

## ON SITE MAPPING OF MICROSEISMICITY AT COOPER BASIN, AUSTRALIA HDR PROJECT BY THE JAPANESE TEAM

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### **ABSTRACT**

A large scale hydraulic injection was conducted at the Australian Hot Dry Rock site in November and December, 2003 in order to develop a commercial size underground heat exchanger. A Japanese seismic team set up the seismic network and data acquisition system, and carried out microseismic monitoring during the period in co-operation with the Australian teams. On-site analysis was done as an almost real-time process by means of auto and manual time picking. Information such as 3D distribution of events, time-spatial growth of seismicity, and roughly estimated magnitude were reported simultaneously. More than 11,000 events were located as the result of the on-site mapping. The information from microseismicity was practically used for planning and determination of the appropriate hydraulic pumping program, and will be critical to the determination of the location for the second well.

### **INTRODUCTION**

The technology of Hot Dry Rock (HDR: similar meaning to EGS) is important since it is useful to expand the possible utilization of geothermal energy under a number of conditions. Japanese expertise spans over 20 years of research programs on HDR projects. Among the HDR community, there is a continued international collaborative project on microseismic analysis called MTC (More Than Cloud) project. The project commenced in 1992. Making good use of these experiences, Japanese

scientists and the Australian HDR project decided to collaborate on the microseismic monitoring.

The Australian HDR project, operated by Geodynamics Limited, began in early 2003 in the north east part of South-Australia, Cooper Basin (Figure 1). There is a huge potential for geothermal energy in the area although it will be necessary to apply HDR technology. The potential is estimated to be enormous for future large-scale renewable energy production.

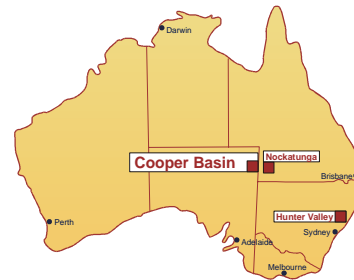


Figure.1. The Location of Cooper Basin

From November 2003, the first large-scale hydraulic fracturing was conducted in order to develop an underground heat exchanger below a depth of 4 km. During the period, we conducted semi-real time microseismic monitoring producing various analyses, such as source location, event history, estimation of non-calibrated magnitude, etc. These results were practically used for planning and determination of the appropriate hydraulic pumping program, and will be critical to the determination of the location for the second well.

In this paper, we describe the results of the semi-real time on-site microseismic analysis.

## AUSTRALIAN HOT DRY ROCK PROJECT AND INJECTION TEST IN 2003

The Australian Hot Dry Rock project commenced in early 2003 in the Cooper Basin about 10km south of the town of Innamincka. The project is operated by an Australian company, Geodynamics Limited. Australia has large volumes of identified high temperature granites within 3 to 5 km depths, and many of them can be used as a potentially clean energy source by application of the HDR technology. Geodynamics is a company with a focus on the development of HDR resources in Australia, and has secured two promising HDR geothermal tenements; one is Cooper Basin and the other is Hunter Valley in New South Wales. At present, the project is in "Stage one" according to the Geodynamics' vision and business plan, in which the main aim is a demonstration of economic heat extraction. In this stage, the company will develop an underground heat exchanger to produce 20 MWth of thermal energy from a two-well circulation system.

In the second half of February, 2003, drilling operations of the first deep geothermal well called Habanero-1 commenced, and 7 inch casing was successfully set at a depth of 4135 m (468 m into granite) in the first half of May in spite of difficult overpressure conditions. The temperature at the depth already exceeded 245 °C. The Habanero-1 was finally completed at a depth of 4421 m (745 m into granite). Plan view of the site showing associated seismic monitoring wells and the schematic of the Habanero-1 are shown in Figure 2 and 3.

The large scale injection was conducted from 06/November in order to create an underground heat exchanger. Several fracture initiation tests were conducted before the main injection. In the main injection, 10 days continuous injection was

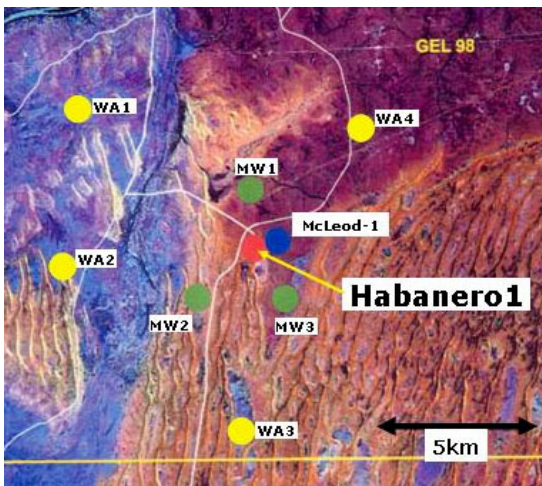


Figure 2. Plan view of the site.

