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STRESS STATE AT THE OGACHI SITE

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ABSTRACT

At the Ogachi site, where CRIEPI is undertaking a research project for Hot Dry Rock geothermal energy development, in-situ rock stress was measured by laboratory tests using the Acoustic Emission (AE) method and the Differential Strain Curve Analysis method (DSCA), together with core disking phenomenon and shut-in pressure. The results of the three - AE, DSCA, and core disking - were consistent with the azimuth of horizontal maximum stress. The direction of maximum stress is estimated as roughly NE-SW, and this direction is consistent with the estimated paths of fracture growth in hydrofracturing, although they are not simple at this site.

1 INTRODUCTION

Rock stress is one of the parameters affecting the reservoir formation in hydrofracturing and water circulation for HDR development. Until 1997, information about rock stress states at the Ogachi site was limited. One source of information was fault mechanism of field AE (Kaieda, 1998), observed during water injection, and another was the laboratory Kaiser effect test (lab. AE method). The latter test needs oriented core, but tests made in 1997 used cores with uncertain orientations. Orientation was determined after retrieving the core by comparing the borehole wall image and natural joints on the core, but there were too many joints.

In 1998, additional tests for rock stress measurement were planned. Since the accuracy of core orientation is crucial to core-based rock stress measurement, we decided to rely only on andesite dikes thicker than a few centimeters to be certain core orientation. Laboratory AE tests and DSCA tests were performed using the accurately oriented cores. Cores from the production well were reexamined and clear core disking phenomena were observed at a few points. Core disking is caused by rock stress, and hence provides valuable information about it. The estimated stress by the lab. AE tests, the DSCA tests, and core disking are presented and discussed. They are also compared with the result from the fault mechanism of field AE.

2 CORE DISKING

2.1 General description of core disking

Core disking is a phenomenon occurs when a core breaks during coring and forms a succession of discs. It is common in hard rock when horizontal stress is extremely high. Sugawara (1978) has presented an experimental criterion for core disking as follows,

$$St < 0.125(\sigma_H - \sigma_h) - 0.25\ \sigma_z \qquad (1)$$

where
St : Brazilian tensile strength
σ_H : horizontal maximum stress in compression
σ_h : horizontal minimum stress in compression
σ_z : vertical stress.

It is well known that when stress anisotropy in the horizontal plane $\sigma_H - \sigma_h$ is very high, each disc exhibits a saddle or potato chip shape. In such cases, the fractured surface of the disc is curved and the diametral direction along a valley on the surface indicates the maximum stress direction.

So core disking can be an indicator of in-situ rock stress in both magnitude and direction.

2.2 Discing observed on production well core

Reexamination of the core from a production well of more than 1000 m depth shows clear core disking at two depths: 1057 m and 1076 m. At both points, the discs exhibit a potato chip shape, suggesting high stress anisotropy in the horizontal plane. The discs have been accurately oriented using a nearby andesite vein. The shape of the core disking suggests that the horizontal maximum direction is N41ºE. The existence of core disking also suggests a large horizontal stress compared to vertical stress. The potato chip shape of the discs indicates a large difference in horizontal maximum and minimum stress. But it is important to note that such stress states are not necessarily distributed over the entire depth of the hole because core disking is observed only at two points of the hole.

3 LABORATORY AE METHOD

3.1 General description of the AE method

The AE method is a way of estimating in-situ rock stress based on the Kaiser effect of material. In general, the effect is as follows: when a material is increasingly loaded, Acoustic Emission is observed after the load exceeds the level the material experienced in the past.

Since a rock specimen has experienced an in-situ rock stress, we can anticipate that a laboratory loading test will reveal it by means of the Kaiser effect. There is some discussion about the difference between in-situ 3-dimensional stress states and laboratory loading conditions. But several studies have proven that lateral stress histories do not affect the result of estimating the axial pre-stressed level by uniaxial loading test (Shin,1991).

3.2 AE test results near the core disking

Specimens for laboratory AE tests were taken from a core directly connected to the core disking at a depth of 1076 m, so the specimens have presumably been subjected to very similar stress states as part of the core disking. AE Kaiser tests were performed in four horizontal directions. Fig. 1 shows an example of AE count vs. time and stress vs. time. We observed that the AE count began to increase at some point. The reading point is indicated by an arrow and the width of reading error is shown by a line.

