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REEVALUATION OF RESERVOIR STRUCTURE AT OGACHI HDR FIELD BY PRECISE SOURCE LOCATION OF AE MULTIPLET

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ABSTRACT

Evaluation of reservoir structure at Ogachi HDR field of CRIEPI (Central Research Institute of Electric Power Industry) has been carried out using multiplets observed during the hydraulic fracturing experiment in 1991. The source distribution of relative location of multiplets suggests that the fracture orientations are NNE-SSW and nearly vertical, that well agrees with the fracture distribution detected by BHTV. The principal stress directions are also estimated using the delineated structural planes and these expected slip directions evaluated from P-wave polarity. The detailed structure, stress field and fracture behavior of fractures are comprehensively discussed using the results of mapping, stress measurement and well logging data.

1. INTRODUCTION

In Ogachi HDR field of CRIEPI (Central Research Institute for Electric Power Industry) , the fracturing experiments were carried out in 1991 and 1992. The source locations of induced microseismicities suggest that two fractures extend to the NNE and ENE, respectively, and is somewhat confusing in interpreting the fracture extension in the reservoir (Kaieda et al., 1993). On the other hand, the precise mapping techniques ie. the doublet analysis and collapsing method have been applied to the induced microsismicities in order to evaluate the detailed reservoir structure (Moriya et al., 1994; Jones and Stewart, 1997). As the result of the collapsing method that analyses extensive microseismic events, it is suggested that the dominant orientation of structures is NNE. On the other hand, the evaluation of reservoir using multiplets, that have similar waveforms to each other and considered as the stress release on the same fault, have been done. The structural planes oriented NNE have been identified. However, the accuracy of relocation is not satisfactory because only one three component detector was used to determine the relative locations in the analysis.

In this paper, we discuss the reservoir structure and stress field based on the results from the analyses on multiplets observed during the hydraulic fracturing experiment in 1991. The detailed structure, stress field and dynamic behavior of structure are discussed using the information from microseismic locations determined using surface network, well logging data and boring cores.

2. IDENTIFICATION OF DOUBLET/MULTIPLET

In this paper, we define a group of similar events a “multiplet”, and a pair of similar events a “doublet”. In Ogachi HDR field, the hydraulic fracturing was carried out in 1991. The induced microseismicities were observed using eight stations in maximum number and 1800 events were detected. The source distribution of microseismicities expanded to NNE-SSW. Multiplets were searched from 585 events. As the first procedure, the microseismic events with similar waveforms are searched by using an automatic algorithm, which clusters similar waveforms using filtered waveform envelop (Lesniak and Niitsuma, 1996). After the automatic identification, the waveforms are observed manually and confirmed that these events can be regarded as multiplet. Figure 1 shows example of multiplet waveforms, and figure 2 shows the result of grouping. A total of 168 events are categorized into multiplets.

3. RELOCATION OF MULTIPLET/DOUBLET

The moving window cross spectrum technique has been introduced to detect the relative time delay of P-wave arrival times, where the frequency band from 75Hz to 125Hz has been considered (Moriya et al., 1994: Moriya and Niitsuma, 1995). The P-wave arrival times, that were picked manually, for each event are re-calculated using the detected time delays, and the re-calculated P-wave arrival times at 5 stations were used to determine the source locations. Figure 3 shows the arrangement of observation wells and fracturing well. A velocity structure was determined using detonation signals from the fracturing well, and a two layered velocity structure, with the boundary dipping to the south-west, has been used to determine the source locations. Figure 4 shows source locations determined by three different methods, that is, conventional mapping method using three layered horizontal velocity model, JHD and the doublet analysis using two layered and dipping boundary velocity model. In case of the doublet analysis, the source locations of 15 events with similar waveforms gather with each other.
Figure 5 is the RMS errors before and after the relocation. RMS error also suggests that the uncertainty of source location is smaller in relative location. If P-wave velocity is assumed to be 5 km/s, the uncertainty of locations after relocation corresponds to about 2 m if RMS is 0.4 ms.

