Comparison of Reflection Image by The Traixial Drill-Bit VSP at Soultz HDR Field With Geological Information

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ABSTRACT

Seismic signals produced while drilling a Hot Dry Rock (HDR) geothermal well in Soultz-sous-Forets, France were detected by a sparse network of downhole detectors in the granitic basement. The signals from a multi-component detector were analysed by the modified triaxial drill-bit vertical seismic profiling method (TAD-VSP) to obtain a reflection image below the drill-bit. In this paper, the distribution of reflectivity below the stimulated zone is compared with geological data from a well deepened to 5000m. This study reveals that the higher reflectivity is correlated to with naturally fractured zone in the granitic basement. These results show the further potential of the TAD-VSP method for the prediction of permeable zones in the HDR/HWR development.

Introduction

It has been widely accepted that conventional geophysical seismic methods such as seismic reflection, seismic refraction and vertical seismic profiling (VSP) do not always give sufficient information about HDR/HWR reservoirs in the basement rock. This is because the high acoustic impedance contrast at the overburden/basement boundary prevents the penetration of seismic energy from the surface into the reservoir, and seismic sources and detectors that operate at high, geothermal reservoir temperatures are not typically available. The seismic while drilling (SWD) technique (Asanuma et al., 1990; Rector and Marion, 1991; Haldorsen et al.,1995) is one of the most promising methods for the reflection imaging of the HDR/HWR reservoirs, because the drill bit can transmit seismic signals at high temperature and in a high-pressure environment. Although the characteristics of the signal from the bit are very different from that of a conventional seismic source; it has a continuous nature, and signal characteristics are highly dependent on the field and drill system, information about the structure of the earth can be recovered by appropriate signal processing.

Seismic signals from the drill-bit which has a wideband nature and high S/N can be acquired by the use of downhole detectors in the basement rock, rather than on the surface. However, cost considerations restrict the number of detectors available, and this makes it difficult to apply conventional seismic array signal processing techniques. Thus, it is important to recover as much information as possible from the waveforms detected by the sparse network. Hodogram analysis, which uses information of the vector field of the elastic wave, detected by a multicomponent detector, is one of the best methods for analysis of signals from sparse networks. Considering above mentioned background, we have been developing the triaxial drill-bit VSP method (TAD-VSP) which uses a downhole multicomponent detector, and have successfully resolved subsurface structures in test sites and geothermal fields to demonstrate its feasibility (Asanuma and Niitsuma, 1995; Asanuma et. al, 1996).

At the Soultz site, Alsace, France a HDR well was drilled into granitic basement and associated drill signals were detected by a multi-component and two single component seismic detectors, both installed in the granitic basement. The authors analysed the signals using the principles of the TAD-VSP and cross-correlation analysis, and then obtained a reflection image around the artificial reservoir which is consistent with logging, the distribution of microseismicity, and the reflection image from the AE reflection method (Asanuma et al., 1999a, 1999b, 2000). The HDR well was extended from 3600 m to 5000 m in 1999, and geological/hydraulic information from the deepened section was collected. In this paper, the reflectivity estimated by the TAD-VSP method is compared with geological and hydraulic information. The authors interpret the reflectors by the TAD-VSP and discuss the feasibility of the TAD-VSP for characterization of the HDR/HWR reservoirs.

Background of the Soultz HDR Field

A HDR project has been underway at Soultz-sous-Foret, Alsace, France since 1987 supported by the EC, France, Germany and other organizations (Baria et al., 1995). A plan view of the Soultz HDR site with locations of wells is shown in Figure 1. The microseismic data associated with the hydraulic stimulation indicate that there are two zones of rock stimulated, the larger zone around a depth of 2900 m, and the smaller zone, at 3500 m deep.

A 3883m deep geothermal well, GPK2, was drilled in 1994-5. Seismic measurements were made while 8-inch and 6-inch roller cone bits were being used. Seismic signals at bit depths from 1608 m to 3858 m were detected by one 4-component sensor in seismic observation well 4550 (depth 1571 m, offset 840 m) and by two single component sensors in wells 4616 (depth 1376 m, offset 518 m) and 4601 (depth 1571m, offset 1253m). All the detectors were fixed to the borehole using very dense drill mud or cement.

Well GPK2 was extended to 5000m depth in 1999 by using roller cone bits. Lithology was characterized by drill cuttings and fractured zones identified by lost circulation of drill mud and by the temperature-spinner log.

We have previously reported that the signal from well 4550 had a relatively white spectra, and that the drill signal is modelled as a point source radiating continuous SV wave dominating over P and SH modes (Asanuma et al., 1996, 1999a). Because the TAD-VSP method is applicable only to multi-component signals, we used only signals from well 4550 in this study.