The horizontal distribution of estimated in-situ rock stress by the AE method is shown in Fig. 2. The direction of horizontal maximum stress has been calculated to be N38ºE and agrees well with the indication of core disking. The maximum and minimum horizontal stresses are 80 and 35 MPa, respectively, and suggest large horizontal stress states compared to depth (ρ gD=28MPa) as well as large stress anisotropy. But it is important to note that since the specimens for the AE test were taken at a point just next to core disking, the indicated stress state is not an average but rather represents an extreme state along the hole.

4 DSCA METHOD

4.1 General description of the DSCA method

The DSCA method utilizes hydrostatic loading of a specimen with strain gauges attached in more than six directions, and with a coating to prevent the penetration of oil. The assumption is that a specimen retrieved from an in-situ stress state has expanded according to the stress state. The expansion is assumed to be accompanied by opening-up of micro-cracks. These micro-cracks will lead to the largest compressibility in the maximum stress direction, and likewise for medium and minimum stress.

4.2 Result of the DSCA test

Specimens of granite for the DSCA test were taken from a 1057 m depth. An example of strain vs. pressure relation is shown in Fig. 3. The relative amount of micro-cracks in each direction is indicated by the initial gradient (β_L) of the respective strain vs. pressure curve. The effect of anisotropy on the matrix itself is correlated by the gradient at a high pressure level (β_H). In the present analysis, the principal stress is assumed to be proportional to β_L- β_H for corresponding directions.

The results of stress analysis are shown in Fig. 4. The relative values of the principal stresses have been correlated by the overburden pressure of ρ =2.7g/cm^3. σ_1, σ_2, and σ_3 are estimated to be 37, 23, and 17 MPa, respectively. To compare to the results of core disking and the AE method, the horizontal maximum stress direction is N67ºE and agrees fairly well.

5 DISCUSSION & CONCLUSION

5.1 Core disking criterion and AE Kaiser test

As stated before, the horizontal maximum stress direction estimated by both the lab.-AE Kaiser test and core disking agreed well. Since samples for AE test were just adjacent to the location of the core disking, if stress state obtained by AE method is consistent with the criterion of core disking, it would further confirm the test result. Substituting the stress values σ_H=80, σ_h=35 and σ_V=28MPa from the AE Kaiser test into equation (1) leads the Brazilian tensile strength, St=74 MPa. This value is just appropriate for the granite at the site.

Thus we have observed the consistency both in direction and magnitude of stresses indicated by core disking and the lab.-AE Kaiser test.

5.2 DSCA method

The specimens for the DSCA test were from a depth of 1057 m, about 20m from the core disking. The direction of horizontal maximum stress was N67ºE, less than 30 degrees different from the results of the AE test and core disking.

5.3 Results of field AE

It should be noted that field AE during injection has given different results concerning the stress direction. The method of Gephart and Forsyth (1984) was applied to the fault plane solutions of AE during injection the test (Kaieda, 1998), and the result is shown by the empty marks in Fig. 5. The horizontal maximum direction is WNW-ESE and different from that indicated by the saddle direction of core disking, the lab-AE test, and the DSCA test.

The combination of the multiplet analysis of AE and analysis of slip directions on fault planes gives another information on rock stress. The result will be presented by Moriya et al. (2000) at this WG Conference. The preliminary result is shown by the solid marks in Fig. 5. This shows that maximum principal stress direction is near vertical.

5.4 Direction of maximum stress

As stated above, different stress directions have been estimated by the different methods. The horizontal maximum stress directions for the lab-AE test, the DSCA test, core disking, and field AE fault mechanism are shown in Fig. 6. The field AE multiplet analysis estimated the maximum stress direction as almost vertical. Thus the results are confusing and decisive information is lacking. So we are obliged to rely on the consistency of the distribution of the clouds of the field AE during injection.

The distribution of the AE epicenter during hydrofracturing and injection tests should be affected by pre-existing natural joints and rock stress. The region of AE sources extends eastward from the upper part (700 m) of the hole and northward from the lower part (1000 m) (Kaieda, 1998). This difference is explained by the difference in direction of the predominant joint sets at the upper and lower part of the reservoir (Ito, 1999). Observing the distribution of the AE epicenter in detail, both regions of AE are toward the northeast direction (Kaieda, 1999). This phenomenon agrees with the horizontal maximum direction suggested by the AE and DSCA tests and core disking. Consequently, the azimuth of maximum stress at the reservoir is tentatively regarded as NE-SW.

