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STRESS FIELDS OF A FRACTURE-TYPE RESERVOIR

Masao Hayashi and Naoyuki Furutani

Kyushu University 86
Kasuga, Fukuoka 816, Japan

ABSTRACT

The strike and dip of fractures indicated by slickensides, hydrothermal veins and joints, in drillcores from the Otake - Hatchobaru geothermal field, Japan, have been determined using an astatic - magnetometer. Slickensides provide information about the stress fields that act or acted on rocks, when both the direction of movement of the hanging wall and the angle of shear are assumed. The stress fields, then, are classified into six types based on the dip- angle of the maximum and minimum stress axes. It is inferred that the NW-trending active faults were originally formed by the " ENE-WSW " lateral stress and have been made permeable by the present " SE " normal stress. In a well, the dip-angle of the maximum stress axis decreases with increasing depth, and becomes almost horizontal (lateral stress) at a greater depth where it often corresponds to a strongly silicified zone. Therefore, the depth of a fracture - type reservoir can be estimated from the distribution pattern of dip-angle of the stress axis.

INTRODUCTION

Hayashi & Furutani (1982) probably were the first who determined the strike and dip of fractures from a geothermal well. Since then, a large amount of data has been accumulated for all of the exploratory wells drilled at the Otake - Hatchobaru field in Japan. This report places emphasis on the stress fields estimated by the analysis of striations on slickensided surfaces. The stress fields are classified into six types based on the dip-angle of the maximum and minimum stress axes. This new classification leads to the elucidation of tectonic changes of the geothermal field in time and space.

GEOLOGIC SETTING

Fig. 1 is the geologic map of the Otake - Hatchobaru field, in which the well locations are shown. The basement consists of Paleozoic crystalline schists and Cretaceous granites (Fig. 2). The Miocene - Pliocene Usa Group, made up entirely of altered andesitic rocks, overlies it unconformably. The volcanic activity continued into the Pleistocene to form the Hohi volcanic rocks of pyroxene andesite (2.0-0.8 Ma). The unconformity between the Usa Group and the Hohi volcanic rocks and associated fractures of later

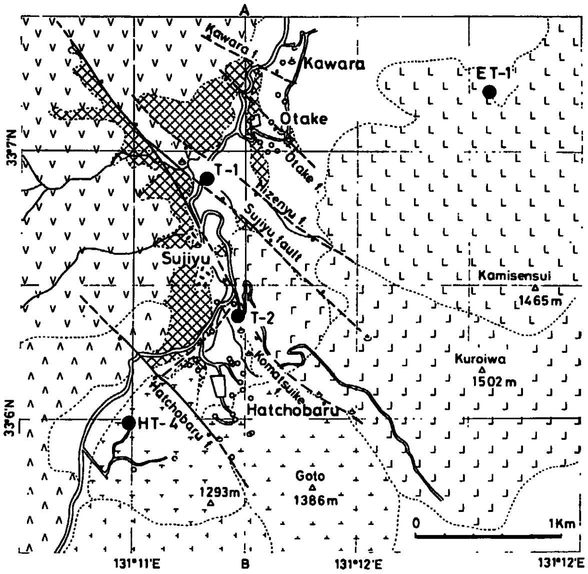

Fig. 1. Well locations in the Otake - Hatchobaru field (lattice:early Pleistocene Hohi volcanic rocks, others:late Pleistocene Kujyu volcanic rocks).

stages are considered to form the main reservoir at Hatchobaru. On the other hand, the reservoir at Otake lies in the middle formation of the Hohi volcanic rocks, which consists mainly of permeable tuff breccia. The Kujyu volcanic rocks, which are younger than $3x10^5$ years as dated by fission track methods, must be the major heat source.

Some NW-trending faults were confirmed by geological mapping (Yamasaki, Matsumoto & Hayashi, 1970), while NE-trending ones were inferred from geophysical methods.