Figure 6 shows the source distribution of 20 multiplets. The origin of the coordinate is set as the wellhead of fracturing well. The fracturing point is north-west of the origin of the coordinate, and the depth is 1000 m. The seismic cloud spreads to NNE. It is notable that the source locations distribute to vertical direction with orientation to NE when we pay attention to event locations in each multiplet. Because it is possible to consider that multiplet is a group of seismic events occurring on the same fault, we have calculated the orientation of the plane delineated from source distribution.

Figure 7 is representing the pole of structural planes (lower hemisphere) derived from hypocenter distribution of each

multiplet. It is suggested that the structural plane tends to have orientation to NE and to be nearly vertical. The fracture distribution detected by BHTV in fracturing and production wells shows that the fractures oriented to NE with dip of about 70 degrees are dominant, that well agrees with the orientation of delineated structural planes. The hydraulic fracturing in 1991 was carried out at the region where the existence of many preexisting fractures was confirmed. Therefore, it is considered that the injected water flowed into these preexisting fractures, and microseismicities were caused by slip along the fracture surfaces due to satisfaction of Coulomb's criteria. Consequently, it is possible to say that the structural planes delineated by multiplets represent the pre-existing fractures behaved as seismic sources.

4. CALCULATION OF STRESS FIELD

In principle, principal stress directions and stress ratios can be calculated using orientation of fault planes and their slip directions. Under an assumption that the structural planes have behaved as seismic source accompanied with the shear slip, we calculated principal stress directions and stress ratios.

The slip directions for each plane are evaluated by the grid test using P-wave polarities at five stations (Moriya et al., 1997). The structural planes dipping to the southeast are estimated to behave as lateral strike slip and normal slip faults, and the planes dipping to north-west behave as thrust fault. Figure 8 shows the lower hemisphere stereographic projection of the principal stress directions, where eight structural planes are used. 85 % of solutions are included within the areas. The maximum and intermediate stress magnitudes normalized by the minimum principal stress are estimated to be 2.31 and 1.21, respectively, under the assumption that the pore-pressure is put as 0.87 of hydrostatic pressure. The directions of minimum stress and intermediate stress are often exchanged with each other. It is because of this that the stress ratio between the minimum and intermediate stresses is small.

5. DISCUSSION

In case of the 1991 hydraulic fracturing, it is explained that the fluid flows into the pre-existing fractures because many natural joints are detected in the wells. Therefore, it is valid to think that the microseismicity is induced by the shear dislocation along the pre-existing fractures due to the increase of pore-pressure.

If we know a principal stress direction and the principal stress ratios, we can calculate the stress condition of fractures, which have arbitrary strike and dip. Based on the Coulomb's law, we can calculate the pore-pressure that causes the shear slip on the fracture after reaching the pressure as follows,

$$P_s = \tau - \frac{\sigma_n}{\mu_s}, \qquad (1)$$

where τ is the shear stress, σ_n is the normal stress and μ is the coefficient of friction.
Figure 9 shows the critical pore-pressure calculated under the estimated stress field and μ is 0.8, where closed circles denote the pole of structural planes, and the overburden pressure is given as 28 MPa. Figure 9 suggests that the structural planes cause shear slip with lower pore-pressure.

The stress field is also evaluated by AE Kaiser effect method using boring cores, DSCA, inversion on slickenside, core disking and so on. Through the comprehensive evaluation, the maximum horizontal stress direction is estimated to be NE so far (Shin et al., 1999). This stress direction is different from the stress direction determined by multiplet, and the reason must be discussed. Figure 10 shows the critical pore-pressure calculated under the estimated stress field based on the information of boring cores. It is also suggested that the structural planes are also easier to slip under the stress field by boring cores and so on.

