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(S)PWD – (Seismic) Prediction While Drilling: Development of a New High-Resolution Seismic While Drilling (SWD) Concept for Geothermal Drilling

Axel Wenke[1], Ruediger Giese[2], Katrin Jaksch[2], Matthias Kopf[2], Horst Kreuter[1], Matthias Reich[3], Jens Reinhardt[1] and Michael Sohmer[3,4]

[1]GeoThermal Engineering GmbH, [2] Helmoltz Centre Potsdam - GFZ German Research Centre for Geosciences, [3]TU Bergakademie Freiberg, [4]Herrenknecht Vertical GmbH

Mailing address: Axel Wenke, GeoThermal Engineering GmbH, Baischstraße 7, 76133 Karlsruhe

E-mail address: wenke@geo-t.de

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ABSTRACT

The increase in the use of renewable energies poses a great challenge today and in the future. In order to raise the percentage of geothermal energy in heat and power production in Germany, the use of low enthalpy systems is the only possibility. Low-enthalpy geothermal reservoirs can be found in depths between 2.000 and 5.000 meters, exhibiting reservoir temperatures between 80 and 170 °C. Typical reservoir types are fault zones in between or at the basis of sedimentary systems with a thickness of a few meters to decameters. For their development, common oil and gas drilling technologies are used. Well designs are typically based on geological interpretations of conventional 2D- and 3D-seismic data. Subsurface interpretations based on these data have a resolution of typically 10 to 60 meters. This limited resolution can cause misinterpretation in the determination of the position or lead to an oversight of fault structures. In the worst case, a potential reservoir may not be detected.

The goal of the project described in this paper is to develop a Seismic While Drilling (SWD) tool which can be integrated into the bottom-hole assembly of the drill string and which transmits seismic data to the surface during the drilling process. This approach shall allow geological structures to be identified that are located ahead of the drill bit in the drilling direction. Hence, drilling path adjustments will be possible during operation. A first prototype of an SWD tool was built and tested in a research mine.

1. INTRODUCTION

A non-economical exploration result with regards to temperature or achievable flow rate is the main risk in developing geothermal projects. Depending on drilling-depth and region, costs of up to 10M USD can arise before the success of a geothermal well is verified. The main financial burdens are the preliminary exploration campaigns, the drilling of a well itself and the following hydraulic tests and reservoir stimulations. A well design is based on preliminary geological and geophysical explorations comprising 2D-seismic data for rough location decisions and 3D-seismic data for developing the appropriate drilling strategy in more detail.

The vertical resolution of seismic data can be defined as the minimum vertical distance between two interfaces needed to give rise to a single reflection that can be observed on a seismic section. In a single noise-free seismic trace this is governed by the wavelength of the seismic signal; the shorter the wavelength (and hence the higher the frequency) the greater the vertical resolution (Emery and Myers 1996).

Today, seismic data are normally acquired with the eco-friendly vibroseis-method. For frequencies between 12 to 96 Hz, which is a common range, the vertical resolution is typically between 20 to 60 m (Figure 1). This means that smaller geological structures, which are often important potential targets for geothermal energy, are not visible in seismic scale. Furthermore, the steps from data acquisition over data processing to geological interpretation can bare additional sources of errors. It is obvious that a technique which can detect geological settings in front of the drill-bit with high resolution would provide significant advantages, since the direction of the drill path can be adjusted during drilling.

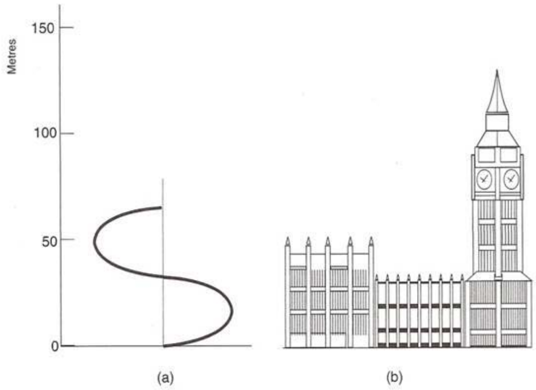

Figure 1: Understanding seismic-scale. A single seismic cycle sine wave of 30 Hz with a wave velocity of 2000 m/s in medium compared to the Big Ben (from: Emery and Myers 1996).

Different borehole tools have been developed in order to obtain a better understanding of the geological setting in a drilled well. Since the 1980s, techniques have been developed to specifically measure physical rock parameters while drilling (LWD – Logging While Drilling). Since the 1990s, Seismic-While-Drilling systems (SWD) have gained significance for hydrocarbon exploration and production. At present, two different methods are employed. The first method relies on generating the seismic signal in the bottom-hole assembly (BHA) and installing the receiver at surface. The second method is based on generating a seismic signal at the surface and placing the receiver in the BHA (Poletto and Miranda 2004).

