Data Acquisition and Analysis of Microseismicity from the Simulation at Soultz in 2003 by Tohoku University and AIST, Japan

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Keywords
Microseismicity, stimulation, Soultz HDR Project, collapsing

ABSTRACT

The second hydraulic stimulation at a depth around 4500m to 5000m was carried out at Soultz HDR site, Alsace, France in 2003 to create a deep reservoir for a pilot plant. Around 38,000 m^3 of heavy brine and water was injected in the 5005m borehole GPK-3 (which was drilled in 2002), and the other deep well GPK-2. The induced microseismic events were detected by a seismic network consisting of three downhole 4-component accelerometers and two 3-component geophones. The authors picked onsets of events using automatic picking software and located the events on-site. The number of triggered events during the stimulation was approximately 87,000, and we picked approximately 8,100 high quality of events. The authors manually re-picked the events, which are automatically picked on-site, and located them by JHD (joint hypocenter determination) and the coherence-collapsing methods. The relocated seismic cloud extends mainly NS direction around GPK-3 and N 45°W around GPK-2.

Introduction

A HDR/HWR project for commercial electrical power generation has been on-going at Soultz-sous-Forets, Alsace, France since 1987 mainly supported by EU, the governments of France and Germany, and power companies (Baria et al, 1995, 1999, 2000). The "pilot plant phase" using a deep reservoir around 4500-5000m has been started in 1999. A well, GPK-2, was extended to a depth of 5080 m with a open-hole section from 4340 m to 5080 m, and the first stimulation of GPK-2 was carried out in June-July, 2000 (Asanuma et al., 2001). A 1000 m^3 of heavy brine was injected in the initial stage of the stimulation for deeper reservoir extension, and 22,000 m^3 of water was then injected with a flow rate of 40-50 l/s. Approximately 8,000 events were manually picked from 40,000 triggers and located. The extension of the seismic cloud to the NW at depths between 4300 m to 5300 m was estimated by the mapping.

After evaluating the hydraulic characteristics of the reservoir created in 2000, the second deep well, GPK-3, was drilled to a depth of 5005m in 2002. This well was targeted to the southern edge of the seismic cloud of stimulation in 2000, to enhance reservoir to southward by the stimulation of this borehole. The second stimulation of the deep reservoir was carried out from end of May to middle June, 2003. The total amount of brine and water injected in this stimulation was approximately 38,000 m^3, most of the brine/water was injected in to GPK-3 but for a short period a new technique was tried by injection in two wells simultaneously i.e. GPK-3 & GPK-2. A new technique ("Focused stimulation") was tried to enhance the permeability between the wells (Baria et al., 2004). Research teams at Tohoku University and National Institute of Advanced Industrial Science and Technology (AIST) set up their computer system and software for semi-realtime picking/mapping in parallel to a system for picking/mapping from contractor with Soultz project (Semore Seismic) for cross-checking of the mapping results. The Japanese researchers re-picked events manually subsequently and applied the collapsing method as a part of the post analysis. In this paper, the outline of the data acquisition and results from the mapping are described.

Outline of Data Acquisition

A plan view showing location of the major wells in Soultz site is shown in Figure 1. The 5,005 m deep well GPK-3 was drilled in 2002 to intersect the southern edge of the seismic cloud induced in 2000. The openhole section of GPK-3 starts from MD of 4,437m. The whole section of GPK-2 and 3 was stimulated by injection from the well head. The induced microseisimicity was detected by a seismic network consisting of 4-component accelerometers in wells 4550, 4601 and OPS-4. Two three-component geophones were also deployed in the wells EPS-1 and GPK-1. The depth of sensors are also shown in the Figure 1. It has been shown that the newly drilled seismic observation well OPS-4 improved location accuracy considerably (Asanuma et al., 2001).

The data from each seismic station was digitized by a system of GEIE with a sampling frequency of 2 kHz, 24 bit amplitude resolution and data length of 10,000 words (5 seconds) per trigger. The Japanese team and the contractor of GEIE shared the same data. The data was sent to a PC and other workstations, and used for nearly realtime mapping for daily reports. The EEIG used a propriety software (Semore Seismic) for auto picking and locating the microseismic events in parallel with the Japanese team, who used a software for automatic picking developed by Soma (Soma et al., 2003). Typical data collected during the stimulation is shown in Figure 2. The onsets of P and S waves are clearly identified. Around 86,985 events were triggered in the AD system during the stimulation and shut-in, and approximately 12,000 of them were picked/located on-site (Soma et al., 2003).