performed. Then, the well was shut-in and several pulse injection tests were done. Maximum flow rate of the main injection was about 25 l/s although flow rate temporally reached 60 l/s during the fracture initiation test with the help of friction reducers. After expansion of the reservoir size, the injection was stopped on 04/December except for several pulse tests. This was followed by injection into perforated casing above the open hole section in late December. The Japanese team conducted the microseismic monitoring for all the injecting activities until 23/December.

## SEISMIC NET WORK AND DATA ACQUISITION SYSTEM

The seismic network for the monitoring during the injection was set up in corporation between Japanese MTC team (Tohoku University, Central Research Institute of Electric Industries: CRIEPI, Japan Petroleum Exploration Co., Ltd.: JAPEX, National Institute of Advanced Industrial Science and Technology: AIST) and Geodynamics. The seismic network consists of three types of detectors; one high temperature deep 3-axis geophone (Tohoku University) at 450 m from the Habanero-1, three 3-axis geophones at about 2 km distances and 850 m depths (Geodynamics), and four 3-axis geophone at wide distance (around 5 km distance) and relatively shallow depth (CRIEPI). The locations of the seismic detector are indicated in Figure 4. Because of the wide and flat area, the seismic network is ideally symmetric.

Figure 5 shows a block diagram of the data acquisition system. Both the Tohoku University and CRIEPI set up in parallel their own recording system (triggered and continuous system) for maximum safety during the data acquisition.

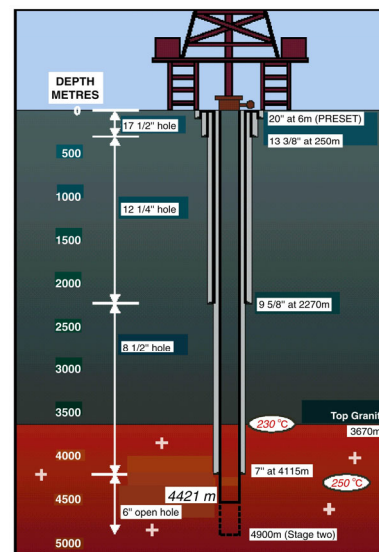


Figure 3. Schematic view of well Habanero-1

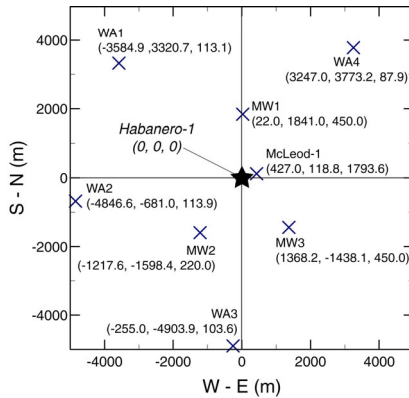


Figure 4. Location of 8 seismic detectors in relative coordinates from surface of Habanero-1.

For the onsite mapping, we used the waveform data from the triggered recording system of Tohoku University. This waveform data used for on site mapping was recorded with a sampling frequency of 5 kHz, data length of 60,000 lines.

### PROCEDURE OF SEMI-REAL TIME ONSITE MICROSEISMIC ANALYSIS

#### Flow of On Site Mapping

Because we could not develop an integrated data acquisition and analyzing system among different individual organizations, true real time analyzing system was not prepared. However, the information of mapping was reported at nearly real-time with some manual operations.

The flow of semi real-time onsite mapping is shown in Figure 6. The triggered recording system is directly connected to the note-PC through the LAN, therefore we can access the wave data simultaneously with the data acquisition. The wave data in binary format is transferred to the note-PC, and then the data is converted to ASCII for various kinds of software. The wave data was observed on viewing software. An auto picking calculation code was also used to enhance the efficiency of the onsite mapping. For the onsite analysis, only P-wave arrivals are used for the source location because we had no reliable S-wave velocity during the injection. After determination of the first arrival time of P-wave, the locations of each event were calculated and indicated as 2D or 3D maps. Time history of occurrence of the microseismicity was displayed for comparing to the pumping schedule. The 3D movies were also produced at the site. We also evaluated a rough magnitude of events from the maximum amplitude, although we could not calibrate the accuracy of them due to saturation for the very large events. All the information from the onsite mapping was provided