In the case that the geophones are installed at surface, the drill bit in the borehole usually acts as the source of the soundwaves (Figure 2). With this configuration, the quality of the seismic signal is not only depending on the type of the drill bit and the geo-mechanical characteristics of the rocks but also on the distance between the source and the receiver. A frequency range of 10 to 100 Hz results in a resolution comparable to conventional seismic systems.

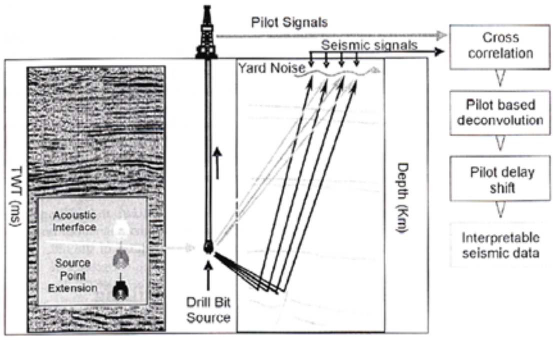

Figure 2: Scheme of an SWD-method with the drill bit as seismic source and receivers installed at the surface (from: Poletto and Miranda 2004).

In the case of the receiver being integrated into the BHA, the seismic signal can be induced by vibrators or explosives (Greenberg 2008). This technique is commonly used to verify existing time-depth models. The recorded information is stored in a downhole memory module. It can be read out during the next roundtrip. All systems of this type presently available are complex in design and difficult to use. None of them has become routinely used tools.

The aim of the research project presented in this paper is the development of a seismic exploration tool which can be integrated into the BHA and which contains both seismic source and receiver. Another important feature is a high-frequency seismic signal for the observation of high-resolution images of the environment ahead of the drill bit. A first prototype was built. First successful runs were performed at a test-site in the education and research mine of the Technical University of Freiberg.

2. TUNNEL SEISMIC PREDICTION

Different methods for seismic prediction for tunneling projects have been in use since the early 1990s, mainly in order to identify potential problem zones. Tunnel seismic is routinely used during automatic tunnel driving, where the cutter shield of the tunnel boring machine (TBM) does not allow access to the heading face and dangerous events could occur unexpectedly (Schmitt et al. 2004). The identification of boulders in unconsolidated rocks or foundations in urban areas is very important. The main geological risks however, are caused by water-bearing strata or faults (Gehrig 2008).

In order to reduce potential risks during tunneling, a geophysical prediction tool is required during driving. The predictions should be available in real time and in visualized form. A high resolution of the rock mass combined with a large predictive depth is desirable. Seismic is the method of choice for such applications.

The first Tunnel Seismic Prediction (TSP) method was developed by Amberg Messtechnik GmbH during the early 1990s and based on seismic reflection. The method is comparable to Vertical Seismic Profiling (VSP). Explosives generate elastic waves at the tunnel wall which migrate through the scanned rock. Reflections are recorded with tri-axial receiver units. Another seismic prediction method based on explosives is the True Reflection Tomography (TRT) by NSA Engineering (Otto et al. 2009), which is used with advantage in solid rocks.

A new approach was taken with the ISIS-system developed at the GFZ-Potsdam during the last years (Giese et al. 2007). The main difference to the above-mentioned methods is the generation of seismic signals by non-explosive sources (Lüth et al. 2008). Seismic waves are induced by impact-hammers or vibrators at the tunnel wall and converted to elastic waves at the heading face. The Sonic Softground Probing (SSP) by Herrenknecht AG is used for tunneling in unconsolidated rocks. Source and receiver are installed in the cutting wheel of a TBM. SSP can acquire seismic data continuously while tunneling, and data visualization occurs in real time. The system was successfully used in the so far biggest TBM, driving a new traffic tunnel in the city of Hamburg (Gehrig et al. 2008).

Making use of the expertise of ISIS, a new approach for an SWD-tool for deep vertical drilling was found and the technique was developed and tested.

3. THE TEST SITE

In the training and research mine “Reiche Zeche” of the TU Bergakademie Freiberg (TUBAF), a test site was installed in a circular gallery surrounding a massive rock formation. For test drives of the first SPWD-prototype, two subhorizontal, smoothly inclining boreholes with a length of up to 30 m and a diameter of 8 ½” were drilled into this block in E/W-direction. A gallery in front of the heading faces of the bore-holes served as seismic reflector (Figure 3). The block itself consists of a massive gneiss body without lithological contrasts. Figure 4 shows a mine map of the test site with the position of the boreholes.

