Proceedings World Geothermal Congress 2015
Melbourne, Australia, 19-25 April 2015

Seismic Monitoring of the Rittershoffen EGS Project (Alsace, France)

Vincent Maurer(1), Nicolas Cuenot(2), Emmanuel Gaucher(3), Marc Grunberg(4), Jérôme Vergne(4), Hervé Wodling(4), Maximilien Lehujeur(4), Jean Schmittbuhl(4)

(1) ES-Géothermie, 3a chemin du gaz, F-67500 Haguenau, France; (2) GEIE « Exploitation Minière de la Chaleur », Route de Soultz – BP 40038, F-67250 Kutzenhausen, France ; (3) Geothermal Research, AGW, KIT, Adenauerring 20b, D-76131 Karlsruhe, Germany ; (4) EOST, 5, rue René Descartes, F-67084 Strasbourg cedex, France

vincent.maurer@es-groupe.fr; others: cuenot@soultz.net, emmanuel.gaucher@kit.edu, marc.grunberg@unistra.fr, hwodling@unistra.fr, jean.schmittbuhl@unistra.fr

Keywords: Geothermal Project, Rittershoffen, Induced Microseismicity, Monitoring, Seismic Network.

ABSTRACT

The ECOGI joint venture (Electricité de Strasbourg group, Roquette Frères and Caisse des Dépôts et de Consignation) is in charge of the development and the exploitation of the Rittershoffen Enhance Geothermal System (EGS) located 6 km east of Soultz-sous-Forêts, in Northern Alsace, France. This EGS reservoir is one of the very few currently under development in Europe and is designed to produce 24 MWth (170 °C, 70 L/s).

The first well of the doublet (GRT1) was completed end of 2012 and reaches, at 2580 m depth, the crystalline fractured basement which constitutes the reservoir formation together with the overlaying Buntsandstein sandstones. A reservoir development strategy was defined, and first consisted in enhancing the connections between GRT1 and the fractured reservoir. These operations were applied in two sequences, respectively in April 2013 and in June 2013. The stimulation operations were successful, providing the expected enhancement of the hydraulic properties of the well. The drilling of the second well, GRT2, started in March 2014.

Since 2012, the induced microseismicity of both Rittershoffen and Soultz-sous-Forêts geothermal projects has been monitored by a seismic network composed of 12 permanent surface stations. To increase the network detection capability, the ECOGI management decided to deploy a temporary network composed of 16 additional real-time telemetered surface stations, in collaboration with the KIT (Karlsruhe University, Germany). Waveforms from all stations are currently acquired in real-time via queries supported by a SeisComp3 server. Microseismicity was carefully monitored during the operations carried out to enhance the reservoir production. The main objective was to avoid inducing a microseismic event felt by population. On the top of that, several innovative other research projects motivated the installation of non-telemetered stations, increasing the network to 300 stations within an area of about 15 km around the drilling platform, thereby constituting an unprecedented and unique seismological dataset associated to a geothermal EGS project.

1. INTRODUCTION

For about twenty years now, the Upper Rhine Graben has been a main target for research on geothermal exploitation in deep fractured formations. Indeed, the scientific pilot site at Soultz-sous-Forêts, established in a deep fractured granitic massif between 3.5 and 5 km depth, has resulted in the development of the EGS technology and has provided the international scientific community with a unique high quality data set. The principle of the EGS technology consists in increasing the low natural hydraulic performance of the geothermal fractured reservoir by thermal hydraulic or/and chemical stimulations. These stimulations increase the fracture permeability so as to allow pumping the geothermal brine at adequate flowrates (Baujard et al., 2015).

Since the last decade, geothermal exploitation activity in the Upper Rhine Graben has been on-going with several French, German and Swiss deep geothermal sites such as Bruchsal, Bruhl, Insheim, Landau, Riehen and Soultz-sous-Forêts, which are active from exploration to exploitation. All these projects deal with deep fractured geothermal reservoirs located within Triassic-sediments and/or crystalline basement.