After observing several tens of events which are picked/rejected by the automatic picking software developed by Soma, we have concluded that events which are rejected by the automatic picking software are considered to be noise because of low signal amplification and high electrical noise. Hence, we manually re-picked onsets of the phase for the events which are automatically picked on-site. We have rejected some events with unclear onsets for reliable mapping. The total number of manually re-picked events for post analysis is 8,076 which is 9.3% of all the triggers (86,985 triggers).

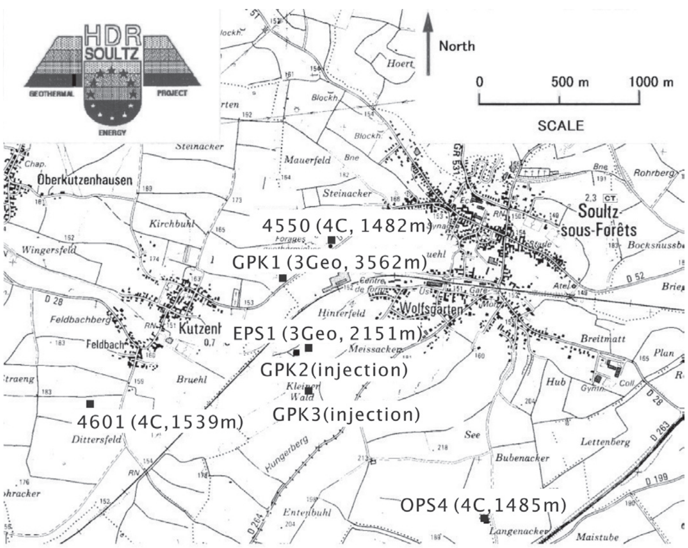

Figure 1. Plan view of the Soultz HDR site.

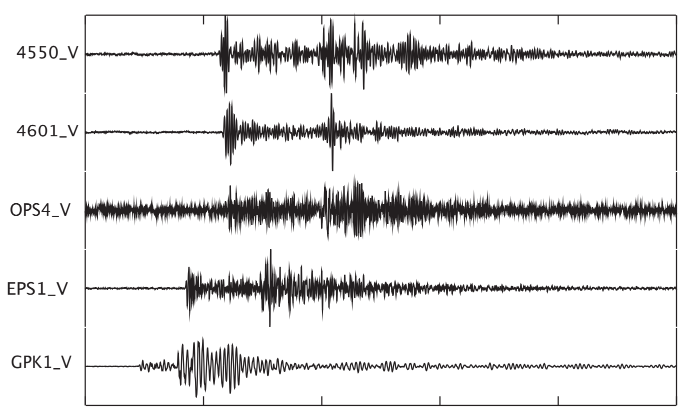

Figure 2. Typical seismic trace collected in the stimulation.

Present Results

Estimation of the Velocity Model

Because no check shot data in the borehole for velocity calibration is available in the mapping of deep reservoir at Soultz, we estimated the optimum velocity for each station ("unique velocity model") by fitting the initial 48 events to one of the most possible feed points in GPK-3 (MD 4,700m). In this procedure, we have firstly located all the picked events with JHD with a unique velocity model and then calculated the average distance of initial 48 events to a point in GPK-3 at a depth of 4,700m. The relationship between the average distance of initial events to GPK-3, 4700m and average residual of all the picked events for 6,000 different velocity models is shown in Figure 3. Results for the velocity model that used in the location of microseismicity in 2000 by the authors is also plotted in the figure. It can be seen that the velocity model gives larger residual and distance to the feed

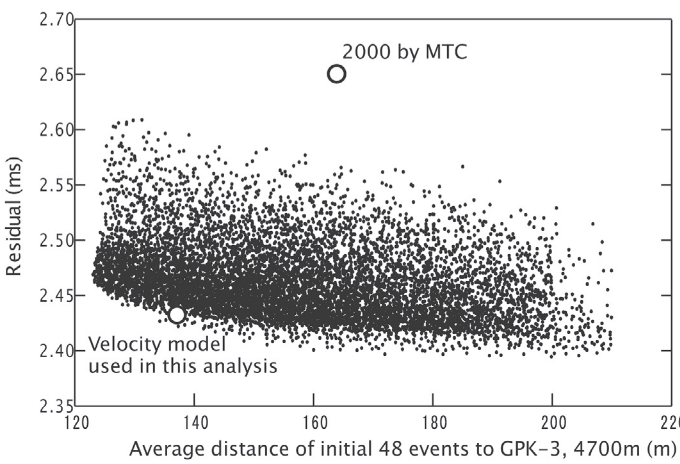

Figure 3. Relationship between residual and distance of initial events to the most possible feed points for different velocity models.