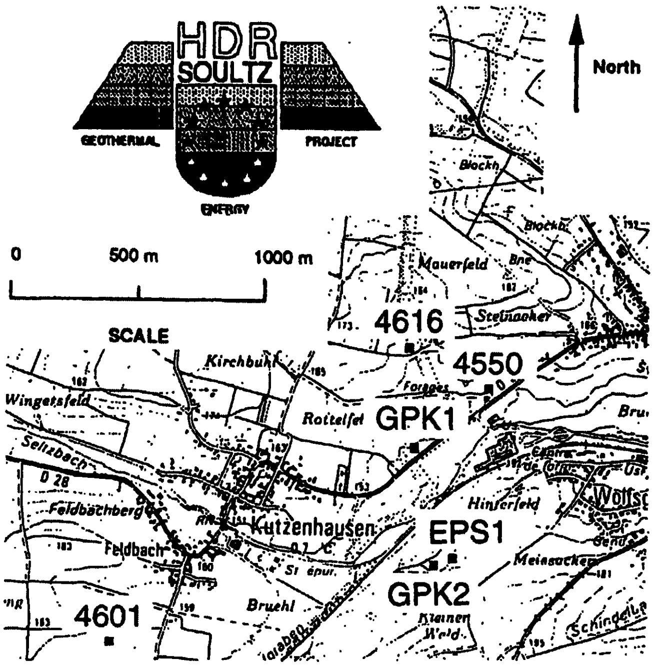

Figure 1. A plan view of the Soultz HDR Field.

Reflection imaging by the TAD-VSP

A signal processing technique to identify reflected waves is one of the key technologies in the drill bit reflection method, because the drill signal is continuous and it is impossible to identify the existence of reflected waves by simple observation. In the TAD-VSP, the seismic signals from the drill-bit are detected by a downhole multi-component detector (Figure 2). The reflected waves superimposed onto continuous drill signals are detected by correlation analysis of three-dimensional hodograms in terms of time delay and propagation direction in the original TAD-VSP method (Asanuma et al., 1996). Although the TAD-VSP has the advantage that a reflection image can be obtained by a single point observation, it does not have directional resolution comparable to that of a conventional seismic reflection survey. In this study, we employ a modified TAD-VSP (Asanuma et al., 2000), which correlates the hodogram in time delay and polarization direction. The modified diffraction stack migration is introduced in order to restrict the location of the possible reflectors (Soma et al., 1997a).

In Figure 3, the reflection image produced by the modified TAD-VSP is compared with the reflection image produced by the AE reflection method (Soma et al., 1997b) and the locations of microseismic events induced by the hydraulic stimulation. It has been revealed that the pre-existing fractured zone at a depth interval of 2800 m - 2900 m and the bottom of the stimulated zone at 3600 m are detected by this method (Asanuma et al., 1999b). Asanuma et al. (1999b) compared logging data from a pre-existing well with the reflectivity imaged by the TAD-VSP, and concluded that permeable fracture zones and altered zones in granite were detected by the TAD-VSP at a depth shallower than 3600 m. However, further interpretation of the reflectors found below 3600 m were not made, because there was not any geological/hydraulic data available before the extension of well GPK-2 made in 1999.

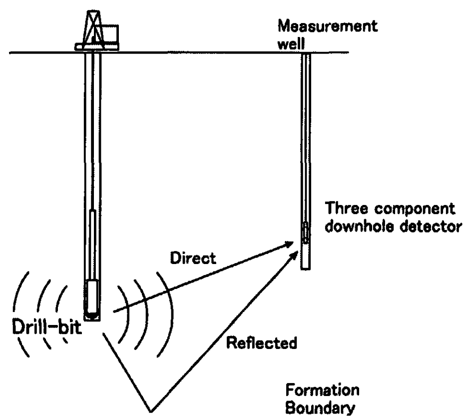

Figure 2. Concept of the TAD-VSP method. A downhole multi-component seismic detector is used for the measurement of three dimensional hodogram. The hodogram is correlated in both time and polarization domains in the modified TAD-VSP.

Comparison of Reflection Image With Deep GPK-2 Data

The distribution of reflectivity along deepened GPK-2 is compared with rate of penetration (ROP), lithology, facies variation, fractured zones and temperature distribution in Figure 4. The lithology and facies variation were mainly estimated by the observation of drill cuttings, and the fracture zones are identified by both cutting observation and the rate of lost circulation