More recently, Electricité de Strasbourg group, Roquette Frères and Caisse des Dépôts et de Consignation gathered to create the ECOGI company (Exploitation of Geothermal-Origin Heat for Industry) with the support of ADEME, Conseil Régional d'Alsace and SAF Environnement for financial and geological risk insurance. Located in Rittershoffen, 6 km east of Soultz-sous-Forêts, in Northern Alsace, this EGS reservoir is one of the very few currently under development in Europe and is designed to produce 24 MWth (170°C, 70 L/s). The geothermal heat will be delivered to a bio-refinery located in Beinheim, 15 km away from the geothermal plant. The ECOGI project is the first EGS project worldwide dedicated to a heat application in high temperature conditions.

2. CURRENT STATUS OF THE PROJECT

The first well GRT1 reached the final depth of 2580 m end of 2012. Various logs and hydraulic tests were performed over the year 2013. A strategy was defined to carry out operations in order to enhance the connections between the well and the reservoir. These operations were applied in two sequences, respectively in April 2013 and in June 2013. The reservoir development strategy was designed by a team composed by ECOGI, ES-Géothermie and EEIG “Heat Mining” (leading the Soultz-sous-Forêts project) staff. The obtained results obtained were positive and the hydraulic properties of GRT1 reached the targeted thermal power. Hence, the drilling of the second well, GRT2, started in March 2014 and should be completed by June 2014. The operations performed to enhance the first well will be repeated if necessary for the second well in summer 2014 (Baujard et al., 2015).

3. SEISMIC NETWORKS

3.1 Telemetered networks

In order to detect any rise of seismicity induced by the geothermal operation, the drilling authorities (DOTEX) required the deployment of a permanent seismic network, composed of 5 to 10 surface stations. Since 2012, the micro-seismicity of both Rittershoffen and Soultz-sous-Forêts geothermal projects has been monitored by a permanent seismic network composed of 12 surface stations:

- The Soultz seismic network is composed of short-period (1 Hz) seismometers, one or three components (L4C/L4C 3D), deployed at surface. Signals are digitized on site by 15-bit GEOSTAR data loggers and sampled at 150 Hz. The signals are then transmitted to a central site via a radio link where samples are synchronized with an external time receiver (DCF). At the central site, a SeisComp3 plugin fetches the GEOSTAR formatted data and makes it available through SeedLink to Strasbourg University (EOST), via an internet connection.

- The Rittershoffen seismic network is composed of short-period (1 Hz) three components seismometers (L4C 3D), deployed at the surface. Signals are digitized by Quanterra Q330S directly in miniSEED format at a sampling rate of 100 Hz, increased to 200 Hz by beginning of 2014, and are sent to a central site via a WIFI connexion. Here a SeisComp server makes data available to the Strasbourg University (EOST) via internet. Unlike the Soultz network, this architecture prevents from data losses in case of transmission failures since the data are always available at the server installed in the field.

In addition to this permanent network, the ECOGI management decided in June 2013 to deploy a temporary network composed of 16 real-time telemetered surface stations in order to monitor the stimulation operations of the first well GRT1. The seismological units loaned by the GIPP-GFZ to the KIT, are composed of three-component seismometers (L4C-3D) and EarthData loggers (PR6-24, old generation), sampled at 300 Hz. Details concerning the temporary network of the KIT can be found in Gaucher et al. (2013).

3.2. Non-telemetered networks

Several other scientific projects motivated the installation of non-telemetered stations. Hence, the KIT decided to make its network denser network before the drilling of the second well GRT2. Consequently, the existing network was completed by 15 three-component stations to provide a more homogeneous network coverage over a radius of 5 km around the well pad. With such a network of 31 3C-stations distributed every 1.5 to 2 km, fully operating since March 2014, the monitoring of the drilling of GRT2, as well as the future stimulation and circulation tests will deliver higher quality results. It will offer a better coverage and a better sensitivity than for the first well stimulation. The main objectives of this project are first the development of semi-automatic microseismic characterization techniques based on dense networks. Reservoir tomography based on the noise induced by the drill-bit during the drilling of the second well GRT2 and recorded by the dense array constitutes the second main objective of the project (Gaucher et al., 2013).

In early 2014, EOST also installed on surface seven broadband stations composed of Trillium T120 seismometers and 24-bits Taurus data loggers, sampled at 200 Hz, along a 15 km circle around the well pad. Together with the other network stations, these stations will be mainly used to produce first-order tomographic images of the upper 3 km using ambient noise correlation techniques. The location of the stations was chosen to study the dispersive character of the recovered surface waves up to ~5 s period for which the sensitivity to velocities in the depth range of the reservoir is maximum. It is also planned to analyse the perturbations of the coda waves of the empirical Green functions that may allow us following the evolution of the reservoir during the stimulation and production periods (Lehujeur et al., 2013).

