EGW 2017
5th European Geothermal Workshop
Karlsruhe, 12-13 October 2017

Overview over the Seismic Monitoring and the Seismicity Induced during Drilling of the Geothermal Well RN-15/IDDP-2 at Reykjanes, Iceland (H2020-DEEPEGS project)

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Keywords: DEEPEGS, Reykjanes, Enhanced Geothermal Systems, Monitoring, Fault Systems, Induced Seismicity, EU-H2020 Project

ABSTRACT

The RN-15/IDDP-2 deep geothermal well of the DEEPEGS EU project on the Mid-Atlantic ridge at Reykjanes, Iceland, is a unique site for geothermal research. With a bottom hole temperature of approximately 426°C, it is one of the hottest geothermal wells ever drilled aiming for fluids at supercritical condition. Due to complete fluid loss, the well has been drilled at flow rates that reach hydraulic stimulation condition. After the drilling, the well was stimulated further by applying different concepts ranging from high flow rate hydraulic stimulation to long-term but low flow rate hydraulic stimulation to increase the reservoir performance at around 4.7 km depth. Processes related to drilling and stimulation are monitored using seismic methods to characterize and understand the processes ongoing during injection and to get insight on the nearby geological structures that may be responsible for permeability in the deep well.

1. INTRODUCTION

The DEEPEGS project is a European H2020 demonstration project with the overall goal to increase the use of Enhanced Geothermal Systems (EGS) in Europe. The concrete objectives of the project are to test stimulating technologies in deep wells in order to deliver new innovative solutions and models for wider deployments of EGS reservoirs, to demonstrate the feasibility of EGS for delivering energy from renewable resources in Europe and to make deep geothermal resources a competitive energy alternative for commercial use. Three different demonstration sites: Reykjanes (Iceland), Valence and Vistrenque/Riom (France) which are representative of different locations and geological formations in Europe have been selected to drill deep geothermal wells and stimulate them (Friðleifsson et al., 2016).

A large number of wells down to < 3,000 m (Fig. 1) exploit the Reykjanes geothermal field that is located on the seismically active Mid-Atlantic Ridge. The concept of using a deep EGS well at Reykjanes comprises injection of fluid underneath the conventional geothermal field to support production. Therefore, the 2,500 m deep RN-15 production well was deepened to 4,659 m depth in the framework of the Icelandic Deep Drilling Program IDDP-2. The drilling operation IDDP-2 was completed after 168 days on January 25th, 2017. Complete loss of circulation fluid occurred below 3,200 m. Temperature and pressure measurements at the well bottom suggest P/T condition of 340 bars and 426°C and thus, supercritical condition of the fluid. Well logging highlights a large permeable zone above 3,400 m and smaller feed zones at 4,450 m and 4,500 m. A number of 13 sections at different depths were cored (Friðleifsson et al., 2017). The conditions that are inferred from temperature and pressure measurements and analyses of the cores point to the assumption that besides brittle also ductile, i.e. slow and aseismic deformation occurs during reservoir engineering. In this study, we present for the first time results from seismic monitoring in such extreme condition.

2. SEISMIC MONITORING

The existing permanent seismic network at Reykjanes was supplemented by 9 temporary stations, 5 from ISOR, 4 from KIT in September 2016. For this purpose, the existing infrastructure of a former project could be used, hence the possible positions of the temporary stations were already known. Among all of them, the best locations were chosen to provide an optimal azimuthal and inclination coverage of the zone of interest by the final network. As a result, the seismic network during drilling and stimulation consists in a total of 26 active stations, 19 of which within a 10 km radius from the well (Fig. 1). The main objectives of the seismic monitoring are i) the reservoir characterization with insight on the fractures created or reactivated during drilling and stimulation, ii) the investigation of changes in the physical processes induced by drilling and stimulation, e. g. seismic slip vs. aseismic creep, iii) the characterization of the local stress field with the help of focal mechanisms, and iv) possibly the identification of the brittle-ductile transition zone in the reservoir.

