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3D Focused Seismic Imaging for Geothermal Reservoir Characterization in Crystalline Rock (Schneeberg, Germany)

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SUMMARY

We present the results of a high resolution 3D seismic survey acquired in the western Erzgebirge near the city of Schneeberg. The project aims at imaging a major fault zone in crystalline rock at a depth of 4-5 km with expected temperatures between 160 and 180°C, which is supposed to be used as a natural geothermal heat exchanger.

We applied advanced imaging methods to the data set. 3D Kirchhoff prestack depth migration delivered a clear structural image of the various fault branches at depths of around 2-5 km. Furthermore we applied the focusing coherency migration method, which uses a coherency function of the data recorded at neighboring traces for imaging. This method even sharpened the image such that the 3D seismic result allows for a profound characterization of this potential geothermal reservoir in crystalline rock.

Introduction

We present the results of a 3D seismic survey acquired in the western Erzgebirge near Schneeberg (Germany) as a site characterization survey for a geothermal power plant. The aim of the project is to use seismic methods to image and to characterize a major fault zone in crystalline rock. This potential naturally hydraulic permeable zone, with expected temperatures between 160-180° at a target depth of about 5-6 km, could be used as a geothermal reservoir.

For this purpose a high resolution 3D Vibroseis survey with more than 5300 source and approximately 8000 receiver locations was performed at the end of 2012 and covered an area of approximately 10 km x 13 km. The 3D survey was complemented by an additional wide-angle seismic survey using explosives along eleven profile lines radially centered at the target area. The region itself is dominated by the NW-SE striking Gera-Jáchymov fault system. The main geological features in the survey area are well known from intensive mining activities down to a depth of approximately 2 km. The seismic investigations aimed at imaging the partly steeply dipping fault branches at greater depths, in particular a dominant steeply NE dipping fault ("Roter Kamm") in the central part of the survey area. Beside this main structure, the Gera-Jáchymov fault zone consists of a couple of steeply SW dipping conjugated faults (Figure 1).

Figure 1 Geological cross-section from SW to NE. The steeply NE dipping normal fault "Roter Kamm" is the main structure of the fault system. It is accompanied by several SW dipping conjugated faults (Berger et al., 2011).

Method

Since we have to deal with steeply dipping geological structures we use Kirchhoff prestack depth migration (KPSDM) type methods for imaging. Coherency migration as one of these types is a focusing migration method based on KPSDM. It uses the coherency of the wave-field (eq. (1) (Neidell and Taner, 1971)) computed from neighboring traces as an additional weighting function in the migration scheme. This coherency calculation is performed for each imaging point $m(x,y,z)$ over N neighboring traces within a time window T depending on the dominant source frequency. The time shift for the neighboring traces is given by the calculated traveltimes for the actual comparison trace j at the imaging point $m(x,y,z)$.

$$C_c(\vec{m}, \vec{r}) = \frac{\int_{-T/2}^{T/2} \left| \sum_{j=0}^{N-1} u_j(t_s + t_{R_j} + t) \right|^2 dt}{N \int_{-T/2}^{T/2} \sum_{j=0}^{N-1} |u_j(t_s + t_{R_j} + t)|^2 dt} \quad (1)$$

Results

We applied a minimal pre-processing to the data consisting of automatic gain control, trace normalization, notch filtering (50 Hz) and top mute. The results are based on stacks of all shots recorded at receivers with max. 2 km offset. Figure 2 shows two SW-NE slices through the coherency migration image using (a) stacked absolute values and (b) phase consistent stack. These slices coincide spatially with the geological cross-section in Figure 1. The coherency image clearly shows a branch of the SW dipping conjugated faults within the granite. In addition a so far unknown structure appears as a zone of diffusive high reflectivity in a depth range between approximately 4 and 6 km. All of the conjugated faults are dipping towards this zone. The uppermost conjugated fault shows an internal offset by approximately 150m equivalent to a normal fault that crosses it and dips to the NE.

Figure 2 Coherency migration image through (a) the absolute value stack and (b) the phase consistent stack. The magenta line shows the assumed top of granite body.

Conclusions

We have processed a 3D seismic data set using coherency migration, a focusing migration technique based on KPSSM. This approach delivers images of very high image quality. We observe a bunch of parallel SW dipping reflectors that appear sharp and highly reflective, whereas the postulated main fault structure (“Roter Kamm”) is not directly visible. These SW dipping reflectors can be interpreted as conjugated faults with respect to “Roter Kamm”. Some of them show an internal structure, including a normal fault related offset, which in turn can be interpreted as an indirect trace of “Roter Kamm”. Beside these structures also a zone of high reflectivity with more diffuse character is visible in the downward prolongation of the conjugated faults. In summary, the resulting 3D image cube clearly shows many interesting reflectors and features which can serve as potential drilling targets for geothermal usage if their permeability has been characterized by other studies not presented here.

References

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