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Seismic Exploration Around the Geothermal Research Well Gross Schoenebeck (NE German Basin) Combining Tomographic and Reflection Seismic Methods

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ABSTRACT

Seismic experiments were conducted to study the seismic structure around the geothermal research well GSB 3/90. Travel time tomography was applied to derive a 2D velocity model along a 40 km long transect centered at the geothermal well location. Checkerboard tests were carried out to evaluate the resolving capabilities of the model. Resolution is highest in the central part around the bore hole where the complete sedimentary section and parts of the pre-Permian can be resolved. The major feature of the model is a general decrease in the velocity within a salt up-doming structure. A modelling approach combining the velocity and temperature fields is used to distinguish between the effects related with the 2D temperature field and lithological heterogeneities. Furthermore, a relationship between salt tectonics and deeper fault systems is discussed.

1. INTRODUCTION

I-GET is an European Union funded project to develop integrated exploration methods for fractured and/or porous fluid bearing geothermal systems. The techniques are tested at typical sites in volcanic, metamorphic and sedimentary environments. We present results from the geothermal site at Gross Schoenebeck located in the NE German basin, North of Berlin. The target horizons for a middle enthalpy geothermal system consist of Rotliegend sandstones and volcanic rocks at depths between 3.9 and 4.4 km. These rocks were deposited during the initial stages of the developing Southern Permian basin. Temperatures of 150 °C required for geothermal power generation are encountered at 4 km depth (e.g., Norden, 2005). Major targets for a geophysical exploration phase before drilling include (1) the geological and sedimentological framework, (2) the detection of fluid-bearing regions, and (3) the mapping of faults and fracture zones.

The seismic experiments (2D and 3D) were conducted to study the regional lithological and tectonic environment, and to provide attributes useful for the geotechnical characterization of the potential geothermal reservoir. Tomographic methods were applied to a refraction / wide-angle reflection seismic data set. The first arrival travel times were determined and a damped least-squares inversion was applied to derive a 2D velocity model along a 40 km transect centered at the geothermal research well. Next, the first arrival signals were aligned and spectral analysis was performed using Fourier and wavelet transform methods for comparison. The spectral data were parameterized (e.g., spectral decay) and a damped least-squares algorithm was applied to estimate the attenuation distribution. Furthermore, wide angle reflections were modelled and imaged by using the velocity model along the 40 km transect. The velocity and attenuation tomography approaches were also applied to the low-fold 3D seismic data providing information for the upper 1000 m in a 2.5 by 2.5 km area around GSB 3/90.

2. SEISMIC EXPERIMENTS AND DATA

Seismic data were measured in two parts (Figure 1): (1) A 40 km profile running approximately parallel to the major horizontal stress component was surveyed to investigate the seismic structure at the regional scale. A length of 40 km was required to guarantee for a sufficient illumination of the reservoir layers at 4 km depth. 45 explosion shots were fired with an average spacing of 800m. Along the entire profile, 190 3-component receivers were deployed with a nominal spacing of 200 m. (2) A low-fold 3D seismic experiment was conducted covering a region of 6 by 6 km around the geothermal research well GSB 3/90. The survey included 45 explosion shots recorded by 190 receiver channels, where the sources and receivers were located along 4 profiles forming a star-like arrangement.

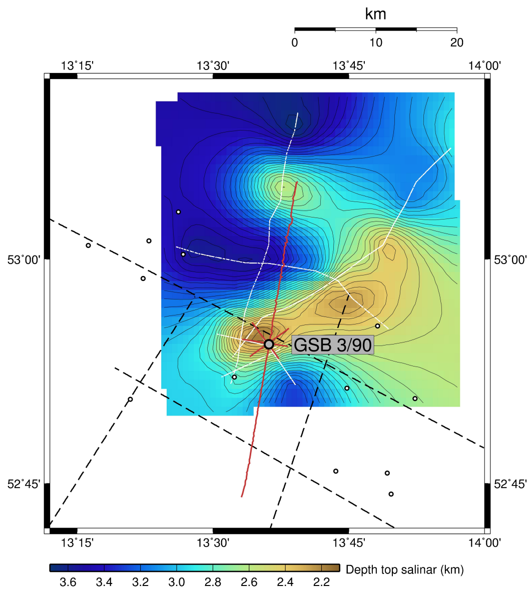


Figure 1: Location map of the 2D and 3D seismic experiments. New I-GET profiles are shown as red lines. Depth contour map of the top Zechstein salinar based on industry seismic (white lines) and bore hole data (Moeck et al., 2008). Black lines represent lineaments in the basement.

The data acquired are of good quality. An example of a central shot location is shown in Figure 2. The data are band pass filtered (5-30 Hz) and are plotted with 4 km/s reduction velocity. The first arrivals which are used for the velocity tomography can be followed to maximum distances of 20 km. Prominent wide-angle reflections are observed at 5-10 km offset and at 12-18 km offset. The first arrival signals show dominant frequencies of 12 Hz.

