INTERPRETATION OF RESERVOIR CREATION PROCESS
AT COOPER BASIN, AUSTRALIA BY ACOUSTIC EMISSION

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Abstract

Hydraulic stimulation of an engineered geothermal reservoir has been carried out at Cooper Basin hot-dry-rock (HDR) field, Australia in 2003. AE monitoring network, which consists of four near surface and one downhole stations, detected approximately 32,000 triggers during the stimulation and approximately 12,000 of them have been located on-site by the single-event determination method (SED). The location of AE showed a sub-horizontal structure that is consistent with the state of tectonic stress and the orientation of existing fractures in the corresponding field. We have estimated the composite focal mechanism, and it showed a reverse fault with a low inclination to West. The plane of the nodal plane agrees well with the structure by the locations of AE. We found that the plane from the focal mechanism is nearly under the critical stress state for shear slip at Cooper Basin. The AE activity was higher than that at Soultz field, where EU and other organizations are carrying out an HDR project, suggesting that the stress state in Cooper Basin site is closer to critical.

Keywords: HDR, Hydraulic fracturing, Tectonic stress, Focal mechanism, Cooper Basin

1. Introduction

The analysis of AE from the hydraulic fracturing/stimulation of hot-dry-rock (HDR) geothermal reservoir is an important method, which enables us to estimate the detailed structure inside the reservoir and the process of reservoir creation. Researchers who worked in worldwide HDR projects in the area of AE/seismic monitoring collaborated to develop advanced AE mapping methods, which has much higher resolution and reliability (super-resolution mapping). The super-resolution mapping techniques have made the integrated interpretation of AE mapping, logging, hydraulic record in fracturing operation and geological information to understand reservoir physics [1]. The post-analysis of AE location and source mechanism analysis using the super-resolution mapping techniques has been done in worldwide HDR projects [2], and mechanism of the reservoir extension has been successfully interpreted in many case.

An HDR project to develop a commercial geothermal power plant is underway at Cooper Basin, Australia, managed by a public company, Geodynamics Limited. In this site, the temperature exceeding 250°C is expected inside the granitic basement at depths below approximately 4,000 m [3]. It has been reported that the maximum tectonic stress is sub-horizontal (East to West) in the central part of Australia (Fig. 1). Because the reservoir extends normal to
the minimum principal stress direction in theory, it was expected that hydraulic fracturing creates the reservoir extending horizontally.

The first hydraulic stimulation to create an HDR reservoir was carried out in November and December 2004 to demonstrate and evaluate the potential of geothermal energy in this site. The Japanese team, consisting of the authors and people from Geodynamics Ltd., deployed an AE monitoring network, and monitored AE during the stimulation. We detected 32,000 triggers during injection of 20,000 m³ of liquid into the granitic basement over 3 weeks, and 11,724 AE events were located on-site [4].

In this paper, we report the analysis of the induced AE events, where we located the AE sources by the super-resolution mapping techniques as a post-analysis and investigated relationship among tectonic stress, focal mechanism, and AE source location. We also discuss the reservoir structures based on the analysis of AE events.

2. AE Monitoring during Hydraulic Fracturing

Figure 1 shows the tectonic stress state and the reservoir pressure as a function of depth, and the maximum stress direction. The hydraulic fracturing was carried at the site, where the horizontal compressional stress is dominant. Therefore, it was expected that the nearly horizontal reservoir was created, because the minimum principal stress direction is vertical. Figure 2 show the history of pump operation during the fracturing.

Figure 3 shows a plan view around the injection well “Habanero1” and AE monitoring stations deployed at Cooper Basin site. The injection well was drilled to a depth of 4,421 m (754 m into granite). Several sub-horizontal over-pressured fractures were found in the granitic section in the well, and most of the existing fractures were plugged to stop lost circulation and inject the water into a targeted fracture at a depth of 4,254 m. This single fracture remained as an initial dominant feed point into the formation. The monitoring network consists of one deep
downhole and four near surface stations. All the monitoring stations are deployed in sedimentary rock over granitic basement.

