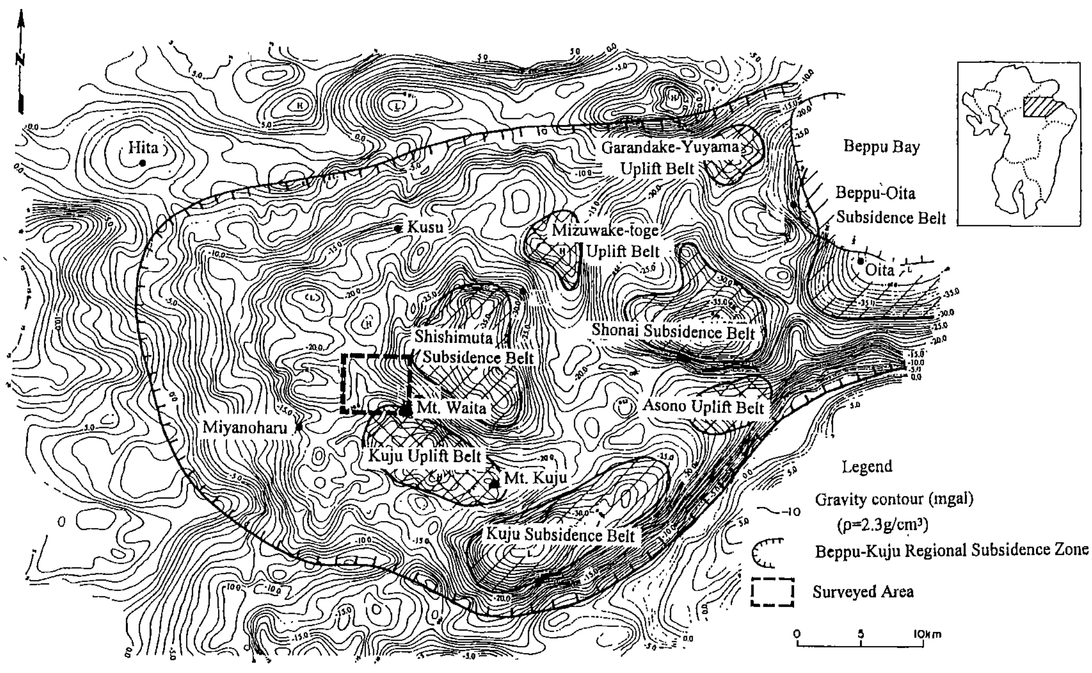

Figure 1. Regional gravity map in central part of Kyushu (NEDO, 1987).