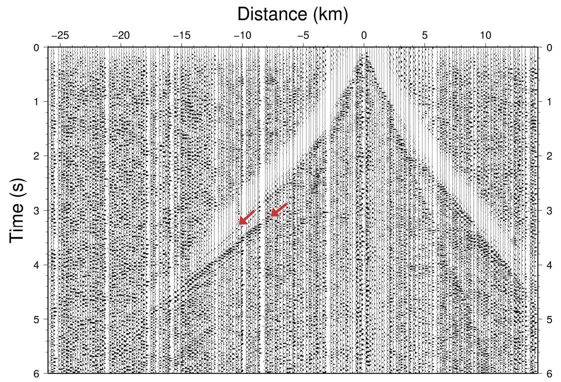
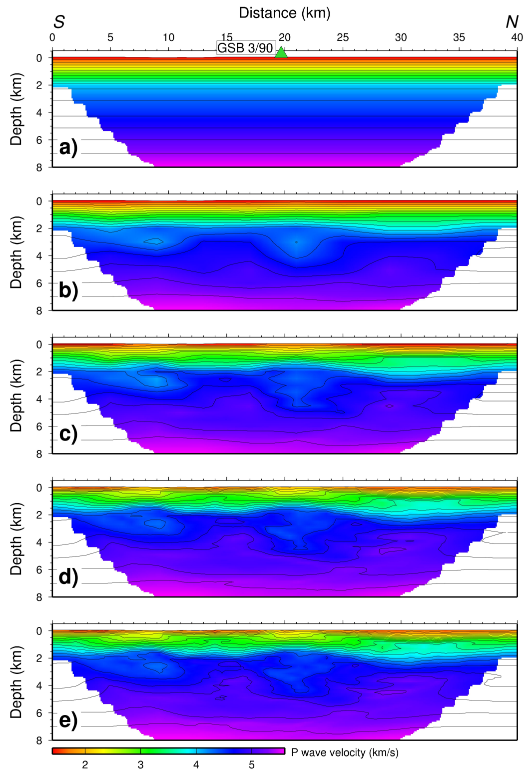


Figure 2: Seismogram section for a central shot location. First arrivals and prominent wide-angle reflections are indicated by red arrows.

3. DATA ANALYSIS AND RESULTS

The initial data analysis included the geometry installation, pre-processing (e.g., trace editing, band pass filtering, deconvolution), and travel time picking. Several travel time data sets were generated by multiple picking, in order to estimate the uncertainty of the individual travel time picks. The average values were used for the inversion of the data. Based on the travel time uncertainties, 4 groups of data with different qualities were distinguished. The inversion procedure included (1) determination of the best 2-parameter model, (2) 1D inversion, and (3) 2D tomographic inversion. In the first step, a model described by the velocity at the surface, and a vertical velocity gradient was designed, and the two parameters (surface velocity, gradient) were varied to determine the error function for this problem. The best model with the minimum value of this error function was then defined as the starting model for the 1D inversion (Bauer et al., 2009). The 1D velocity function was described by nodes at 1 km depth intervals. The final velocity model from this 1D inversion served as the initial model for the 2D tomographic inversion (Figure 3a). The damped least squares algorithm of Thurber (1988) was applied to continue the optimization of the velocity model. A graded inversion approach involved several stages with increasing numbers of model nodes (Figure 3). During this iterative procedure, the horizontal and vertical spacing of the grid nodes was varied from 4 km by 1 km, to 0.6 km by 0.15 km for the final model shown in Figure 3e (Bauer et al., 2009).

The velocity model was compared with the regional marker horizons as interpreted from pre-existing 2D industry reflection seismic profiles which are compiled within a 3D geological model (Moeck et al., 2008). Following this comparison, the velocity model reflects the major stratigraphic structure of the sedimentary section. However, as a new outcome of the I-GET study, the velocity tomography reveals unexpected heterogeneities within the layers. Particularly within the salt layer, the velocity varies in the order of 0.4 km/s. A systematic velocity structure is imaged, where decreased velocities correspond with the regions of salt up-doming, and increased velocities in the range of thinner salt sections. To explain this pattern we favour two major influencing factors: (1) A lithological differentiation takes place during the salt tectonic processes, where less dense material with decreased seismic velocity moves to the up-doming zones, and denser material with higher velocities like anhydrite remains in the thinner outflow parts of the salt layer. (2) The velocity variations in the salt layer could reflect a distortion of the temperature field caused by the increased heat flow within the regions of salt up-welling (Norden, 2004). In order to evaluate the latter mentioned hypothesis, a joint modelling of seismic velocity structure and temperature field was carried out



(Bauer et al., 2009).

Figure 3: Tomographic inversion of the first arrival travel time data. Cross sections a-e show the development of the model during a graded inversion approach, where the node spacing is systematically decreased with increasing iteration number.

Another interesting result of the velocity tomography is a vertical feature of decreased velocity which is found at the depth level underneath the Rotliegend sandstone layers. This is located below the top of the central salt up-doming in the middle of the profile. A comparison with pre-existing interpretations of deep fault structures derived from seismic and potential field data shows that the vertical low velocity feature could represent the image of a major regional fault zone (see also Figure 1). In this case, a direct evidence would be found for the relationship between pre-existing deeper fault structures and its influence on the localization of salt tectonic activity as already debated by a number of authors.

The results are additionally compared and integrated with other methods like seismic attenuation tomography, analysis of wide-angle reflections, and magnetotelluric imaging (Munoz et al., 2008). New insights in this combined analysis are revealed by application of neural network techniques. The major results of the study (velocity anomalies within the salt architecture, deep fault structure below salt up-doming) provide important constraints for the modelling of the temperature field and the geomechanical behaviour of the geothermal system.

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