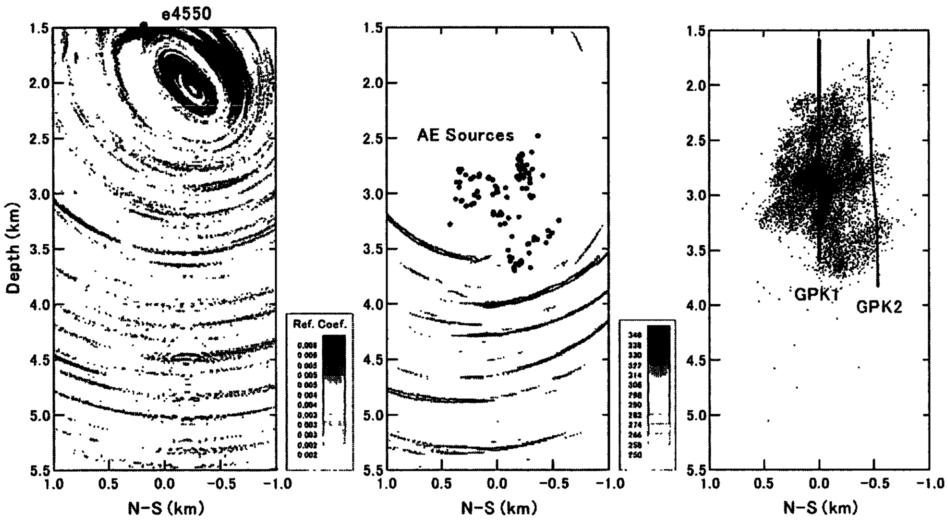

Figure 3. Distribution of reflection coefficients estimated by the modified TAD-VSP. Distribution of reflectivity by the AE reflection method and location of microseismic events generated during stimulation in 1993 are also shown.

of the drill mud. The temperature distribution was measured by a conventional logging tool.

It is seen from Figure 4 that the reflectivity imaged by the TAD-VSP method generally correlates well with the top of fractured zones at the depths of 4040m, 4200m, 4450m - 4800m and at around 5050m. Fractured zones were identified, by geological investigation, as being continuous in the depth interval from 4450 m to 4800 m. The reflectivity imaged the TAD-VSP shows variation in this depth section, suggesting that the reflectivity of each fractured zone is not homogeneous. The depth of the permeable zones are estimated by a temperature log (shown as a bold line in Figure 4, overleaf). The permeable zones at a depth of 4450 m to 4550 m and 5020 m to 5040 m appear as higher reflectivity bands in the results given by the TAD-VSP. The permeable zone at the depth interval from 4750 m to 4800 m is not clearly seen in the TAD-VSP results. This permeable zone is nearly at the bottom of a continuously fractured zone from 4450 m to 4800 m, and hence the reflectivity (acoustic impedance) may not be lower than the other surrounding permeable zones.

Therefore, the reflectors estimated by the TAD-VSP method in the deeper part of Soultz HDR system are identified as pre-existing fractured zones in the granitic basement.

Conclusions

Seismic signals from a drill bit were detected by a sparse network of downhole detectors in the basement rock during the drilling of an HDR well at Soultz. A reflection image inside the granitic basement was obtained by the modified TAD-VSP method which has better directional resolution than the original method. The reflectivity estimated by the TAD-VSP below the stimulated zone was compared with newly collected geological information acquired in 1999. It has been shown that the reflectivity imaged by the TAD-VSP method is highly correlated with naturally fractured zones inside the basement. This result suggests that the TAD-VSP method is an effective tool when used to predict pre-existing fractured zones in basement rock, and the information obtained by the TAD-VSP method can be used in the design and planning of HDR/HWR reservoirs.

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References

Asanuma, H., Niitsuma, H., and Chubachi, N., 1990, An analysis of three dimensional AE Lissajou pattern during well-drilling and estimation of source direction, Prog. Acoust. Emiss., 5, 436-443.

Asanuma, H., and Niitsuma, H., 1995, Triaxial seismic measurement while drilling and estimation of subsurface structure, Geotherm. Sci. Tech., 5, 31-51.

Asanuma, H., Park, J.N., Niitsuma, H., and Baria, R., 1996, Characterization of subsurface structure at Soultz-sous-Forets (France) by triaxial drill-bit VSP, SEG Exp. Abst., 202-205.

Asanuma, H., Liu, H., Niitsuma, H., and Baria, R., 1999a, Identification of structures inside basement at Soultz-sous-Foret (France) by the triaxial drill-bit VSP, Geothermics, 355-376.

Asanuma, H., Liu, H., Niitsuma, H., and Baria, R., 1999b, Reflection imaging of HDR reservoir at Soults-sous-Forets using drill bits as a downhole seismic source, GRC Transactions, 23, 247-252.

Asanuma, H., Liu, H., Niitsuma, H., and Baria, R., 2000, Discrimination of polarization of reflected waves in the triaxial drill-bit VSP and imaging of subsurface structure at Soultz, France, SEG Exp. Abst (in CDROM).

Baria, R., Garnish, J., Baumgartner, J., Gerad, A., and Jung, R., 1995, Recent developments in the European HDR research programme at Soults-sous-Forets (France), Proc. World Geotherm. Cong., 2631-2637.