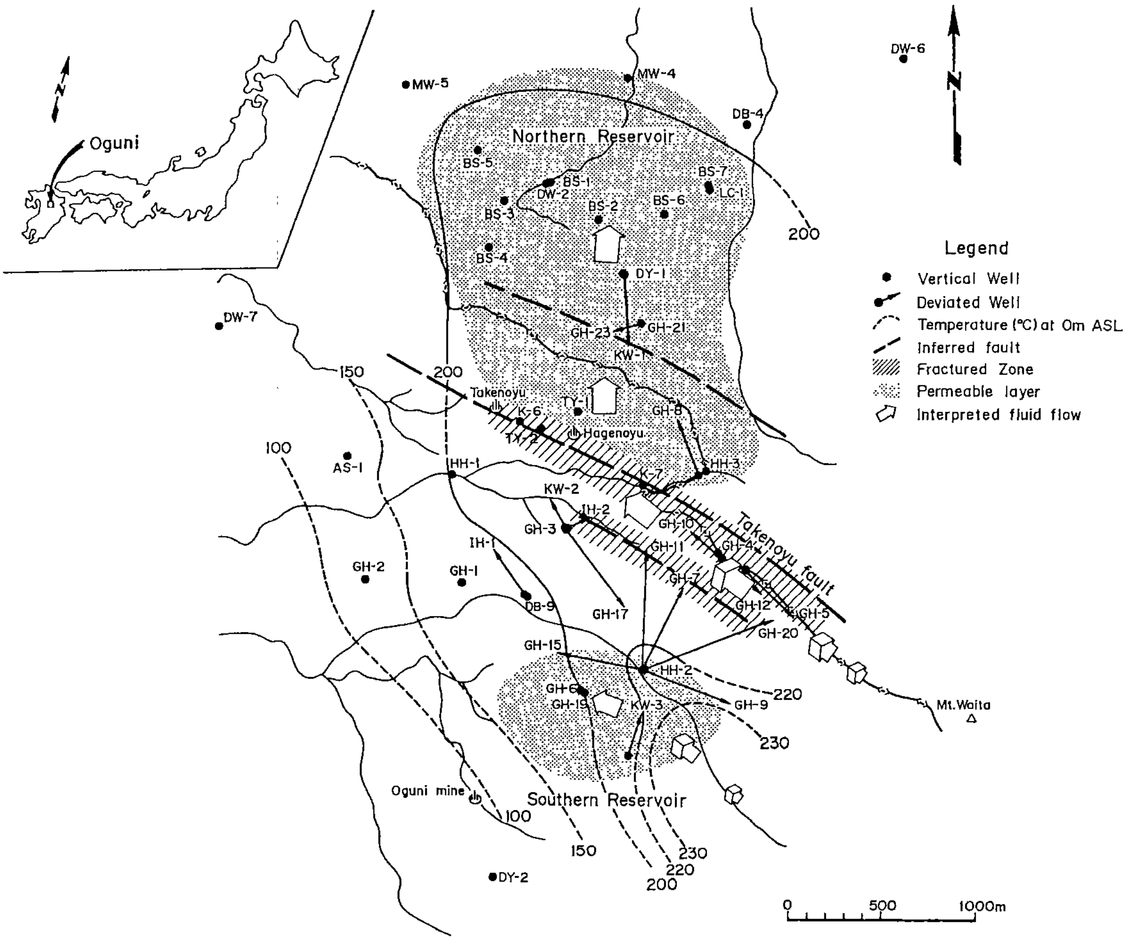

Figure 2. Characteristics of the Oguni reservoir.

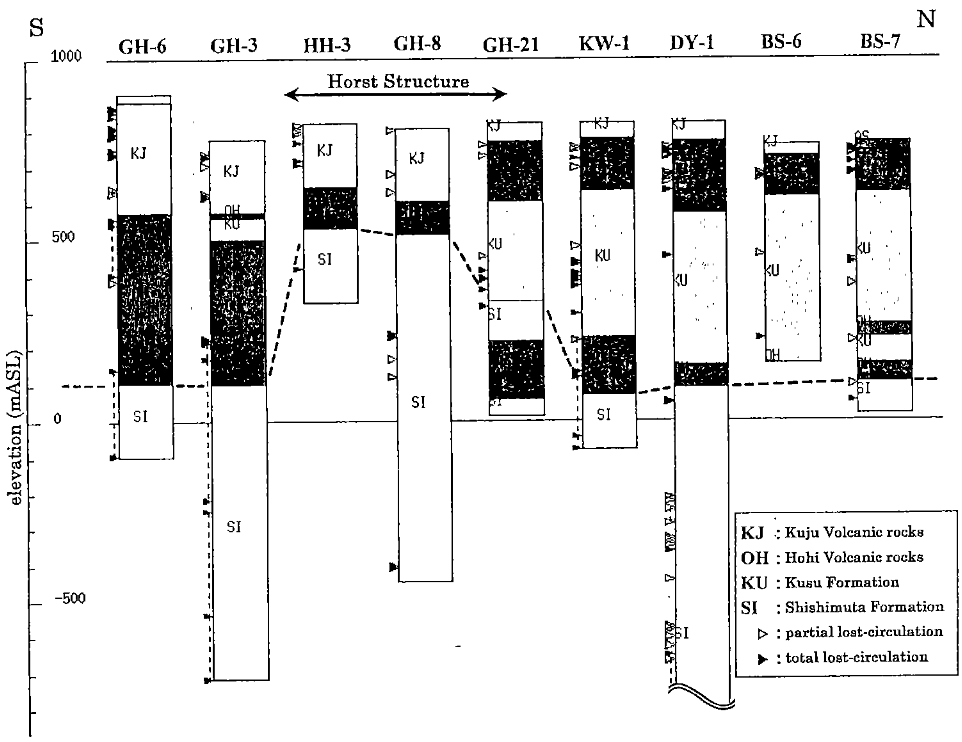

Figure 3. Correlation of the columnar sections of wells.