On the top of that, a project has been launched to install a temporary network of 250 seismic stations in Northern Alsace covering the geothermal sites of Soultz-sous-Forêts and Rittershoffen. It will consist in a 2D homogeneous grid of completely autonomous stations installed every 1.5 km for a period of approximately 30 days in August 2014. This ultra-dense network will constitute an array of about 30x30 km², suitable to observe the low frequency part of the seismic signal in the form of a wave-field and not only as a series of individual records. Using beamforming techniques, it is expected that this array will provide more detailed and homogeneous 3D velocity models, from events-based and ambient noise tomographic methods (Lin et al., 2012). The used seismological unit will be the Z-Land 3C, rented to the Fairfield society. It is an integrated system composed of three short period geophones, a 24-bit acquisition system and a lithium cell that can operate continuously during ~15 days at a sampling rate of 500 Hz.

Installation of these temporary networks and microseismicity monitoring are realized in the framework of the LabEx project G-EAU-THERMIE PROFONDE (investissement d'avenir), a cross-border collaboration between industrial companies ECOGI, and ES-Géothermie, academics (KIT, EOST) and the EEIG "Heat Mining" of Soultz-sous-Forêts.

Error! Reference source not found. shows the location of all seismic stations constituting the networks installed around the Rittershoffen and the Soultz-sous-Forêts geothermal projects.

3. DATA PROCESSING

Waveforms from the telemetered stations are currently acquired in real-time via queries and supported by a SeisComp3 server. This server, located at University of Strasbourg (EOST) and dedicated to geothermal projects in the Rhine Graben, performs both real-time processing of the data and their archiving.

In order to locate microseismic events, a first 1D velocity model was build according to previous local studies based on the Soultz-sous-Forêts project (Cuenot et al., 2008). Moreover, a second 1D velocity model was build based on sonic and stratigraphic logs performed in the GRT1 well (Duringer and Orciani, 2013)(Figure 2).

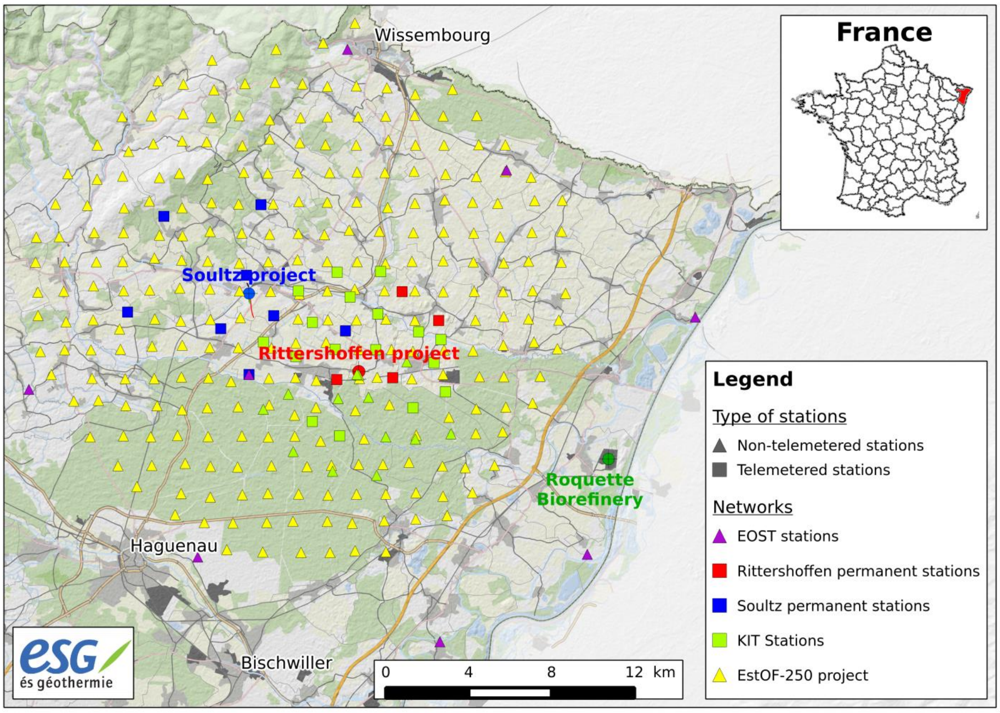

Figure 1: Setting of the projects and locations of seismic stations networks.