5.5 Magnitude of stress

The specimens for lab.-AE tests were taken from a core just next to one of the core disking phenomenon. Core disking was found at only a few points of the entire borehole core. Rock stress is generally considered to vary from place to place. The core disking at this site is considered to be caused by local stress concentration.

So, although the stress value estimated by lab.-AE test is reliable for that location because it is consistent with the criterion of core disking, it is not the representative value for the site. It is difficult to estimate the average of stress state from almost the maximum value for the site. But relying on an experience of stress measurement, the half of the maximum value may be taken as the representative stress at the reservoir (σ_H=40).

DSCA method has given the result σ_1=37, σ_2=23 and σ_3 =17 MPa, and gives the horizontal components σ_H=30 and σ_h=22MPa.

Shut-in pressure at about 1000m depth has been obtained as 23MPa from pressure vs. flow rate curves. The immediate shut-in pressures were almost the same. The value 23MPa is slightly larger than the minimum stress estimated by other methods, but considered roughly consistent.

As described above, the various data are roughly agreeing concerning the stress magnitude. The magnitudes of stress at the reservoir are regarded as σ_H=30～40, σ_h ≒ 22 and σ_v ≒25 MPa, or 3 dimensionally σ_1 ≒37, σ_2 ≒23 and σ_3 ≒17.

REFERENCES

Gephart, J. and Horsyth, W.(1984). An improved method for determining the regional stress tensor using earthquake focal mechanism data, Application to the San Fernando earthquake wequence, J. Geophys. Res., 89, 9305-9320

Ito, H.(1999). Geological condition around the Ogachi HDR site, Ogachi HDR Workshop, CRIEPI, Mar. 1999

Kaieda, H.(1998). AE and electric measurements for evaluating fractures created by hydraulic fracturing as HDR geothermal reservoirs at Ogachi, Akita prefecture, Japan, Proc. 4th SEGJ Int. Symp.,p.317-321, Tokyo, Dec. 1998

Kaieda, H.(1999). Ogachi reservoir structure estimated by AE and geophysical measurements, Ogachi HDR Workshop, CRIEPI, Mar. 1999

Moriya, H., H. Niitsuma and H. Kaieda(2000). Reevaluation of reservoir structure at Ogachi HDR field by precise source location of AE multiplet, WGC 2000, Japan

Shin, K.(1991) Kaiser effect of rock in acousto-elasticity, AE & DR ; 5th conf. on Acoustic Emission/Microseismic Activity in Geologic Structures and Materials, Penn. State Univ, June 1991

Sugawara, K.(1978). A Study on Core Discing of Rock, J. Mining & Metallurgical Inst. of Japan, 1978-11, p.797-803 (in Japanese)