Haldorsen, J. B. U., Miller, D.E., and Walsh, J.J., 1995, Walk-away VSP using drill noise as a source, Geophysics, 60, 978-997.

Rector, J. W., and Marion, B.P., 1991, The use of drill-bit energy as a downhole seismic source, Geophysics, 56, 628-634.

Soma, N. and Niitsuma, H., 1997a, Identification of structures within the deep geothermal reservoir of the Kakkonda Field, Japan by a reflection method using acoustic emission as a wave source, Geothermic 26, 43-64.

Soma, N., Niitsuma, H., and Baria, R., 1997b Estimation of deeper structure at the Soultz Hot Dry Rock Field by means of reflection method using 3C AE as wave source, PAGEOPH 150, 661-676.

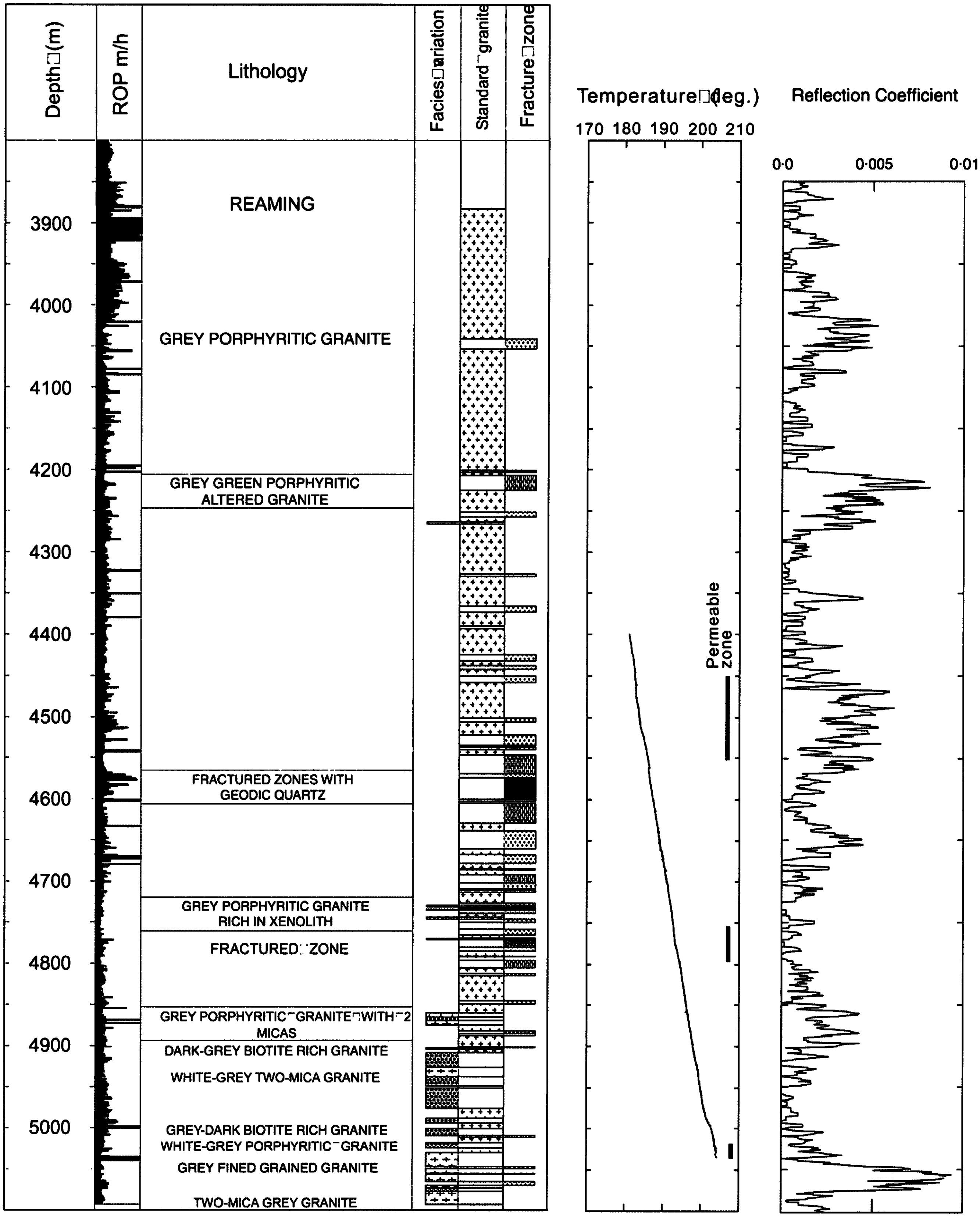

Figure 4. Comparison of reflection coefficients along the extended GPK2 with rate of penetration (ROP), lithology, fracture zones and temperature distribution. The positions of permeable zones estimated from the temperature log are shown by the bold line in the diagram.