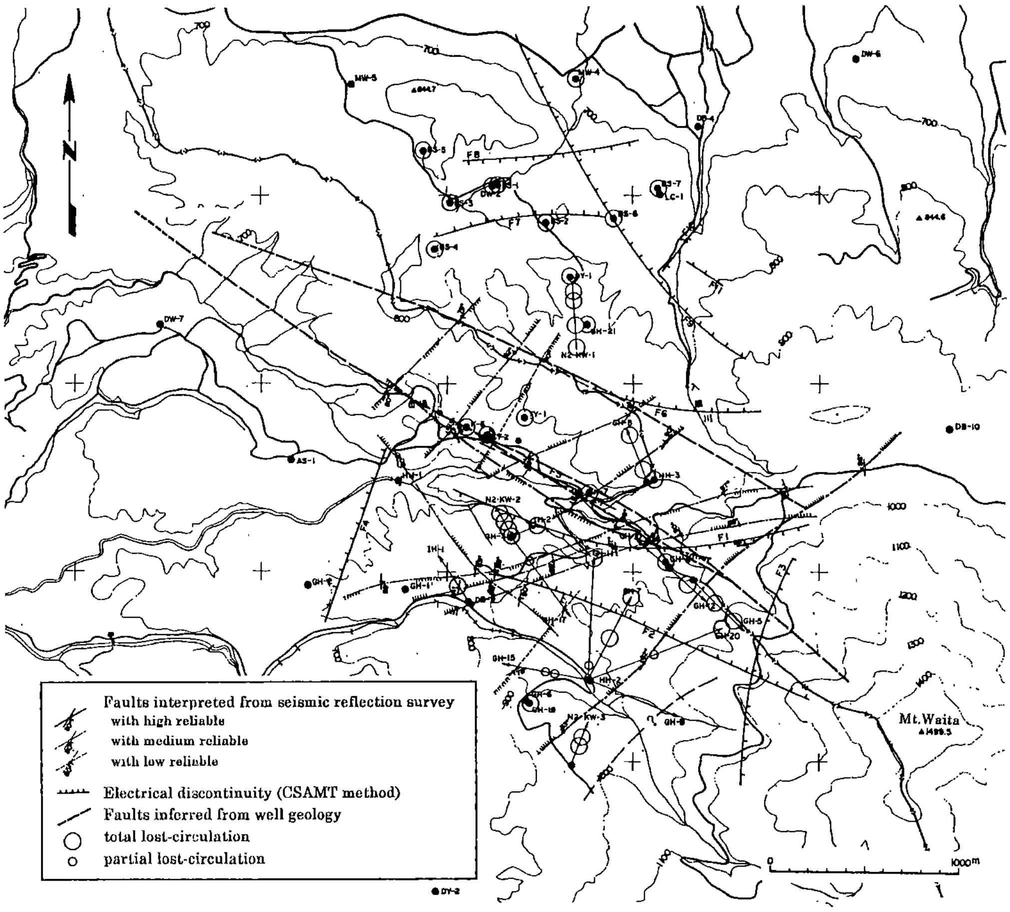

Figure 4. Distribution of fracture and lost-circulation.

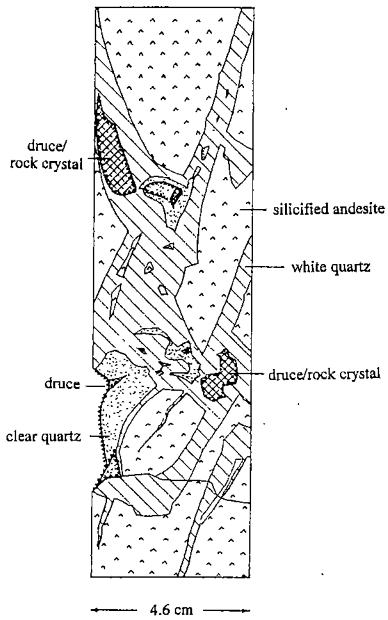

Figure 5. Sketch of typical fracture as boring core.