A total of 118 borecores were obtained from Wells ET-1(11), T-1(15), T-2(19), and HT-4(73). They include such fractures as slickensides (fault), hydrothermal veins and joints. About 80 % of the borecores are from the Hohi volcanic rocks and the rest, from the upper part of the Usa Group, probably of Pliocene age.

EXPERIMENT

The top of a fracture is named tentative north, " N' ". The direction of striation on a slickensided surface is described by the angle

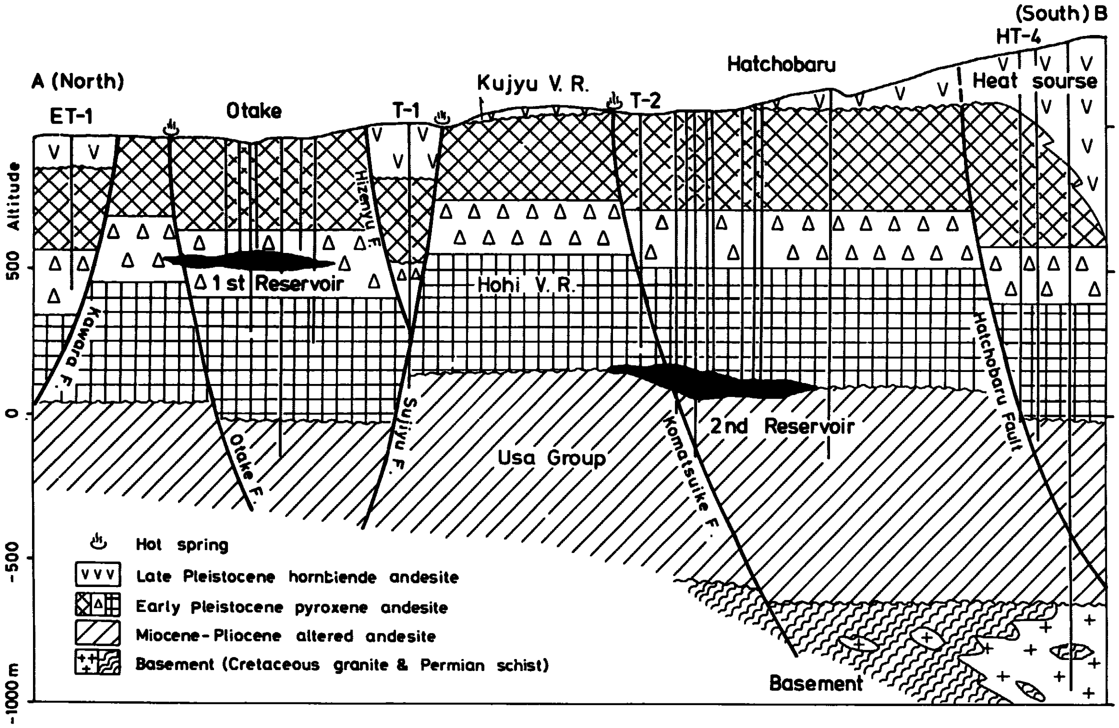

Fig. 2. North-south cross section of the Otake-Hatchobaru field.

between the tentative north and the direction of movement of its hanging wall measured clockwise. The lower column is cut and used for the determination of the declination and inclination of remnant magnetism. Since the cores were collected mainly from the Quaternary formations, the direction of magnetization is assumed to trend toward the present north, resulting in the determination of the strike - dip of the fracture in situ. The astatic magnetometer used is of the same type described by Hayashi & Furutani (1982).

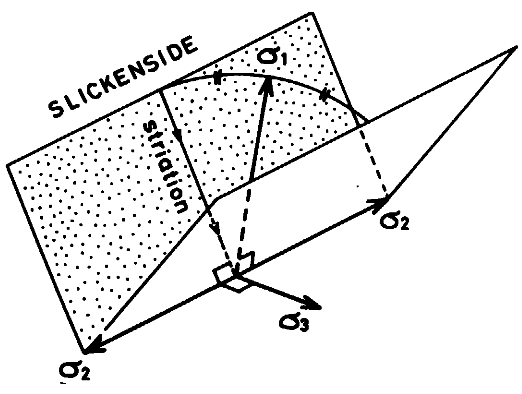

Fig. 3. Figure showing the relation between the two shear planes in a conjugate set and the three principal stress axes.