3. AE Source Location

Three-dimensional distribution of AE sources estimated by the single-event determination (SED) [5, 6] is shown in Fig. 4. We can see that the hydraulic stimulation brought a sub-horizontal AE cloud that has lower inclination to West. The AE cloud has a thickness of approximately 300 m and horizontal extension of approximately 3 km North to South. Figure 5(a) shows the three-dimensional distribution of AE sources located by the collapsing method [7] as well as a vertical cross section near the injection well. The collapsing method is one of the statistical optimization techniques of the AE to estimate structure of AE sources in large scale. The plan view in Fig. 5(a) is similar to that of Fig. 4, although the thickness of the AE cloud after collapsing is thinner than that by SED. The thickness of the AE cloud in Fig. 5(b) is 30 or 50 m, and the all-inclusive structure has low inclination to West. We can also see that the AE cloud is composed of several large sub-parallel structures.
Fig. 4: 3-D AE source distribution by single event determination (SED).

Fig. 5: 3-D AE source distribution located by collapsing method.
4. Focal Mechanism

We observed the polarity at the onset of the P-wave of over 1,000 events with a magnitude larger than M0.3. We have found that almost all the events showed similar polarity, implying that the focal mechanism of AE events was similar. Thus, we decided to estimate focal mechanism by the composite focal mechanism method [5]. Figure 6 shows distribution of polarity at the onset of P-wave in the lower hemisphere of the stereographic projection. AE signals detected by stations at WA-1 and 2 showed dilatational motion, and those for WA-3, 4 and McLeod-1 showed compressional motion. Figure 6 shows the estimated fault plane solution. Since the observation network was sparse, the unique solution cannot be determined. Therefore, only one reliable nodal plane is drawn in Fig. 6. Another plane can be expected to have low inclination, dipping to West. Referring the orientation of the entire AE cloud, the plane shown in Fig. 6 is considered an auxiliary fracture plane and the actual plane is considered a thrust fault with a lower inclination to West. The low inclination of the plane consists with all-inclusive structure of the AE cloud.

![Fig. 6: Distribution of first motion of P-wave on lower hemisphere stereographic projection.](image)

5. Discussion

We have obtained a thin AE cloud with the thickness of 30-50 m by the collapsing method. This result suggests that the AE cloud is a single-planer structure at many portions but in some part the layered AE clouds are separated 200-300 m and they are connected with sub-vertical cloud. According to the source locations by the collapsing method, we can interpret that single fracture and the group of sub-parallel fractures were stimulated, although we cannot yet eliminate the possibility of “over-collapsing” because this method is based on statistical theory and not directly related to the physical phenomena. On the other hand, the global orientation of the AE cloud is consistent with the fault-plane solution estimated by the composite focal mechanism model.

We have drawn a Mohr’s stress circle of tectonic stress at the depth of 4,400 m (Fig. 7), assuming that the maximum horizontal stress is the first principal stress and the minimum is
vertical. This assumption is supported by the result of focal mechanism from AE. We also plotted a direction of a plane from the focal mechanism analysis (Fig. 7). From this figure, we can find from the focal mechanism that the pre-existing subsurface fractures were under nearly critical stress state for shear slip before the hydraulic fracturing.

We compared the characteristics of AE from hydraulic fracturing with the data collected at Soultz HDR field in 2003. The hydraulic fracturing at Cooper Basin induced AE events and events appeared at a distant point from the injection well from the initial stage of the stimulation. These characteristics of AE are consistent with the assumption that AE was induced at fractures, which were favourably oriented to the principal stress and were under critical stress state before the fluid injection.

The structure of AE source by the collapsing method is simple and we can find several large sub-parallel structures. Results of focal mechanism analysis, discussion with Mohr’s circle and comparison with Soultz data were consistent with the phenomena that limited fracture was dominantly stimulated. AE multiplet analysis or clustering analysis must be done to confirm it, because it has been proved that these methods are effectively used to estimate phenomenon of AE sources [8].

![Fig. 7: Mohr Stress Circle at the depth of 4400 m.](image)

6. Conclusions

We analyzed AE during a hydraulic fracturing at Cooper Basin HDR site, Australia. The AE cloud extended sub-horizontally with small inclination to west. The orientation of the AE cloud is consistent with the focal mechanism estimated by composite model as well as tectonic stress at the field. The stress analysis showed that the AE was induced at existing fracture that is under nearly critical stress state. These results can be interpreted by a reservoir creation process where single or limited number of sub-parallel fracture with horizontal extension was mainly stimulated in this field. The authors will try to obtain further interpretation of the reservoir creation process through multiplet analysis.
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References