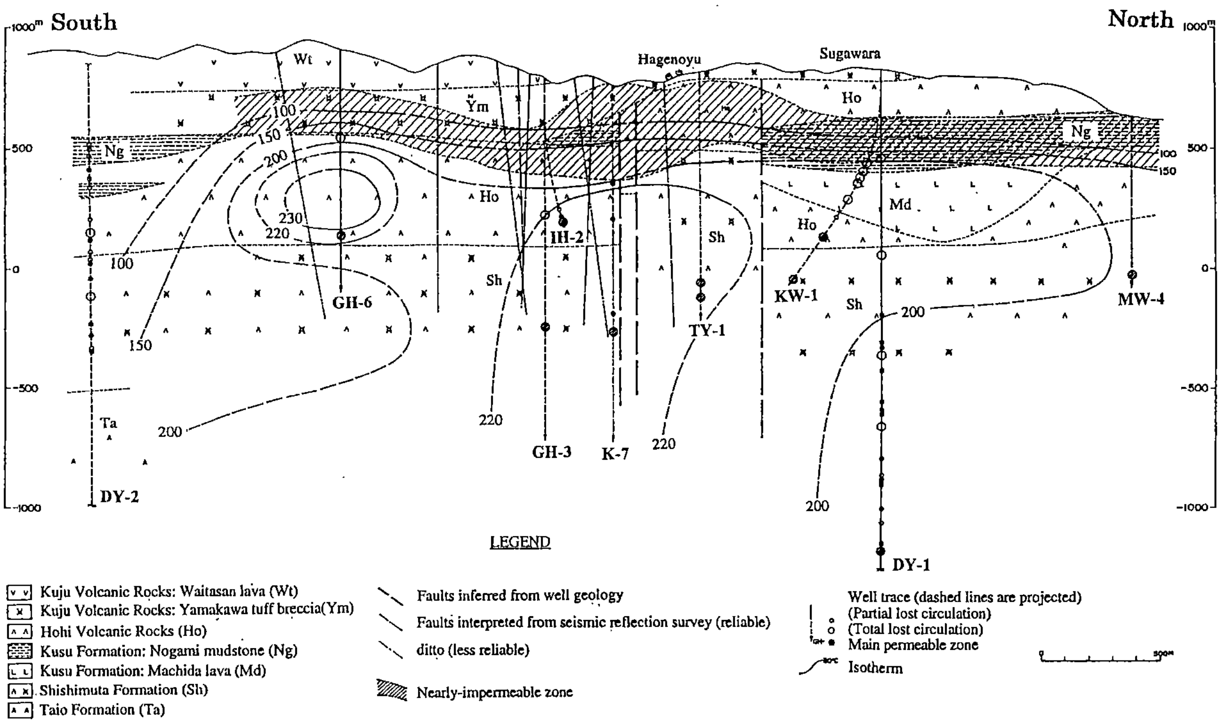

Figure 6. Schematic cross section of the Oguni geothermal filed.

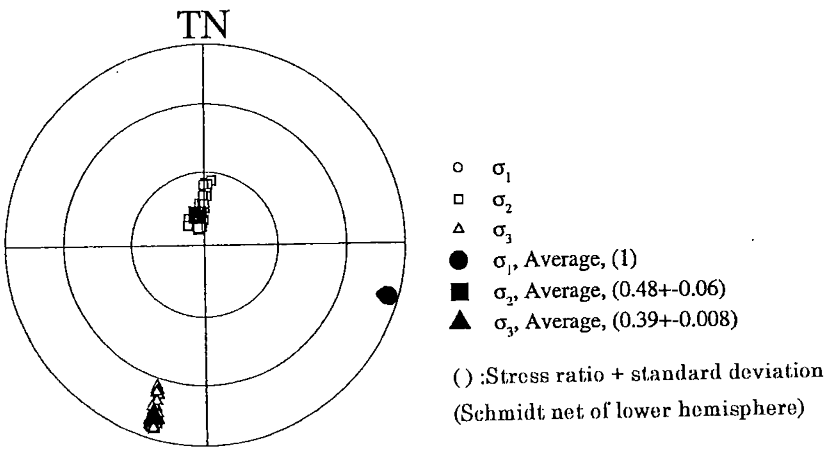

Figure 7. Estimated stress components by using DTF data.