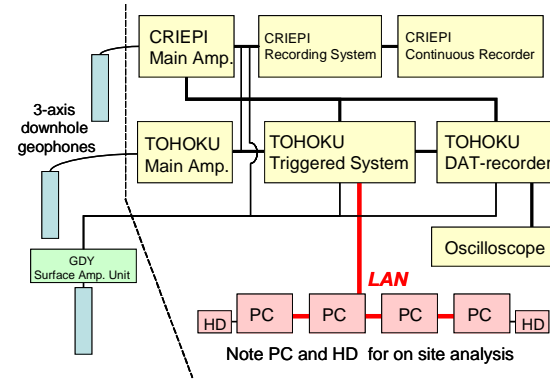


Figure 5. Block diagram of data acquisition system

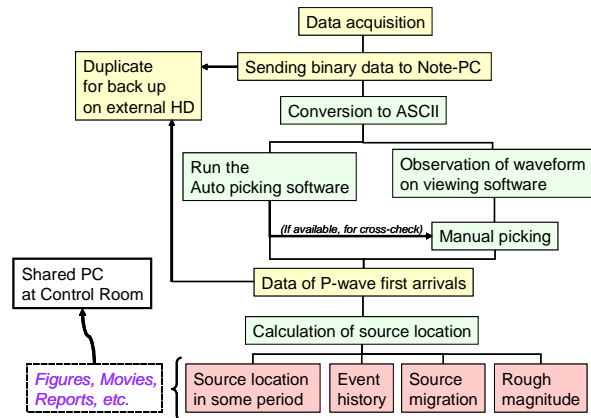


Figure 6. Flow of on site semi real-time mapping

for the operation of injection immediately after processing the acquired waveforms.

#### Auto Picking of P-wave First Arrival

The auto picking technique for microseismicity from fluid injection has been developed by AIST, which consists of combination of various approaches to find the first wave arrival. Since the actual waveforms at HDR field is very complex, the method based on single or few wave theory is often useless even if the theory is generally regarded to be reliable. Because of recent performance improvements for the mobile computer, on-site complicated calculation is realistic and capable of real engineering use of the microseismic analysis to make a usable distribution of fractures in real-time.

The calculation of the auto picking imitates the actual careful processing by manual picking. Rough evaluation of P- and S- area is performed by moving signal-to-noise ratio analysis. Then, candidates of P- and S-wave arrivals are determined by the analysis of autoregressive model. Phase index analysis of the wavelet transform is used to detect a discontinuity in the waveform, which is a tool for a fine adjustment of the detected point. For determination of S-wave arrival points, relationship of the angle between

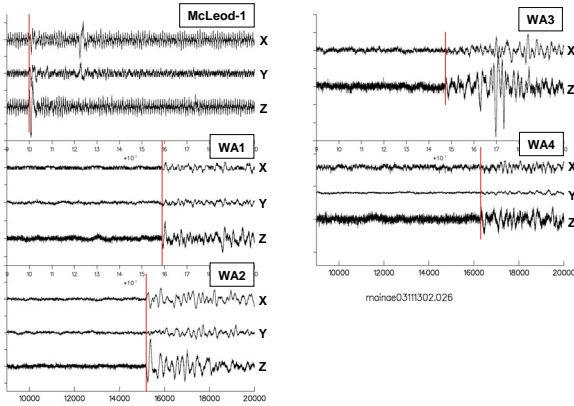


Figure.7. Example of the auto picking. Red bar shows picked P-wave arrival point for each detector.

possible P- and S-wave is evaluated by the analysis of wave direction in time-frequency domain using another wavelet transform, although we did not use S-wave for on-site analysis.

An example of the auto picking for the waveform obtained at the Australian HDR site is shown in Figure 7. In many cases the auto picking correctly picked and the picked points of P-wave are almost identical to those by manual pick, even if the signal condition was not ideal. When we compared the source location between the auto picking and manual picking, the macroscopic distributions of the events were very consistent. The number of located events by the auto picking was reduced to about 2/3 of those from manual picking. This was because mistakes of auto picking causes higher residual (remaining error or misfit) in the calculation of source location and events were rejected by the location program. Rejection was due to influences of electric noise, road noise by trucks, very low signal-to-noise level of some waveforms, as well as performance of the auto-picking method.

