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Deep geothermal energy for Lower Saxony (North Germany) – combined investigations of geothermal reservoir characteristics

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Abstract

For the economic success of a geothermal project the hydraulic properties and temperature of the geothermal reservoir are crucial. New methodologies in seismics, geoelectrics and reservoir geology are tested within the frame of the collaborative research programme "Geothermal Energy and High-Performance Drilling" (gebo). Within nine geoscientific projects, tools were developed that help in the evaluation and interpretation of acquired data. Special emphasis is placed on the investigation of rock properties, on the development of early reservoir assessment even during drilling, and on the interaction between the drilling devices and the reservoir formation. The propagation of fractures and the transport of fluid and heat within the regional stress field are investigated using different approaches (field studies, seismic monitoring, multi-parameter modelling). Geologic structural models have been created for simulation of the local stress field and hydromechanical processes. Furthermore, a comprehensive dataset of hydrogeochemical environments was collected allowing characterisation and hydrogeochemical modelling of the reservoir.

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Keywords: deep geothermal; North German Basin; exploration; exploitation; characterisation; modelling

1. Introduction

In Germany, successful deep geothermal projects are mainly situated in Southern Germany in the Bavarian Molasse Basin, furthermore in the Upper Rhine Graben and, to a minor extent, in the North German Basin. Mostly they are hydrothermal projects with the aim of heat production. In a few cases, they are also constructed for the generation of electricity.

In the North German Basin temperature gradients are moderate. Therefore, deep drilling of several thousand metres is necessary to reach temperatures high enough for electricity production. However, the porosity of the sedimentary and crystalline rocks is not sufficient for hydrothermal projects, so that natural fracture zones have to be used or the rocks must be hydraulically stimulated. Furthermore, formation waters in the North German Basin are highly mineralised and can therefore cause compositional and structural alteration of well case materials. Precipitating minerals can even lead to clogging of wells and damage pumping equipment.

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In order to make deep geothermal projects in Lower Saxony (Northern Germany) economically more attractive, the interdisciplinary research program “Geothermal Energy and High-Performance Drilling” (gebo) was initiated in 2009. It comprises four focus areas: Geosystem, Drilling Technology, Materials and Technical System. It aims at a significant increase of economic efficiency by introducing innovative technology and high tech materials as well as by optimising exploitation.

In this paper we give an overview of results of the focus area “Geosystem”, in which geological, geophysical, geochemical and thermo-hydraulic-mechanical (THM) modelling aspects of the geothermal reservoir are investigated. The nine sub-projects contribute to the research fields of geophysical exploration, drilling and stimulation, characterisation and THM-modelling of the reservoir. Thus, the projects offer different approaches leading to an improvement of geothermal exploration and exploitation as well as to a better understanding of the processes within geothermal reservoirs.

2. Projects on geophysical exploration

Among the main aims of our combined investigations is the development of an exploration strategy for fault systems. Combined seismic and geoelectrical investigations were carried out at the Leinetal Graben, a prominent fault system in the southernmost part of the North German Basin in Lower Saxony. This structure was chosen because it is cropping out at the surface, and it comprises typical rocks of the North German Basin. The measurements allow for a complex investigation of a North German setting for a geothermal reservoir, characterised by the presence of fault zones. Fault systems are considered as valuable hydrogeothermal reservoirs for energy extraction, as their permeability may be enhanced compared with the surrounding host rock.

2.1. Detection of fault zones using P- and SH-wave seismics

Several high-resolution seismic P-wave surveys were carried out along and across the eastern margin of the Leinetal Graben. Imaging ranges in depths from ~50 m (base Jurassic) to ~1.5 km (inside Zechstein). A westward dipping reflector which is very prominent in the P-wave images down to 400 m below sea level was chosen as target for additional SH-wave surveys. S-waves image the subsurface at higher resolution compared with P-wave surveys due to the shorter wavelengths of S-waves. Furthermore, they give additional information on rock properties as they propagate through the rock matrix only and are unaffected by pore fluids or gases, thus allowing for the determination of the shear modulus. In combination with P-wave measurements, the bulk modulus can be computed, as well as an estimate of porosity could be deduced.

The P-wave profiles image the Eastern bounding fault of the Graben and its deformed forefront with very high resolution. Outcrop locations of major fault segments match with geological information and surface field mappings. The roll over structure in the strongly deformed (folded and faulted) foreland provides an indication of tectonic inversion in the Graben (from early extensional to compressional regime).

The SH-wave profiles carried out for comparison show quite different behaviour in their reflectivity in depths of 200 m to 400 m below sea level (Fig. 1). While the westward dipping reflector is clearly visible in the P-waves, the SH-waves show only discontinuous reflections.

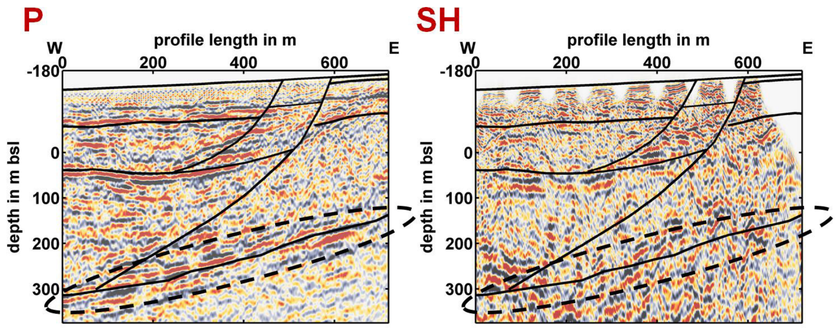

Fig. 1: Comparison of P- and SH-wave measurements along the same profile perpendicular to the eastern margin of the Leinetal Graben. While in the P-wave section a westward dipping reflector (marked by black dashed line) is very prominent, the same area in the S-wave section shows different reflection characteristics (also marked by black dashed line). Both profiles are shown unmigrated; bsl means below sea level.

2.2. Detection of fault zones with electric and electromagnetic methods

Fault systems are typically indicated by relatively low resistivity values if conductive minerals and/or brines within fractures are present. Electromagnetic methods are preferable to detect these zones, because they are highly sensitive to map these