Figure 3: Gallery of the research mine.

In order to identify potential seismic reflectors, a fracture geometry mapping of the tunnel walls was performed. Most of the mapped structures were found to be thin fissures not obvious enough to be detected during the tests. Two water-bearing joints with a width of 1-2 decimeters striking in E/W-direction were found, situated subparallel to the boreholes at a distance of a few meters (Figure 4). Hence, the test site can be described as a lithologically homogeneous setting containing five conspicuous seismic reflectors.

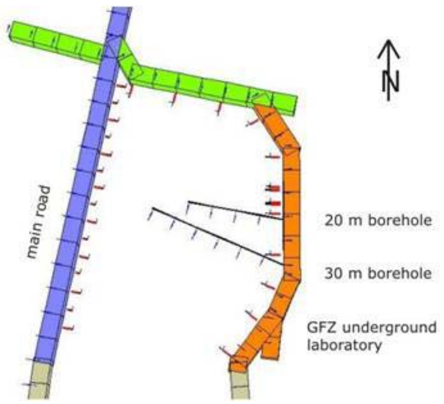

Figure 4: Snapshot by ISIS of the test site in the training and research mine of the TU Bergakademie Freiberg. The red lines show the position of surrounded geophones.

Figure 5: Water-bearing fault in the homogeneous gneiss formation of the test-site.

4. TESTING THE SPWD PROTOTYPE

Since February 2009, an SPWD prototype is being tested in the mine. It has four magnetostrictive actuators emitting seismic signals to the borehole wall in different directions. The induced frequency is high, ranging from 600 to 6000 Hz and producing a signal with corresponding short wave lengths of 10 cm to 1 m. Four 3-component receivers measure the seismic signals in the borehole. An inclination sensor and a rangefinder show the orientation and position in the borehole. Figure 6 shows the SPWD prototype. The result obtained is a high-resolution image of the rock body. In the surrounding gallery, a set of geophones is installed in order to verify the records of the SPWD prototype.

The main goal of the test program was a determination of the reproducibility of the induced and received signals with respect to fissures and faults in the proximity of the borehole. In addition, the influence of different layouts of sources and receivers in the borehole on the directional response characteristic was to be tested. With respect to the overall objective of the project, signal emission in the direction of the wellpath was the main aspect during the tests. In addition to the high frequency of the seismic signal, the use of a cascading design of the actuators was expected to deliver a higher imaging quality.

Figure 6: Inserting the SPWD prototype.

5. SPWD FOR DEEP DRILLING TECHNOLOGY

The long-term goal of this project is the development of a competitive tool for applications in deep drilling projects. In order to achieve this goal, it is necessary to consider systems, workflows and technical feasibilities of deep drilling technology and to incorporate these technical specifications in the early phases of product design. For deep drilling, a number of highly technological solutions have been developed over the past decades. Current SWD-, MWD- (Measuring While Drilling) and LWD- (Logging While Drilling) systems are complex and expensive tools. In order to develop low-enthalpy geothermal systems, lower cost systems and components will be required to reach economical profitability.

The SPWD-tool has to compete with existing, highly developed technical solutions and has to be compatible with recent applications. Boundary conditions like temperature, pressure plus drill-mud composition and dynamics have to be considered. Challenges to be solved include:

- An autonomous power supply
- Data transfer during drilling
- A streamlined design
- Integration into a conventional BHA

6. OUTLOOK

The evaluation of the test results of the laboratory tool will define the requirements for the design of a first SPWD field prototype tool. The measurements will provide information on the optimum configuration of the source and the receiver units. A simultaneous activation of the seismic signals is mandatory. After successful detection of the reflectors at the test site, the processing of the data will require to be optimized for heterogeneous geological settings. An evaluation of the recorded data from the geophones installed in the galleries will verify the modifications.

After having completed a successful lab test phase in the research mine, the SPWD prototype will be modified for integration in a real drill string. In order to proof its functionality, this field prototype will be tested in an existing research borehole with a depth of about 300 to 700 m drilled in a sedimentary environment.

As a next step, the SPWD-tool will be enhanced for integration into the “intelligent” part of a BHA. Particularly for the development of low-enthalpy geothermal reservoirs, the SPWD-tool will provide advantages by allowing for precise predictions while drilling, enabling geothermal reservoir discoveries and reducing exploration and thus economical risks for project developers.

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