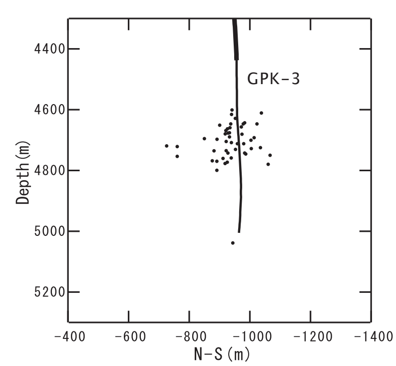

Figure 4. Location of the initial 48 events after velocity optimization.

point. We have decided to use a model which brings considerably reasonable fit to the feed point and residuals. The location of the initial 48 events after velocity fitting is shown in Figure 4.

Location by JHD

Location of all the picked events by JHD with unique velocity model is shown in Figure 5. The mean residual (remaining error) after JHD was 2.43ms which is approximately 1/3 of that in 2000. All the picks except for S of 4601 and OPS-4 were used with uniform weighting, because reliability of pick of S from these stations was considered to be lower by observation of traces. The JHD location from 2000 stimulation is plotted together with that of 2003 in Figure 6. The location of microseismic events were estimated by using a model to fit initial events in 2000 to a feed point in GPK-2. The source migration by JHD for all the day of the seismic monitoring is shown in Figure 7, overleaf.

The following characteristics of the seismic cloud in 2003 are found from the JHD location and its spatial-temporal change,

a) The volume of the cloud is approximately double of that in 2000. The north-western part of the seismic cloud extended approximately 1,000m NW of GPK-2.

b) The seismic cloud extended to NS direction at depth interval from 4250m to 5250m until 8th day from the start of stimulation where liquid was injected to GPK-3 only. After the end of the double injection from GPK-2 (4 June), the seismic events started to appear at NW 600m of GPK-2 at a depth around 4,400m. Afterwards, a part of seismic cloud around GPK-2 grew N45W at 300m SW of GPK-2 at depth around 4,500m.

c) The seismic activity around GPK-2 was lower all through the stimulation.

d) After shut-in, the seismic activity grew southward of GPK-3 at depth of 4,000 to 5,000m, and NW of GPK-2 at depth around 4,500m.

Relocation by Coherence Collapsing

The authors have developed software for Coherence Collapsing which selectively relocate events with higher mutual coherence to a point following the concept of the original Collapsing method (Asanuma et al., 2003). Location of all the events and events with higher mutual coherence (>0.68) by the Coherence Collapsing is shown in Figure 8. The location of the events with higher mutual coherence distributed widely in the seismic cloud, and we can not see any strong trend. The percentage of the events with higher coherency was approximately 25% which is much smaller than that for shallow reservoir (40-59%)(Moriya et al., 2002). These results may suggest that the mechanism of reservoir extension is more complex in the deep reservoir and the flow path are more widely distributed in the stimulated zone.