The result, that the different stress fields are estimated but the structural planes are evaluated to be under critical condition, is also observed in Fenton Hill in U.S.A.. The structural planes delineated from microseismic source locations are identified as critical fractures under the different stress fields determined by using fault plane solutions, borehole break out and clustered similar events. However, the reason has not been clarified. Therefore, it is necessary to examine what the stress field can be obtained from multiplet.

6. CONCLUSIONS

The reservoir structure has been reevaluated by using multiplets. The source locations of multiplets suggest that the structural planes are oriented to NNE directions and the dip is nearly vertical, and which has been confirmed from BHTV data. Therefore, it has been understood that the precise source location of multiplets give us the structural planes of fractures that would behave as seismic sources.

The stress field determination method on multiplet has been also examined. The critical pore-pressure of the structural planes is evaluated to be smaller under the different stress fields estimated by two principally different methods. This phenomenon is also observed at other HDR field. Therefore, it is necessary to examine what the stress field is estimated by using multiplets.

ACKNOWLWDEMENT

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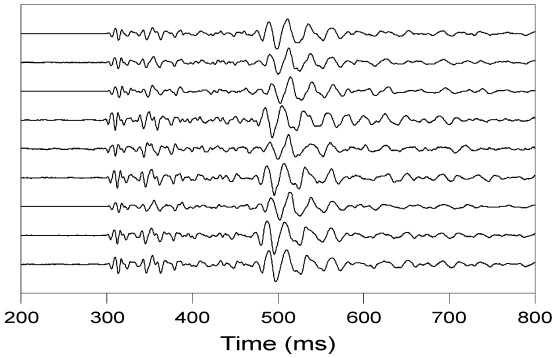


Fig. 1: Example of waveforms of a multiplet.

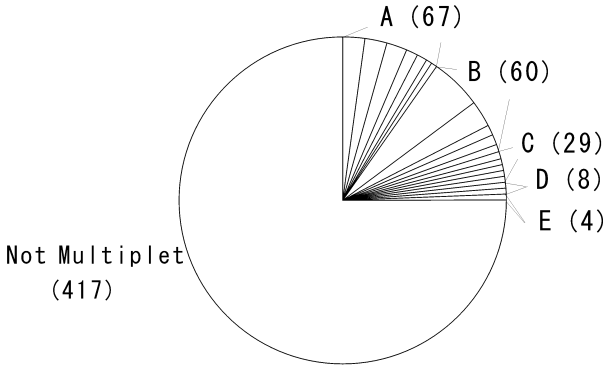


Fig. 2: Percentages of multiplets and doublets.

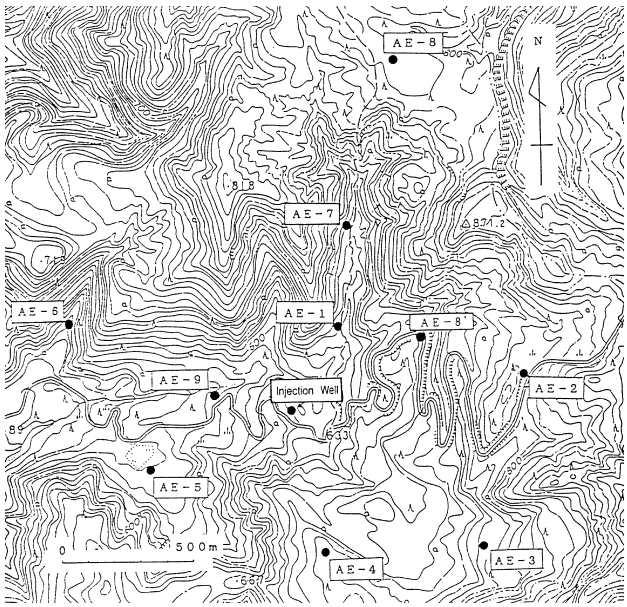


Fig. 3: Arrangement of observation wells and fracturing well (CRIEPI).
Well AE-1, 2, 3, 5 and 6 are used for estimating relative source locations.