The three principal stress axes are obtained as shown in Fig. 3. The intermediate stress axis is on the same plane as the slickenside and at a right angle to the direction of the striation on it. The maximum stress axis is at a right angle to the intermediate stress axis, and is midway between the two shear planes within the angle of shear. The minimum stress axis is perpendicular to both axes. The angle of shear is assumed to be 60° since the distribution pattern of the dip-angle of all the fractures is concentrated at around 60° at greater depths.

CLASSIFICATION AND DEFINITION OF STRESS FIELDS

Since the dip-angle of each of the three principal stress axes can range from 0° to 90°, the stress fields are classified according to the dip-angle of σ_1 and σ_3 as shown in Fig. 4. Of these, the normal stress fields have dip-angles of σ_1 larger than 60°, the reverse stress fields have that of σ_3 larger than 60°, and the lateral fields have both angles smaller than 30°. The normal - lateral and reverse - lateral stress fields are of intermediate types with respect to the above three. Lastly, the oblique stress fields range from 30° to 60° in both dip-angles.

When the direction of the principal stress axis is taken into consideration, the stress fields are defined as follows: The compressional stress fields include those whose dip-angle of σ_1 is smaller than 30°: reverse, reverse - lateral, and lateral. If the direction of σ_1 is EW, the terms EW compressional, EW reversal, EW reverse - lateral and EW lateral can be used. The intermediate stress fields consist of the oblique

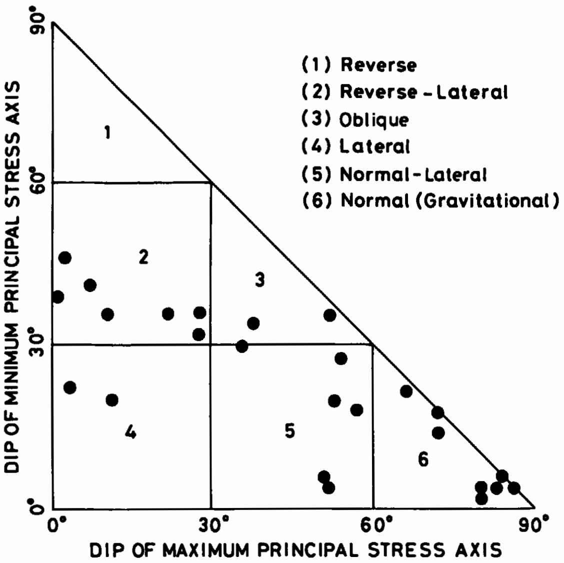

Fig. 4. New classification of stress fields found at the Otake-Hatchobaru field.

