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Mapping permeable fractures at depth in crystalline metamorphic shield rocks using borehole seismic, logging, and imaging

J. Chan (1), D. R. Schmitt (1), G. Nieuwenhuis (1), E. Poureslami Ardakani (1), J. Kueck (2), and M. R. Abasolo (2)

(1) Department of Physics, University of Alberta, Edmonton, Canada (judithc@ualberta.ca), (2) ICDP-OSG, GFZ-Potsdam, Potsdam, Germany (jkueck@gfz-potsdam.de)

The presence of major fluid pathways in subsurface exploration can be identified by understanding the effects of fractures, cracks, and microcracks in the subsurface. Part of a feasibility study of geothermal development in Northern Alberta consists of the investigation of subsurface fluid pathways in the Precambrian basement rocks. One of the selected sites for this study is in the Fort McMurray area, where the deepest well drilled in the oilsands region in Northeastern Alberta is located. This deep borehole has a depth of 2.3 km which offers substantial depth coverage to study the metamorphic rocks in the Precambrian crystalline basement of this study area. Seismic reflection profiles adjacent to the borehole reveal NW-SE dipping reflectors within the metamorphic shield rocks some of which appear to intersect the wellbore. An extensive logging and borehole seismic program was carried out in the borehole in July, 2011. Gamma ray, magnetic susceptibility, acoustic televiewer, electrical resistivity, and full-waveform sonic logs were acquired to study the finer scale structure of the rock formations, with vertical resolutions in the range of 0.05 cm to 80 cm. These logs supplement earlier electrical microscanner images obtained by the well operator when it was drilled. In addition, we are also interested in identifying other geological features such as zones of fractures that could provide an indication of enhanced fluid flow potential – a necessary component for any geothermal systems to be viable. The interpretation of the borehole logs reveals a highly conductive 13 m thick zone at 1409 m depth that may indicate communication of natural brines in fractures with the wellbore fluid. The photoelectric factor and magnetic susceptibility also appear anomalous in this zone. Formation MicroImager (FMI) log was used to verify the presence of fractures in the borehole in this conductive zone. This fracture zone may coincide with the dipping seismic reflectors in the reflection profile. To better understand the velocity structure and to look for the effects of fractures, a high resolution zero-offset vertical seismic profile (VSP) was conducted to measure the seismic responses at the borehole. VSP data can be used to delineate the structural and stratigraphic features surrounding the borehole that could not otherwise be resolved from surface seismic reflection data. A comparison of VSP data with borehole logging data is expected to provide information on the local lithological changes, mineral composition of rocks and on the presence of fractures.