## RESULTS OF ONSITE MICROSEISMIC ANALYSIS

### Signal Condition

At the beginning of the microseismic monitoring, we made a spectral analysis to know the signal condition. The power spectra of some seismic signals during the first fracture initiation test were compared with those of back ground noise (Figure 8 and 9). It is clear that the seismic signal has a frequency range from nearly DC to 80 Hz. The 50 Hz noise from generators appeared at the McLeod-1 sensor, although most of the signal has good quality. Practically, the 50 Hz noise was not a problem for source location even when using auto picking. The traffic noise of trucks

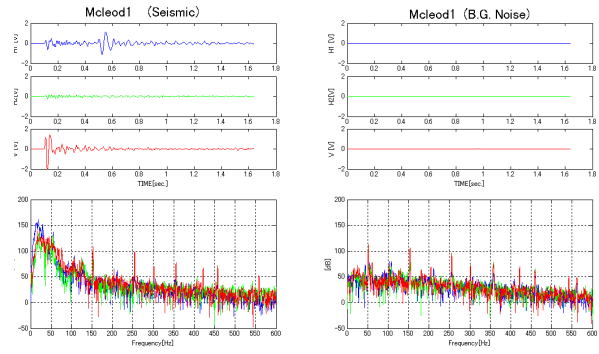


Figure.8. Power spectra of seismic signal and noise detected at McLeod-1

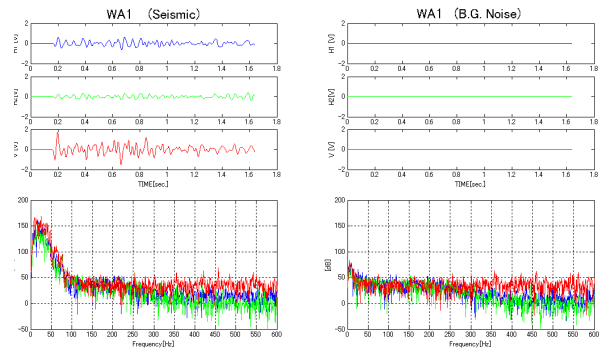


Figure.9. Power spectra of seismic signal and noise detected at WA1

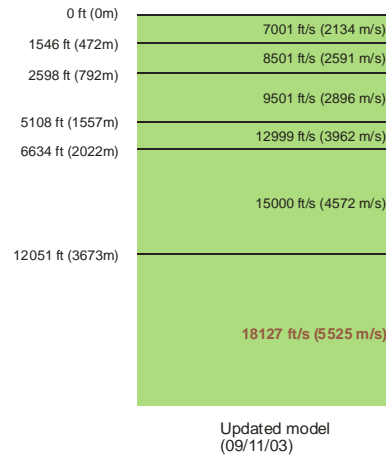


Figure.10. Velocity model used in the on site mapping

was often detected mainly by the shallow network near road.

### Optimization of Velocity for On Site Mapping

Because we had no in-situ test shot so far, initially we used the layered velocity model based on pre-existing data such as VSP, logging, and geological investigation. However, there is ambiguity in the velocity of the bottom layer. We, hence, optimized the velocity of the bottom layer on the assumption that the initial small number of events occur around

the depth of pre-existing permeable fracture at the depth of 4254 m which was observed by well logging with the pressure-temperature-spinner tool.

The optimized velocity model used for the on site mapping is shown in Figure 10. By use of this velocity model, the structure formed by 170 events observed at the beginning of the fracture initiation tests matched the depth of the pre-existing permeable fracture.

**Event History**

The event history was reported as a number of events per 10 minutes for comparison with the pumping schedule. It was useful to know the event activity and relationship between pumping and event occurrence. The results were continually referenced for deciding the strategy for continued injection at the site.

Most of the event activities correlated with the pumping schedule. The higher event rates were generally observed for higher pumping rate. However, seismic activity usually continued for some time after shut-in.

**Source Migration Analysis**

Time history of depth and distance from the injection well was reported in order to watch the growth of the fractures. The depth control in growing fracture is particularly important for this HDR project, because a horizontal growth was predicted from the known stress field, and the shallower sediments contain oil and gas resources.

Figure 11 shows an example of source migration analysis during the 2nd fracture initiation test. We see the horizontally expansion of fracture to the distance of about 300 m after 7:00, but on the other hand, the depth of fracture stayed around 4200 m. The result implied that the plane type of reservoir was growing during this period.

**On Site Mapping**

The source locations were reported at the site for all the period of the injection. Totally over 11,000 events were located and reported as various figures, technical reports, and 3D movies, and they were referred to the pumping operations. We show the source location of all the events during the injection in Figure 12. Finally, the seismic cloud reached a length of 3 km, which is the largest HDR reservoir yet produced.