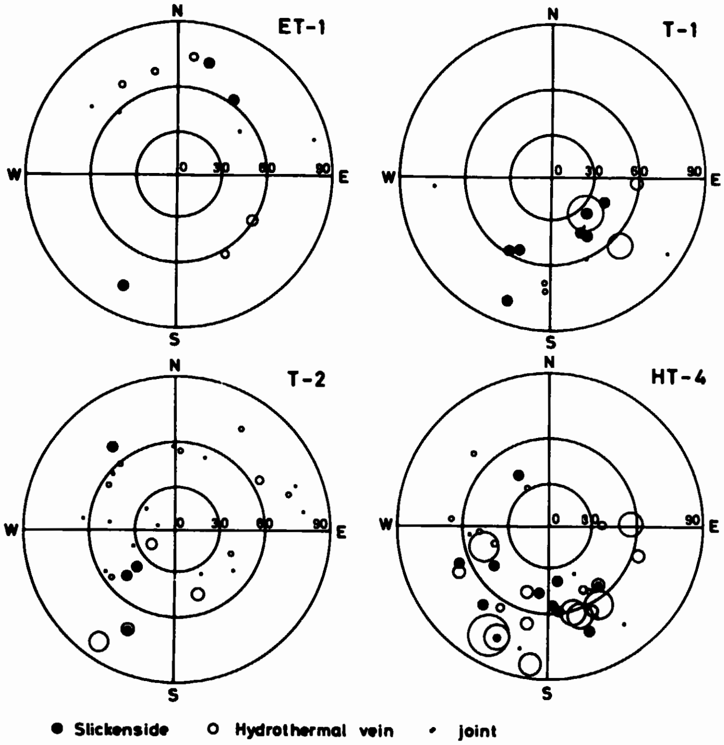

Fig. 5. Upper Wulff net projections of fractures found in the Otake-Hatchobaru wells. The diameter of veins are proportional to their width.

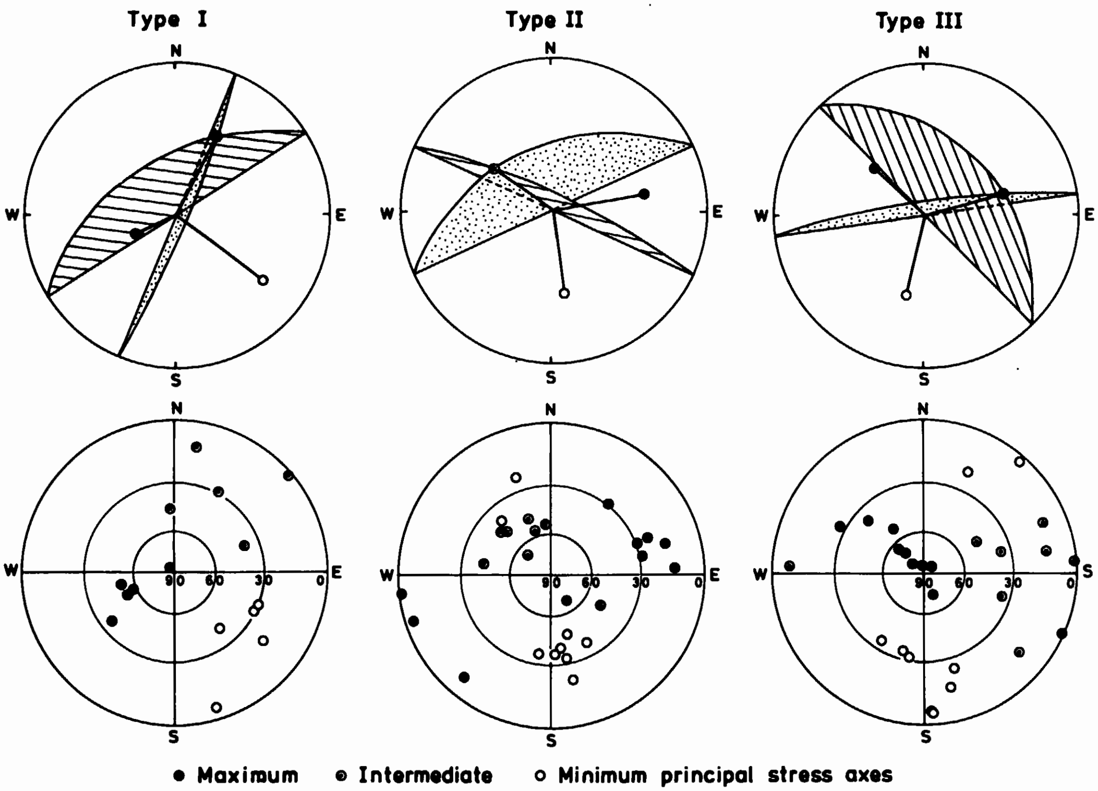

Fig. 6. Representative stress fields in the Otake-Hatchobaru field. The great-circle slanted with lines indicates a slickensided surface. The dotted great-circle is the other plane of the conjugate set of a fault system.

and normal - lateral types. The normal or gravitational stress fields, as well as the intermediate ones, are characterized by the direction of σ_3 rather than σ_1 (e.g. EW normal), because it determines the strike and dip of the faults. Lastly, the tensional stress fields are defined as those formed under tentional stress, and should be also identified by the direction of the minimum stress axis, σ_3 (e.g. EW tensional).