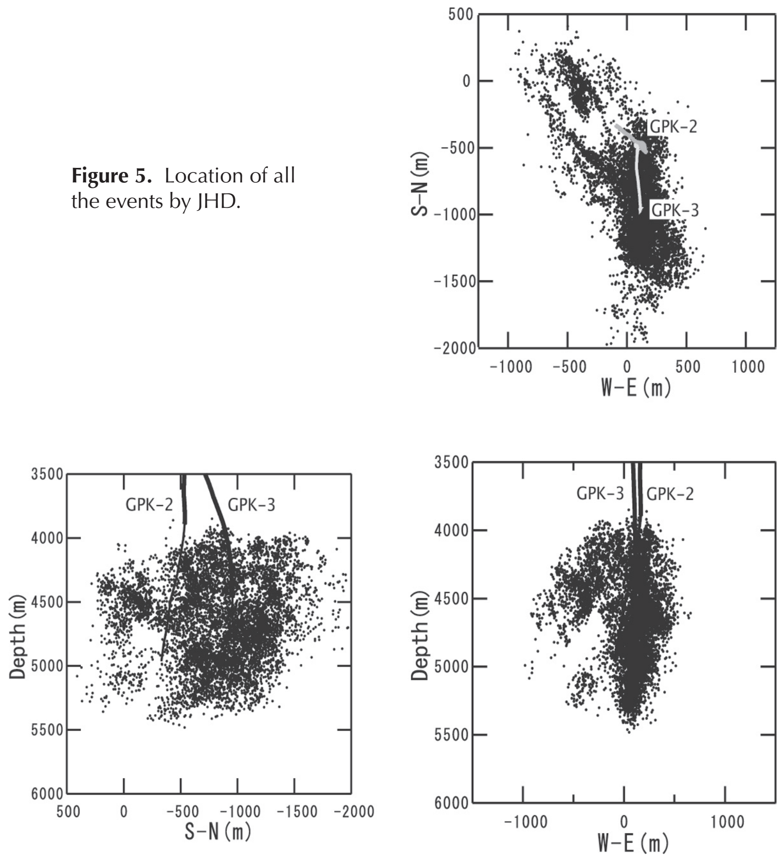

Figure 5. Location of all the events by JHD.

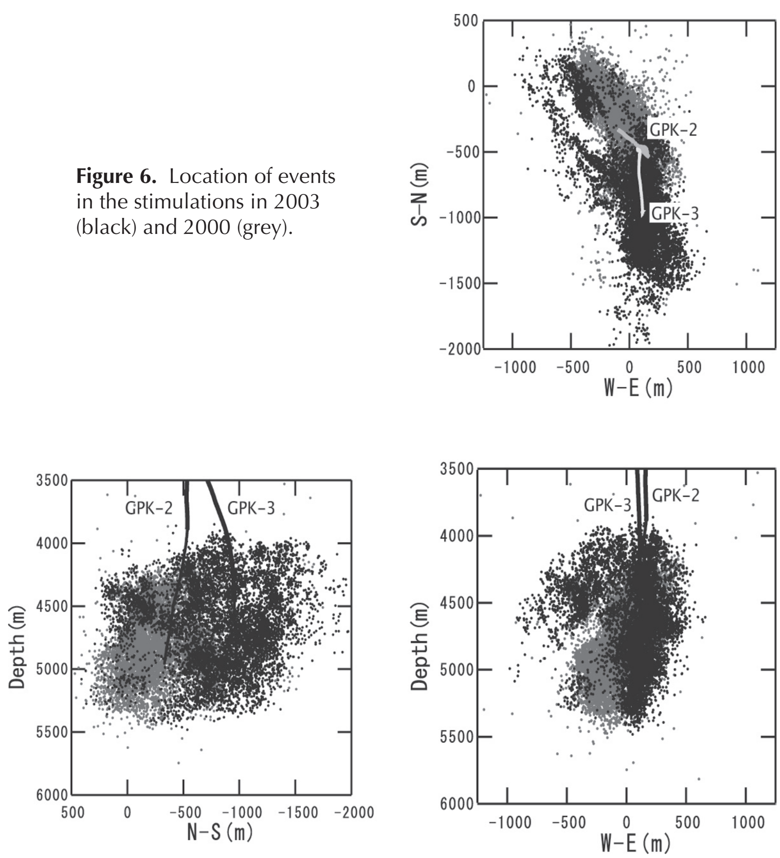

Figure 6. Location of events in the stimulations in 2003 (black) and 2000 (grey).