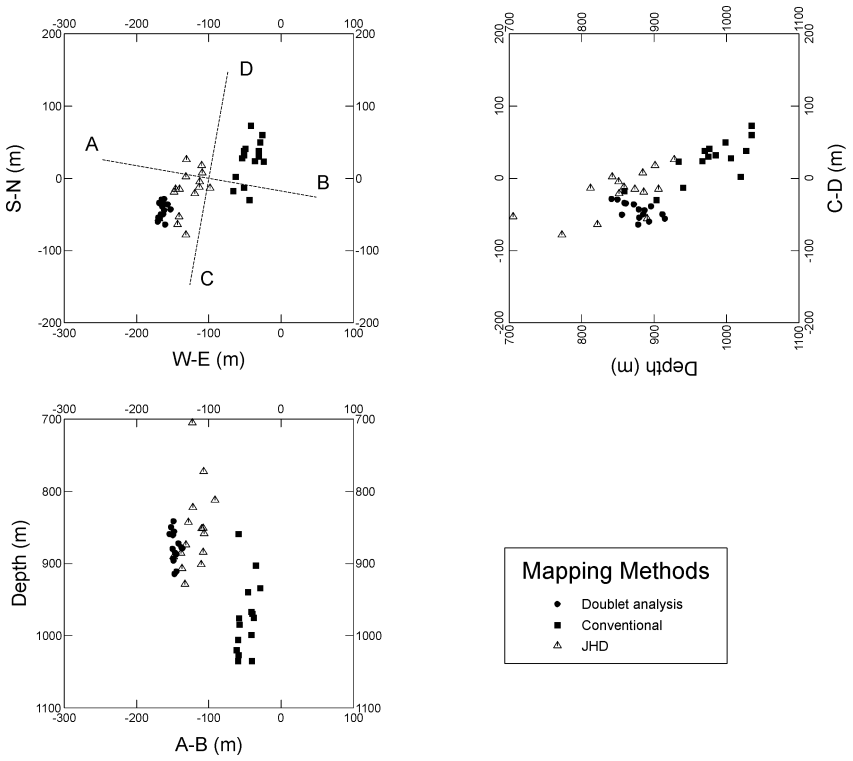


Fig. 4: Source locations determined by different mapping methods, where the doublet analysis(●), conventional mapping method(■) and JHD(△) are examined.

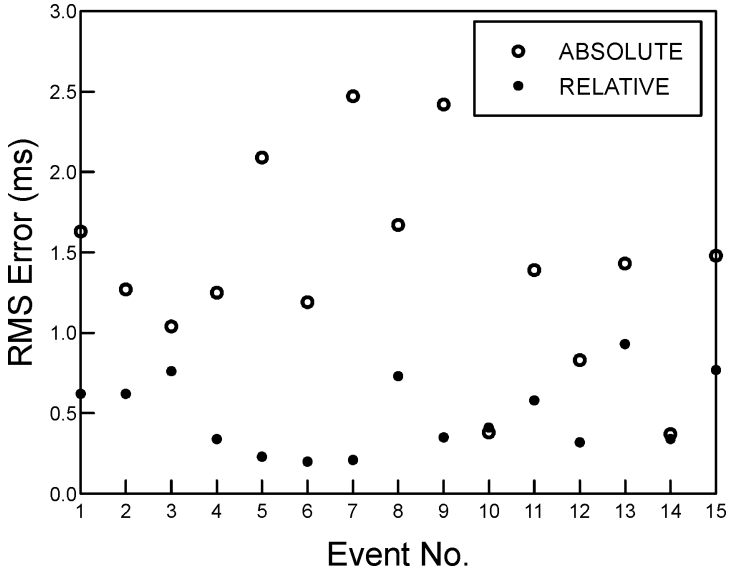


Fig.5: RMS errors before and after relocation.