RESULTS AND DISCUSSION

The fractures whose strike and dip have been determined are plotted in the upper hemisphere Wulff nets in Fig. 5. Important fractures and hydrothermal veins generally dip southwards. It suggests that both fractures of a conjugate set tend to dip in the same direction (in the case where σ_1 and/or σ_3 incline moderately), or that only one of them develops under certain stress fields.

Fig. 6 indicates the representative three types of stress fields found at Otake - Hatchobaru. Type I are of normal and normal - lateral stress fields whose σ_3 trends SE on average, forming the faults having NE strikes and SE dips, and occur at greater depths. Type II are of reverse - lateral stress fields whose σ_1 trends ENE-WSW, resulting in the formation of NW trending faults of relatively high - angles and NE ones of moderate angles. This type is dominant over the Otake - Hatchobaru fields not only horizontally but also vertically. Type III are of normal or normal - lateral stress fields whose σ_3 trends approximately SW, and is well in accordance with the stress fields of Kyushu, which were seismologically estimated. This stress must have caused the NW fault planes of Type II to open, because its maximum horizontal stress axis is almost parallel to the strike of Type II faults. Accordingly, the NW faults of Type II as well as those of Type III may play the role of conduits for geothermal fluids at present. In Fig. 4, the dip-angles of all stress axes determined are plotted, indicating that they are homogenously scattered over in the figure except for in the reverse stress field.

At Well HT-4, the dip-angles of the maximum stress axis change with depth as illustrated in Fig. 7. As in the other wells, the dip -angles decrease with increasing depth from 90°(normal) to 0°(lateral), and then it abruptly becomes normal again. The depth where the dip-angle is almost horizontal often corresponds to a strongly silicified zone in a reservoir. The depth interval where the dip-angle is moderate (reverse -lateral or normal-lateral) is in accordance with intermediately altered zones. On the contrary, the place of normal stress fields coincides with partially altered zones that may be almost impermeable. Therefore, the location of a fracture - type reservoir and a cap layer can be estimated by plotting the dip-angle of σ_1 against depth.

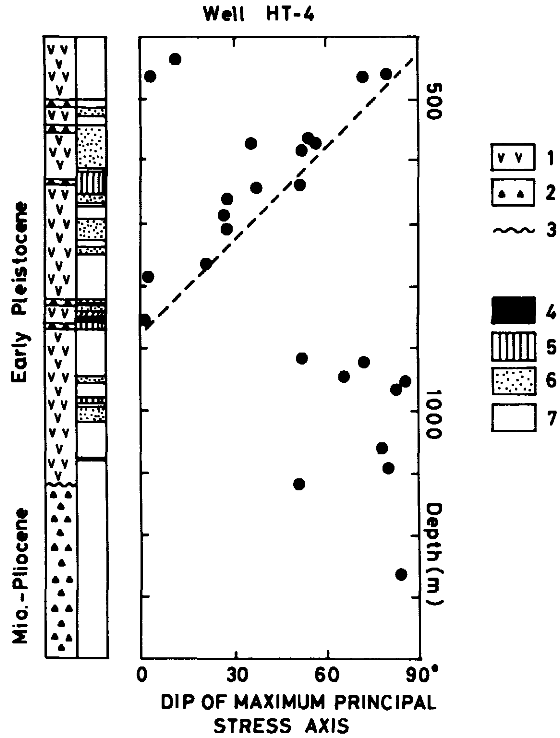

Fig. 7. Dip-angles of the maximum principal stress axis with depth in Well HT-4.
1. andesite lava. 2. tuff breccia, 3. unconformity, 4. silicified zone, 5. kaolinite zone, 6. alumino-clay zone, 7. partially altered zone.

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