

Part 2: Microseismic aspects of the Basel 1 geothermal reservoir

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The generation of an efficient hydraulic subsurface heat exchanger system is crucial for economic production of electricity and heat from an Enhanced Geothermal System. The circulation of water at sufficiently low flow impedances through natural discontinuities typically requires hydraulic stimulation to improve the hydraulic properties of the naturally fractured rock mass. This fluid injection process induces shearing on favourably oriented fracture patches which results in an increase of hydraulic conductivity due to self propping effects. The rupture procedure is accompanied by a stress release that causes the emission of seismic energy.

Monitoring these so called microseismic events provides valuable information with respect to the spatial and temporal reservoir growth, the reservoir geometry and assists in the optimum targeting of subsequent geothermal wells.

A sophisticated microseismic network array has been realized with a focus on appropriate network sensitivity, hypocenter location accuracy and operational reliability. Absolute event hypocenters were mapped in real-time applying an automatic routine for event detection, P- and S-wave onset time determination and an exhaustive grid search for event location. In parallel to this auto-processing routine the auto picked traveltimes were visually checked and the events relocated where necessary. Within the time frame 2nd to 15th December 2006 covering a hydraulic injection phase from 2nd to 8th December, some 13600 events were detected. Applying tight and consistent location criteria reliable event locations were obtained for 3146 events, the location error of which was of the order of 100 m. The overall image of the seismically active volume displays a subvertical disc like structure trending about N159°E and a single offsetting branch with an azimuth of N100°E. The dominant NNW-SSE reservoir trend corresponds with the direction of S_{Hmax} (N144°±14°E) and the predominant azimuth of natural discontinuities (N140°-170°E).

In a post processing step the microseismic data set have been relocated using a relative location method (Waldhauser and Ellsworth, 2000) which enabled the mapping of small scale seismically active features. These clusters of coherent events form predominantly elongated oblate ellipsoid shaped structures of about 100 m to several 100 m length. The location error in between relative located events is typically in the order of < 10 m. The physical meaning of these mapped structures is still subject to ongoing investigations.

Assuming the validity of the double couple model, the fault plane solutions for a range of events with varying magnitudes were carefully analysed based on P-wave first motion polarity observations. The interpreted focal mechanisms indicate a strike slip dominated stress regime which is in line with independent

stress field observations (Plenefisch & Bonjer, 1997)). The direction of the preferred fault plane is close to the optimal angle for frictional sliding and corresponds with the azimuth of an interpreted strike slip fault plane of a small natural earthquake swarm in the Pratteln region close to Basel in 1990 (Deichmann et al., 2000).

Since the project site is located in close proximity to its consumers – within the city of Basel - the real time monitoring of events that may cause unacceptably high levels of ground shaking was critical. Based on a four step seismic response procedure (derived from the “Traffic Light” system by Bommer et al., 2006) the level of induced seismicity has been carefully assessed. The measures to be taken were based on three independent criteria: public responses, local magnitude (M_l) and peak ground velocity (PGV). The latter two parameters were provided in real-time by the Swiss Earthquake Department as an independent and neutral institution.

On the 8th of December due to a M_l 2.7 event the injection rate was reduced in line with the seismic response procedure. A few hours later, as a precautionary measure, the injection was stopped and the well shut in. This action was taken one step ahead of the seismic response procedure. Nevertheless, several hours later a M_l 3.4 event occurred which led to a preliminary suspension of the project activities. Three further aftershocks with $M_l > 3$ occurred following the Bleeding Off of well Basel 1. These events were on the 6th and 16th of January 2007 and on the 2nd of February 2007 respectively 29, 39 and 56 days after the Bleeding Off phase commenced.

Due to the high significance of stimulation related perceptible ground shaking with respect to the continuation of this project and the progression of geothermal energy production by EGS systems, intense research efforts are currently ongoing to better understand the causal interrelationship that led to the unacceptably high ground shaking. The overall target is to develop measures of avoiding such stimulation related events that are widely felt and can cause public concern.

REFERENCES

- Bommer, J.J., Oates, S., Cepeda, J.M., Lindholm, C., Bird, J., Torres, R., Marroquin, G., Rivas, J. (2006): Control of hazard due to seismicity induced by a hot fractured rock geothermal project, *Engineering geology*, 83, 287-306.
- Deichmann, N., Ballarin Dolfin, D., Kastrup, U. (2000): Seismizität der Nord- und Zentralschweiz, NAGRA, Technischer Bericht 00-05.
- Dyer, B.C., Schanz, U., Spillmann, T., Ladner, F. and Häring, M.O. (submitted to *The Leading Edge*): Microseismic imaging of a geothermal reservoir stimulation.
- Plenefisch, T., Bonjer, K.-P. (1997): The stress field in the Rhine Graben area inferred from earthquake focal mechanisms and estimation of frictional parameters, *Tectonophysics* 275, 71-97.
- Waldhauser, F., Ellsworth, W.L. (2000): A Double-Difference Earthquake Location Algorithm: Method and Application to the Northern Hayward Fault, California, *Bulletin of the Seismological Society of America*, 90, 6, 1353-1368.