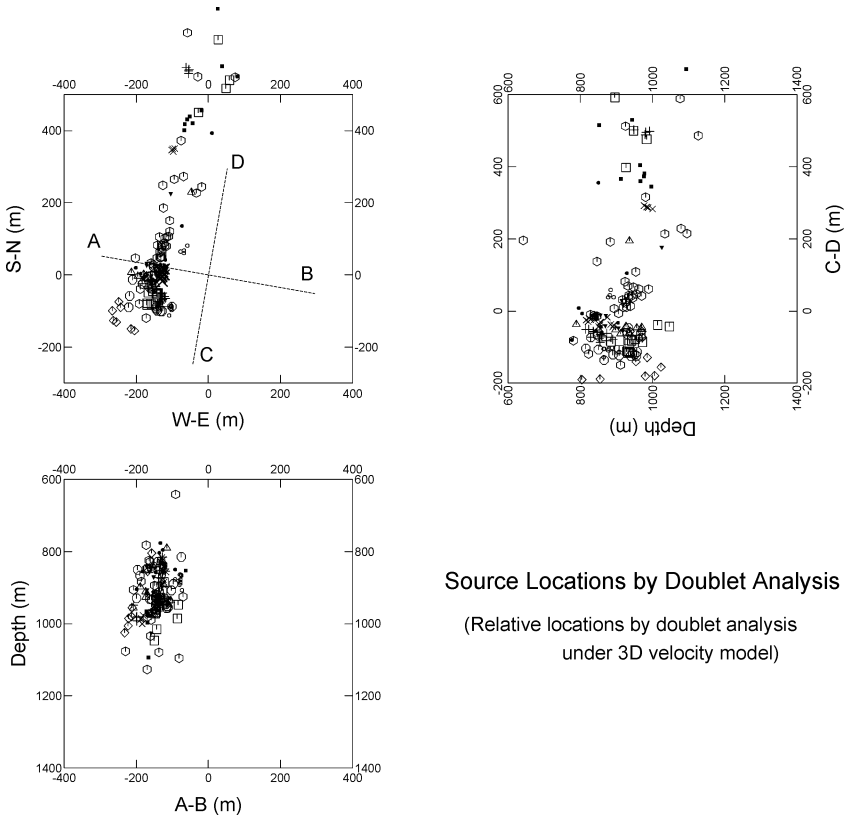


Fig. 6: Source location of multiplets, where relative locations of 20 groups of multiplets are estimated.

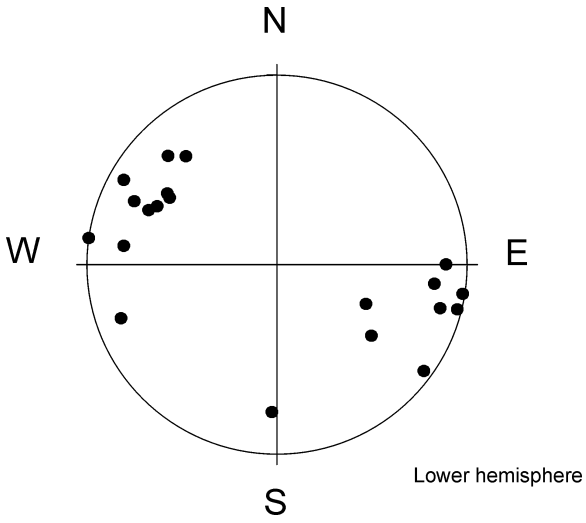


Fig. 7: Poles of structural planes.

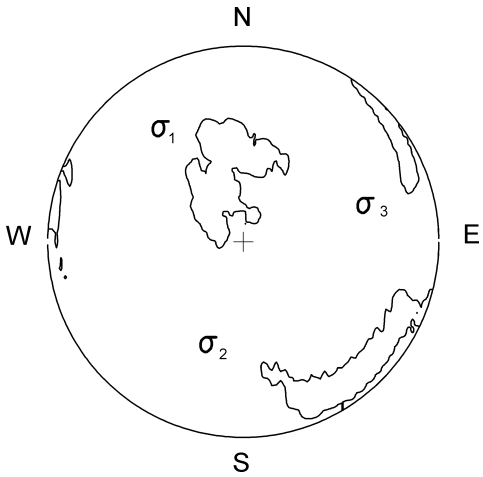


Fig. 8: Estimated principal stress direction.