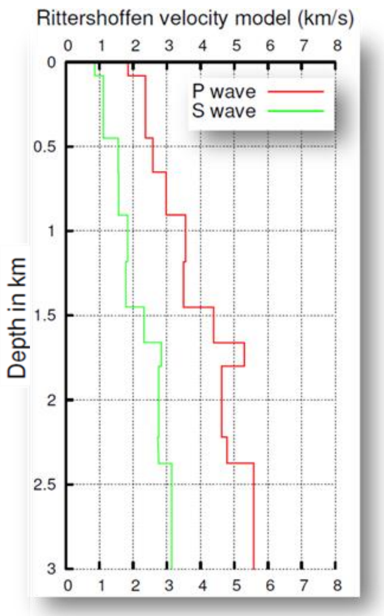

Figure 2: Velocity model of Rittershoffen built to locate the microseismic events

Special attention has been paid to configure the auto-detection and location modules of the SeisComp3 server in order to allow it operating at a very local scale. Despite an intensive work on tuning of SeisComp3 detection and location parameters, based on waveforms playbacks, no significant improvement was identified. The SeisComp3 automatic system limits were reached with our very local scale application. Hence, modifications of the source code of the SeisComp3 automatic location module were applied. The main changes consisted in adapting the system to work at a very local scale adapted to geothermal projects. This eventually led to a better detection level and better location capabilities of the system. Finally, the corresponding parameters were used during the monitoring of the stimulation of the first well.

During the stimulation of GRT1, 174 induced events were automatically detected, however a much larger number of events were visible. Hence, manual processing of all visible events was initiated to build an exhaustive catalogue of the seismicity induced during these operations. This work is still in progress. A first estimate indicates that the rate of the automatic detection system is around 10% of the total number of visible events, leaving room for further improvements. This work is still in progress and these changes are currently analysed to be possibly back ported to the mainstream of Seiscomp3, to improve the permanent automatic processing. On the top of that, the realization of a seismic catalogue using manual picking of the microseismic events is in progress. It will allow several studies in order to improve the quality of the real-time seismic monitoring of geothermal projects.

4. PRELIMINARY RESULTS

The micro-seismicity was continuously monitored during the operations carried out to enhance GRT1 connection to the reservoir. The main objective of ECOGI was to avoid inducing an event felt by the neighbourhood population. The maximum magnitude threshold set by ECOGI (Mlv=1.7) was never reached and no event was felt by the population neither in April nor in June 2013.

The main seismic episode occurred in June, during the hydraulic stimulation of the well GRT1. The largest microseismic event reached a magnitude Mlv of 1.6. About a hundred microseismic events were manually picked and located in April 2013, and, based on the automatic detection procedure, a total of 174 events were detected, manually picked and located in June 2013. A small crisis of 37 detected induced microseismic events occurred about 4 days after the end of the water injection. **Error! Reference source not found.** shows the distribution of the seismicity induced by the stimulation of GRT1; hourly rates and magnitudes are plotted. **Error! Reference source not found.** shows an epicentre map of the located seismicity induced by the stimulation of GRT1 colour coded with time.