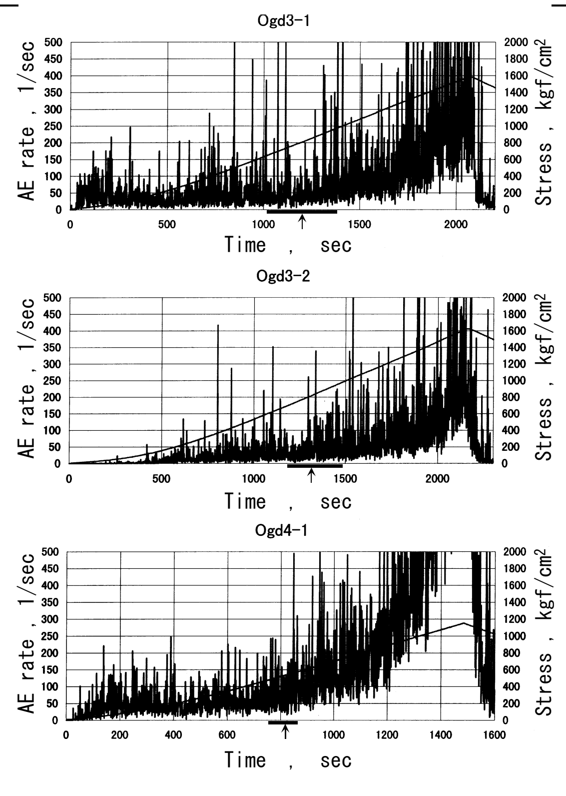

Fig.1 Examples of results of lab.-AE test

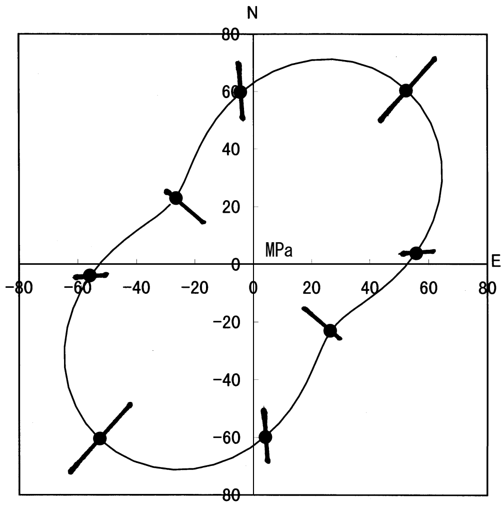

Fig.2 Estimated horizontal stresses by lab.-AE test

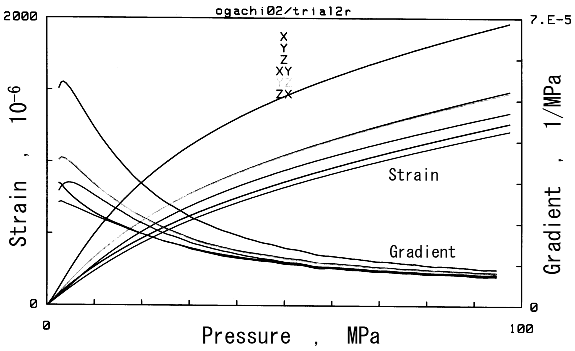

Fig.3 An example of strain curve of DSCA

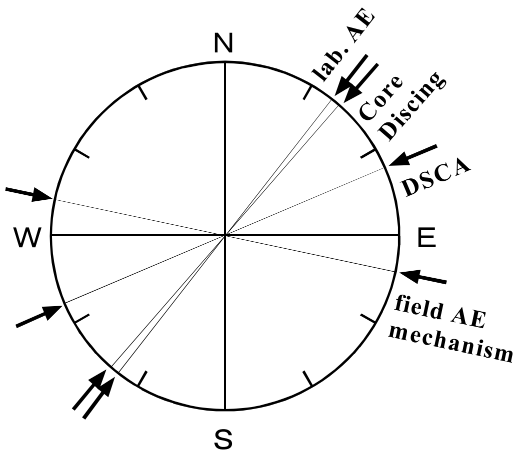

Fig.6 Distribution of horizontal maximum stresses by several methods

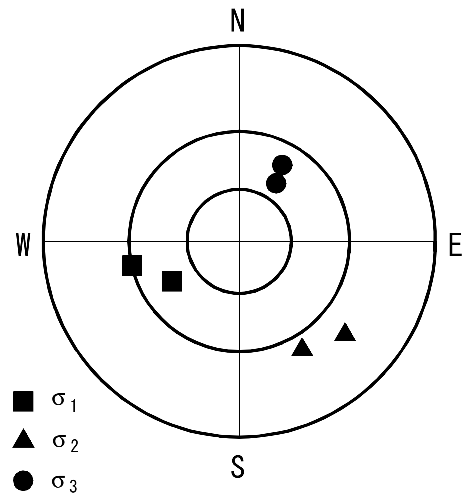

Fig.4 Distribution of principal stresses by DSCA (lower hemisphere projection)

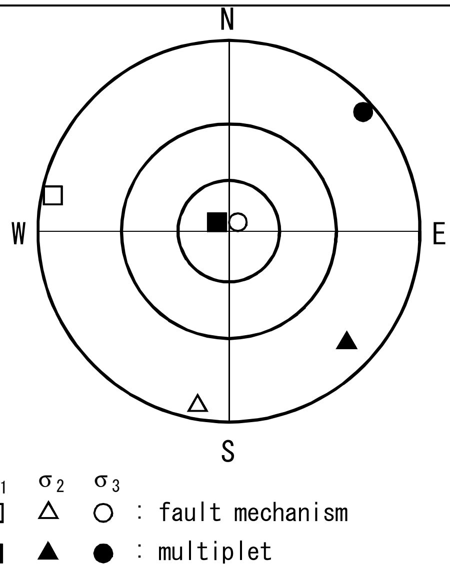

Fig.5 Distribution of principal stresses by field AE methods (fault mechanism & multiplet) (lower hemisphere projection) (Moriya, et al., 2000)