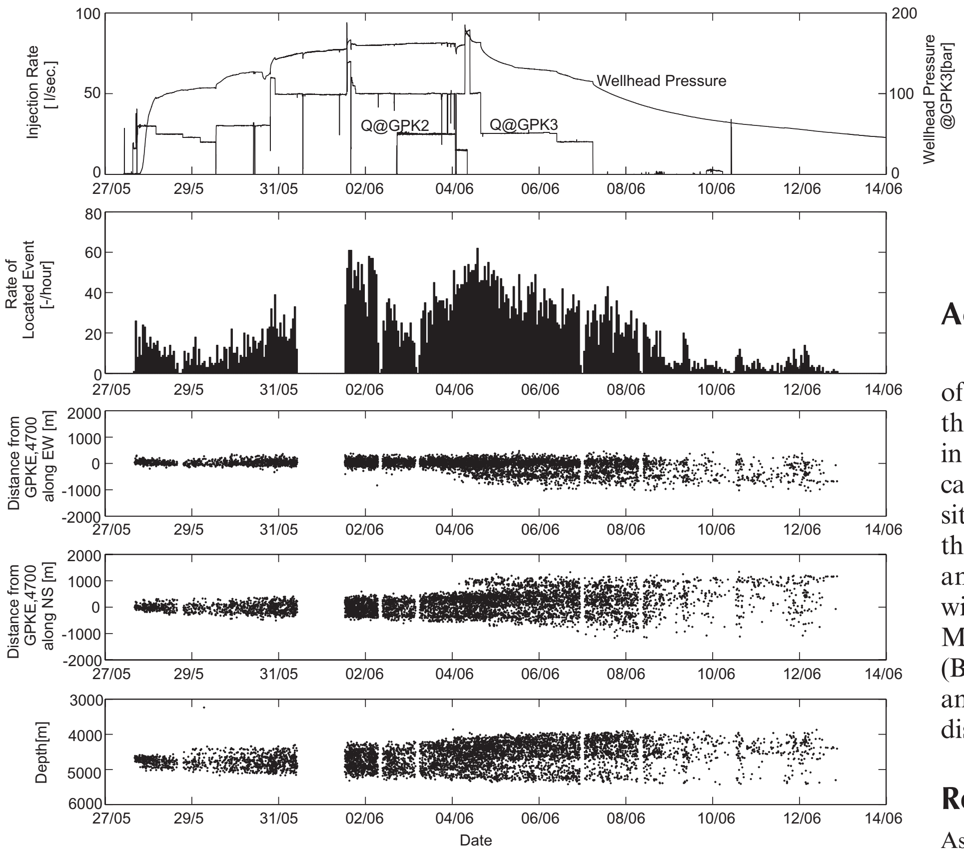

Figure 7. Seismic source migration.

Conclusions

The team of Japanese researchers analyzed approximately 8,000 microseismic events during a stimulation at the Soultz HDR site in 2003. The seismic location showed NS striking sub-vertical structure around the injection well, GPK3, and showed NW extension around GPK-2. The kink in the structure of the seismic cloud in the horizontal plane may be correlated to existing geological structures, but further investigation from various aspect are needed. The double injection from both GPK-2 and 3 seems that it effectively worked to stimulate a zone beyond GPK-2, suggesting that hydraulic connection between the wells are improved.

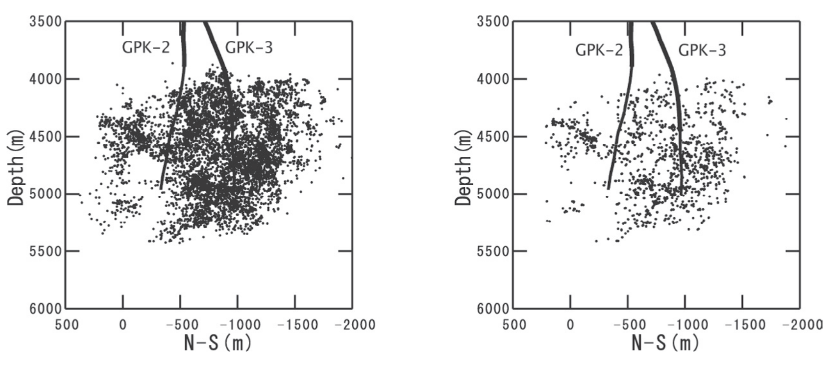

Figure 8. Relocated events by the Coherence Collapsing method. Left: All the events, right: events with higher mutual coherency.

The drill of the third deep well is underway has been completed in April 2004, and final stimulation is planned in the summer of 2004 at the Soultz site. The authors wish the success of the drilling, stimulation and building a pilot plant at this site to demonstrate the advantages of the HDR/HWR systems.

Acknowledgements

The work presented here was done as a part of the MTC Project. We would also like to thank EEIG Heat Mining for its cooperation in data acquisition and for offering hydraulical/geological data from the European HDR site at Soultz which is supported mainly by the European Community, BMWI (Germany) and ADEME (France). The authors also wishes to acknowledge other members of the MTC/MURPHY Project, Dr. J. Baumgaertner (BESTEC) who made the cooperation possible and Dr. Ben Dyer, Semore Seismic, for their discussion, advice and encouragement.

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