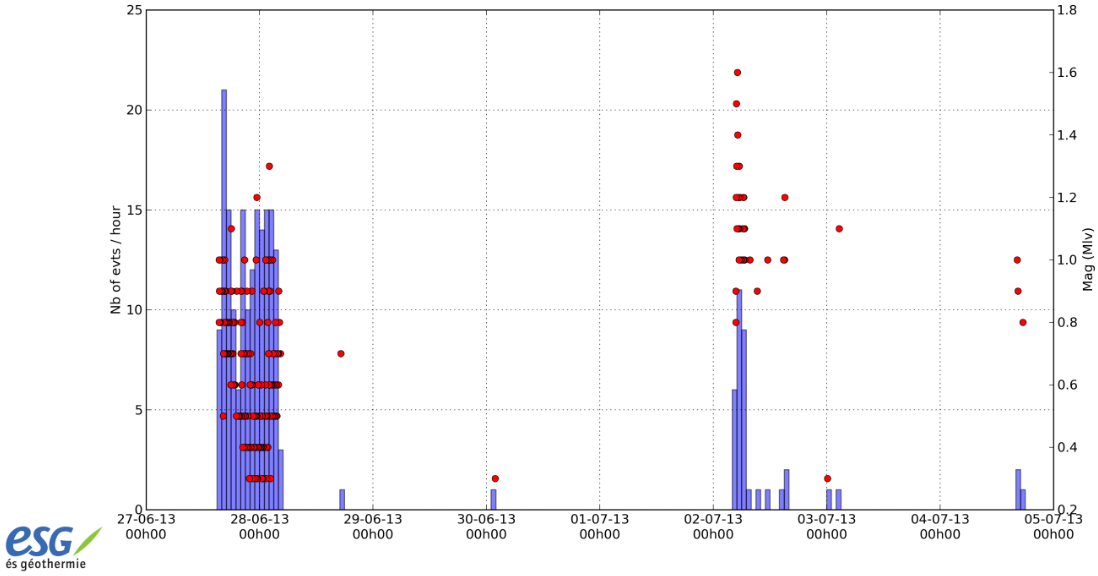

Figure 3: Microseismic activity automatically detected during the stimulation of GRT1 in June 2013. . The blue bars represent the number of events detected per hour and the red dots the magnitude reached by the events

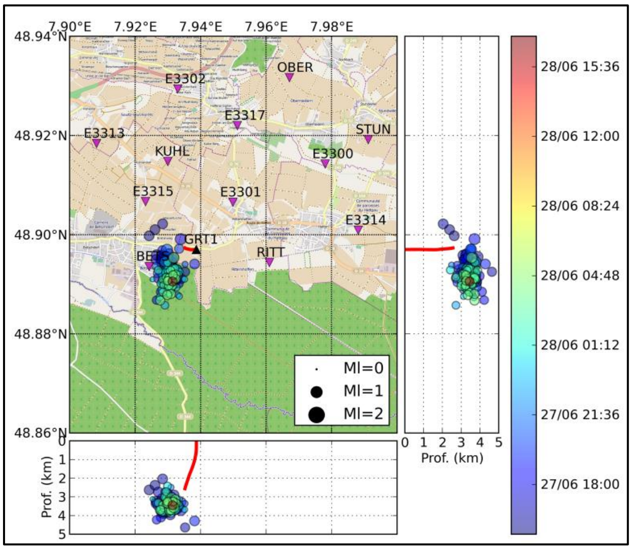

Figure 4 : Location of the events automatically detected during the stimulation of GRT1 in June 201. The color code corresponds to the origin time of the events.

The location of the microseismic cloud is tightened around the bottom of the first well GRT1. The cloud is spreading on a 1 by 3 km ellipse, slightly shifted to the south compared to the bottom hole. The mean depth is around 3500 m to be compared to the depth of the main structure that has been crossed at 2350 m, indicating that the velocity model of Rittershoffen is probably generally too slow. The shifts observed both in depth and in latitude could also be explained by the geometry of the network. Indeed, at that time, no station was installed in the southern part of the well pad, leading to a North/South bias in the coverage.

5. FUTURE WORK

All networks, combining around 300 stations, should monitor both the drilling operations, the stimulation and production operations of the Rittershoffen wells. Such a very dense array will provide an unprecedented and unique seismological dataset at the scale of a geothermal reservoir that can be used to test and validate different passive seismological techniques for the exploration and exploitation phases of geothermal fields.

Considering this large passive seismological dataset, two possible working directions are considered. The first one would be based on imaging technics such as ambient noise correlation, anthropogenic noise sources and drill-bit tomography.

The spacing between the stations will allow applying ambient noise tomography at periods ranging from 0.2 to 5 s, which would image the first 5 km of the crust by ambient noise correlation. The method is very efficient between 2 and 5 s thanks to the oceanic origin of the noise. The surface waves in that range of periods are sensitive to wave velocities between 2 and 5 km depth, the depth of the geothermal target. Between 0.2 and 1 s, the classical method of ambient noise correlation fails because of the spatial heterogeneity of noise sources. However, on-going work (Lehujeur et al., 2013) shows that the use of pairs of sub-networks (double beamforming method) enables isolating the noise sources that truly contribute to the reconstruction of the Green's function between those sub-networks, and restores the ability to apply ambient noise tomography in the period ranging from 0.2 to 1 s. The network density will offer a very good resolution of structures throughout the studied area.