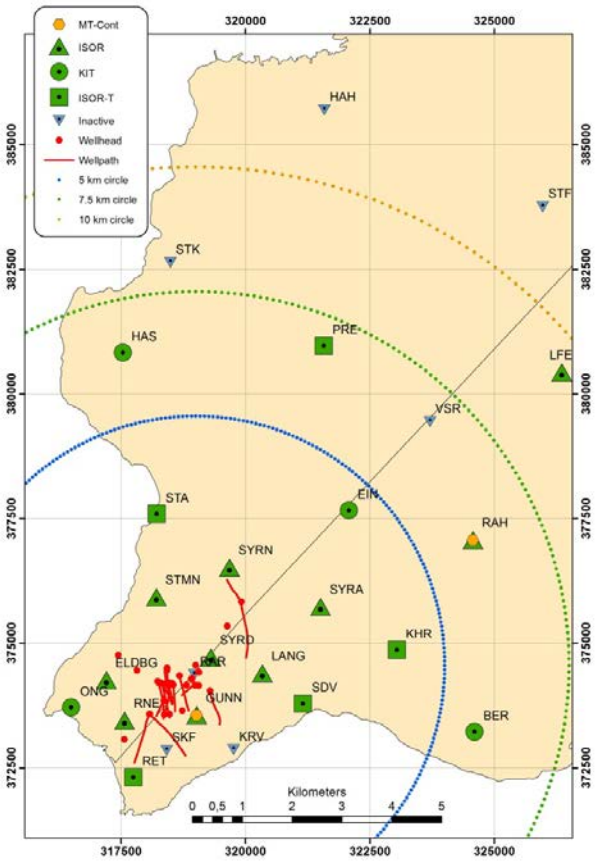

Figure 1: Distribution of seismic monitoring stations and wells in the conventional geothermal field at the Reykjanes site (Iceland). A total of 19 seismic were deployed in a 10 km radius from the RN-15/IDDP-2 well.

3. INDUCED SEISMICITY

The evaluation of the seismic monitoring is currently ongoing. The manual picking of p- and s-wave arrival times and the polarization of the p-waves from the waveforms is performed with the software Seiscomp3 and already completed for the events monitored during the drilling period. The events were relocated with the Software NonLinLoc in a 1D velocity model to get a first insight in the results of the seismic monitoring.

During the drilling of the IDDP-2 well over 400 earthquakes are monitored with magnitudes between 0.4 and 2.4. Not all of them are induced by the drilling process, around 50 events seem to belong to a natural offshore swarm approximately 2 km away from the well. There may be other natural events which cannot be separated from the induced ones at the current state of work. Most of the events form a rather dense seismic cloud between 2.5 and 5.5 km depth close to the well. Some clustering of the events may occur in this cloud, though it is too early in the evaluation process for an interpretation due to high location errors. The distribution of events over depth shows a clear peak in the number of events at around 4 km that might indicate the presence of a main cluster at this depth level. During the drilling 0 to 19 events per day occurred with an average value of a bit more than 3 events per day. An exception was recorded on the 27.11.2016 when 52 events are monitored which belong mostly to the offshore swarm and are unrelated to the drilling.

4. CONCLUSION

The RN-15/IDDP-2 deep geothermal well in the Reykjanes field is unique in many regards and the outcome of this EGS project could imply major redistribution of the geothermal energy in the European energy mix. The extreme pressure and temperature conditions in the well requires the application and the development of non-invasive techniques to describe and exploit as best as possible the geothermal reservoir. This strongly multi-disciplinary work reaches the limits of the current state of the art and thus promotes highly collaborated research. First results obtained by the seismic monitoring show that the seismic risk for the drilling of IDDP-2 is unproblematic with event magnitudes not larger than 2.4. This allows a continuation of the operation as planned according to the traffic light system for Reykjanes. A first evaluation of the seismicity monitored during drilling is promising but before interpretations of the seismic cloud regarding geological structures in the underground can be performed, the picking has to be finished for the stimulation period and the catalogue has to be improved to reduce location errors.

5. OUTLOOK

Further detailed analyses are currently ongoing to better localize the seismicity and hence gain detailed spatial and temporal information. The manual picking of arrival times and polarization of the events for the whole monitoring period, especially the stimulation periods, will be completed soon. The next steps focus on the improvement of these pickings. Therefore, we will perform a semi-automatic relative picking by wave form cross-correlation and relocate the events in a 3D velocity model to gain a final catalogue with reliable absolute as well as relative locations of the events. It might also be possible to correlate some induced events with the drilling operations to calibrate the event locations in space and time. Furthermore, we plan to compute the fault plane solutions from the picked p-wave polarities to get directional information about the rupture planes. When this processing is finished the seismic catalogue will be used to identify fault structures in the seismic cloud to gain knowledge and understanding of the architecture of the deep part of the reservoir at Reykjanes. After the drilling and the main stimulation at Reykjanes is finished, the temporary stations will soon be removed from the site and the KIT stations will be installed on the next site of the DEEPEGS project in Valence.

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