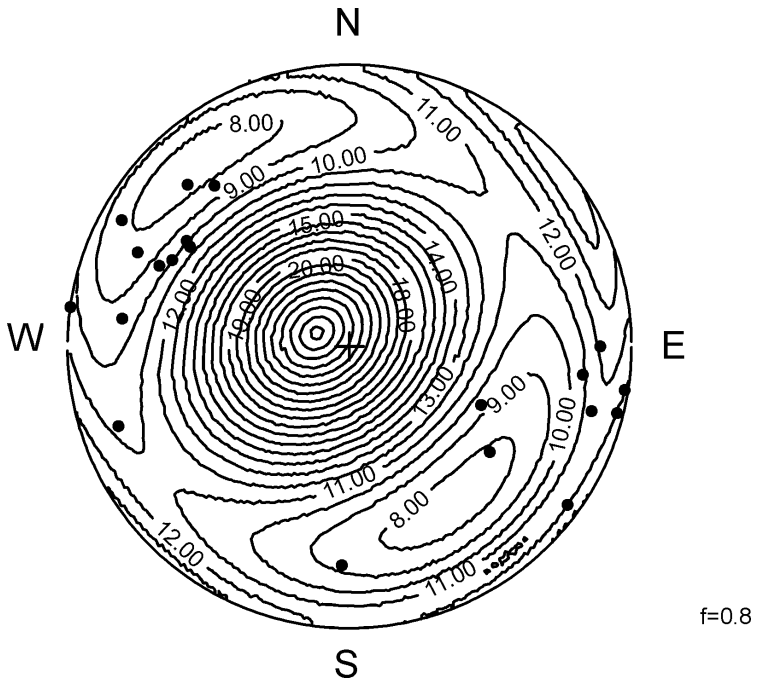


Fig. 9: Critical pore-pressure calculated under the stress field by doublet analysis.

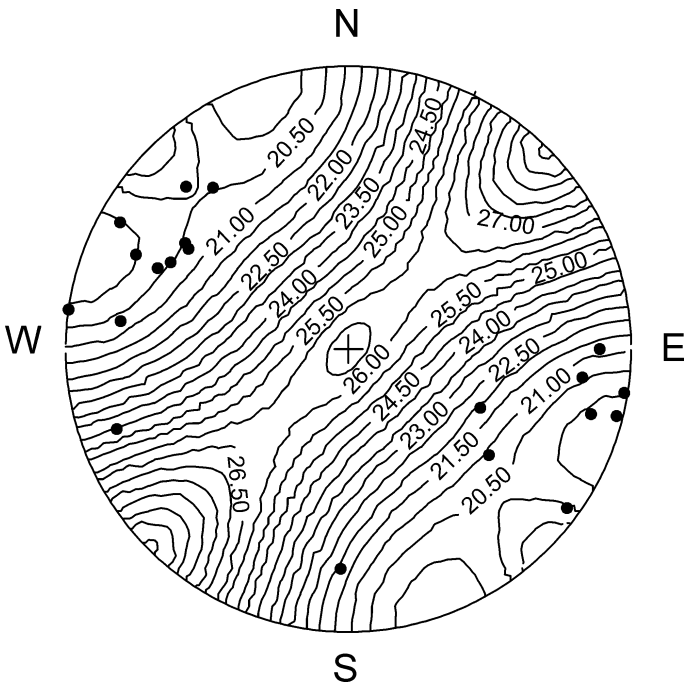


Fig. 10: Critical pore-pressure calculated under the stress field by information of boring cores.