Moreover, mapping anthropogenic sources of noise is crucial for imaging methods based on ambient noise correlation. For frequencies over 0.5 Hz, most of the seismic noise originates from anthropogenic activities. Hence, processing the data set will produce maps of seismic noise level at various frequencies, which are necessary to quantify the magnitude of completeness that can be reached for different types of network configurations around existing or future geothermal sites. Also, analyses of the temporal variations of the medium from the variations of the seismic noise coda correlations between pairs of stations (Brenguier et al., 2008) are considered.

The other working direction focuses on the characterization of the induced seismicity. Besides classical processing technics which would benefit from the dense network, application of existing and development of waveform-based processing techniques are foreseen. The main advantage of such a dense network is to provide microseismic locations with a more accurate and homogeneous precision across the area. The spacing between stations will allow to better constrain the depth of induced seismicity. Moreover, the use of ultra-dense network will grant the consistency of the completeness of the catalogue throughout the area. Waveform-based and relative relocation methods could also be considered as well as monitoring temporal variations of the medium via local earthquake tomography (e.g. Calò & Dorbath, 2013).

All these different techniques may bring similar types of results in 4D, for similar periods of field development. This will enable comparing the results, performing quality controls, and highlighting the pros and cons of each technique.

ACKNOWLEDGEMENTS

The authors would like to thank ECOGI for funding part of the monitoring network and for sharing data with the scientific community. The project is in the framework of the LabEx project G-EAU-THERMIE PROFONDE (investissement d'avenir). We also thank the Geophysical Instrument Pool Potsdam from the GFZ German Research Centre for Geosciences (Germany) and the Fairfield Company for providing most of the temporary seismological units. We also would like to thank Gempa GmbH and the GFZ for providing and maintaining the SeisComp3 software.

REFERENCES

Baujard, C., Genter, A., Graff, JJ., Maurer, V., Dalmais, E.: ECOGI, a new deep EGS project in Alsace, Rhine Graben, France. World geothermal Congress 2015, WGC2015 , Melbourne, Australia (2015).

Brenguier, F., Shapiro, N., Campillo, M., Ferrazzini, V., Duputel, Z., Coutant, O., Nercessian, A.: Towards forecasting volcanic eruptions using seismic noise. *Nature Geoscience*, **1**(2), (2008) 126-130.

Calò, M. and Dorbath, C.: Different behaviours of the seismic velocity field at Soultz-sous-Forêts revealed by 4-D seismic tomography: case study of GPK3 and GPK2 injection tests, *Geophysical Journal International*, **194**(2), (2013), 1119-1137, doi: 10.1093/gji/ggt153.

Cuenot N., Dorbath C., Dorbath L.: Analysis of the microseismicity induced by fluid injections at the EGS site of Soultz-sous-Forêts (Alsace, France): Implications for the characterization of the geothermal reservoir properties, *Pure and Applied Geophysics*, **165**, (2008), 797-828.

Duringer, Ph. and Orciani, S.: Chrono-stratigraphic analysis of the GRT-1 deep geothermal borehole, *internal confidential report*, Strasbourg University for ECOGI, (2013).

Gaucher, E., Maurer, V., Wodling, H. and Grunberg, M.: Towards a dense passive seismic network over Rittershoffen geothermal field, 2nd European Geothermal Workshop, Strasbourg, France, 24-25 Oct. (2013).

Lehujeur, M., Vergne J., Schmittbuhl J., Maggi, A.: Imaging a deep geothermal reservoir using ambient noise correlation, European Geothermal Congress 2013, EGC2013, Pisa, Italy (2013).

Lin, F., Li, D., Clayton, R., Hollis, D.: High-resolution shallow crustal structure in Long Beach, California: application of ambient noise tomography on a dense seismic array, *Geophysics*, **78**(4), (2013), Q45-Q56, doi:10.1190/geo2012-0453.