At the beginning of the injection, first several tens events were located just around the open hole section of the Habanero-1. The depths concentrated near the pre-existing permeable fracture after the velocity optimization. At this time, the main fracture plane

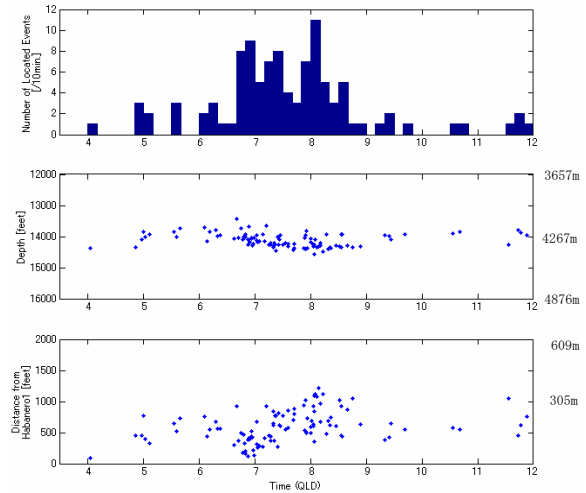


Figure.11. Migration of source in the 2nd fracture initiation test

was clearly outlined by the event location. Then the reservoir was gradually expanded during the first part of the injection. After the tests for the fracture initiation, the planar shape of the reservoir became clearer as expected from the regional stress regime around the HDR site. Several events with very large magnitude (about M3 class) began to occur in this early period. The seismic activity and the expansion of the events were rather high for a relatively small injected volume.

Since the large scale main injection, growth of the seismic cloud was clearly observed everyday in keeping with the general shape of the reservoir. It was interesting that the shape of outer boundary of the seismic cloud was often apparently linear and a shape of parallelogram was clearly formed. The result implies that some structural lines exist inside granite body and play an important roll on the progress of front line of fractures. Further study and interpretation should be needed on this phenomenon because the linear features are not fully consistent with the expected regional stress regime.

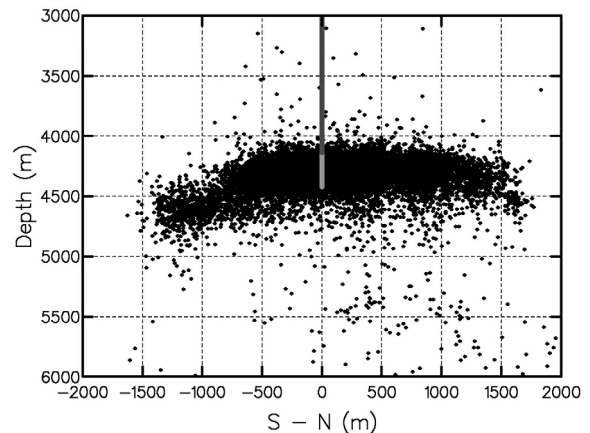


Figure.12. Source location of all the events during the injection

We continued the on site mapping until the end of December even after the main pumping activities. These later events, resulting from pumping through perforated casing were located mainly near the outer boundary of the previously developed seismic cloud, although some new expansion was also observed.

### **Observation of Large Magnitude Events**

In order to classify the energy of the microseismicity, rough magnitude was calculated during the on site mapping. The calculation was based on the maximum amplitude of the waveform considering the past observation using the same instruments, although reliable calibration could not be done at the site. Because of the saturation of the signal, accuracy in the number for events over M1 is not guaranteed. Geoscience Australia was able to report their estimation of magnitude for a number of events above M2.5. The number of events over M1 was continuously reported during the main injection.

The distribution of events with large magnitude was rather uniform. However, it often seemed that very large events were observed in advance of apparent progress of the reservoir. Much further analysis is yet to be done.

### **CONCLUSION**

The Japanese seismic MTC team conducted microseismic monitoring and on site mapping during the large scale hydraulic injection in November and December, 2003, in corporation with the Geodynamics HDR project in the Cooper Basin, South Australia. We successfully provided various information at nearly real-time, and the information was practically used to guide the injection program.

Totally more than 11,000 events were successfully located by the on site mapping, and the developed reservoir shows a sub-horizontal planar structure as expected from the known stress regime. Therefore, from the point of view of seismic location, the fracturing was well controlled and seems reasonably successful as planned.

The huge dataset obtained here is not well analyzed yet. The geological conditions are rather different to all existing HDR projects, and further analyses will be useful not only for the Australian project but also for scientific progress in HDR studies.

### **ACKNOWLEDGMENTS**

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