Log Analysis of Fractures in a Deep Borehole, Northeastern Alberta, Canada*

Judith S. Chan[1], Douglas R. Schmitt[2], and Jochem Kueck[3]

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[1]University of Alberta, Edmonton, Alberta, Canada (judithc@ualberta.ca)
[2]University of Alberta, Edmonton, Alberta, Canada
[3]ICDP-OSG, Potsdam, Germany

Abstract

With the thin sedimentary strata in Northeastern Alberta, a deep borehole (TVD 2.4 km) located outside of the western suburbs of Fort McMurray offers the unique opportunity to characterize the Precambrian crystalline basement rocks of Northeastern Alberta. The main use of this deep borehole is to provide details on the physical properties, the state of stress, and the existence of fracture porosity in the basement rocks toward the ongoing geothermal investigations undertaken by the Helmholtz-Alberta Initiative (HAI).

In July 2011, an extensive suite of geophysical logs were acquired in the borehole with 875 m depth coverage of the crystalline basement. Existing image logs reveal a number of fractured zones in the Precambrian rocks that correlate with conductive zones outlined by the resistivity logs. By analyzing the relationship of these observations with the level of radiogenic heat production in the basement rocks, they could potentially become useful indicators for the development of a geothermal reservoir in which fluid flow in fractured rocks is of importance.

Introduction

The boreholes in Northern Alberta focus on the exploration of oil sands deposits within the Cretaceous rocks, hence subsurface study using well logs is limited to shallow depths. The crystalline basement of the Alberta Basin has primarily been studied using geochronology, gravity and magnetic data, and deep seismic reflection profiles (e.g. Lyatsky et al., 2005; Ross et al., 1990; Ross and Eaton, 1999; Ross et al., 1995). The availability of a deep borehole that penetrates deep into the crystalline basement rocks is uncommon and therefore offers a unique opportunity to study the basement rocks. One such borehole is available near the western suburbs of Fort McMurray (Township 89, Range 10, West of the 4th Meridian) (Figure 1). This borehole penetrates through 550 m of the sedimentary strata and extends for another 1.8 km into the crystalline basement rocks. It is by far the deepest well drilled into the metamorphic Canadian Shield rocks in Western Canada.

In order to obtain high resolution imaging through the crystalline basement rocks, an extensive suite of geophysical logs was acquired by the Operational Support Group (OSG) of the International Continental Scientific Drilling Programme (ICDP) and the University of Alberta in July 2011. These new data could be used to supplement the existing logs that were previously acquired by the well operator for detailed subsurface analysis which will also be utilized to provide a detailed geophysical imaging of the crystalline basement rocks.

Well Logging

Deep drilling into the crust of the Earth allows us to carry out in situ measurements in the borehole to study the physical properties of the rocks surrounding the borehole. The most recent log operation for this deep borehole was run from 1005 m to the maximum accessible depth of tools at 1880 m. 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. Logs from separate logging operations and vintages were correlated using the natural gamma radioactivity curve surveyed in each logging tool by applying appropriate depth shifts. Quality of the well logs can be affected by the borehole conditions, poor calibrations and incorrect scaling of the data and hence these bad data are corrected to ensure the proper interpretation of the well logs.

Observations

Wireline logging offers the resolution in the geometry of fractures that could not otherwise be resolved by seismic reflection profiles. Prominent reflectors identified in the crystalline rocks using seismic reflection profiles can be interpreted as fracture zones after correlating the features with local borehole information (e.g. Juhlin, 1995; Schmelzbach et al., 2007). Such dipping reflectors have also been observed in a 2D seismic reflection profile located approximately 600 m south of the our borehole at ~1400 m depth. Fractures and faults provide permeable pathways for fluids to flow in the rocks, which is beneficial for the future development of geothermal systems.

The enlargement of borehole can provide an indication of fractured zones when the rock edges of fractures are chipped away during drilling. A multiarm, multidirectional dipmeter tool was used to assess the borehole geometry and condition by recording high resolution (5 cm) caliper measurements that show two borehole diameters that are 90° apart. Plotting of the caliper log responses and bit size information can be used to recognize different types of enlarged borehole including gauge hole, breakout, washout, and key seat (Plumb and Hickman, 1985). Two enlarged borehole zones are identified at 1187-1259 m and 1760-1794 m (Figure 2, Track 4). Both of these zones correlate to relatively higher magnetic susceptibility (Track 6) and photoelectric factor (Track 3), in addition to lower total magnetic field response (Track 7).

In the fractured crystalline rock, resistivity is very sensitive to the presence of interstitial fluids and alteration minerals (Boness and Zoback, 2004). Hydrothermal alteration of the rocks influences the formation resistivity where the alteration minerals of different resistivities could be attributed to geothermal activity (Steingrimsson, 2011). Two different tools have been used to measure the resistivity responses in the borehole. The first set is micro-spherically focused logs (MSFL) acquired in 1994 and 2003 which measure the conductivity of the rocks near the borehole and has shallow depths of investigation. The second and most recent set is the dual-laterologs (DLL) which offer greater depths of investigation compared to MSFL. Three significantly lower resistivity intervals are identified at 1406–1424 m, 1461-1471 m, and 1878-1891 m (Figure 2, Track 5). These anomalies outline sections of the deep borehole that provide indications in the presence of brine in the fractured zones. The smaller radius of investigation for the MSFL provides a higher resolution of the formation resistivity and is useful in complementing the newer resistivity curves for recognizing fractured zones in this project.

Electrical images are created from raw electrical image curves that correspond to a volume of rock within a few centimeters of the borehole wall (Davatzes and Hickman, 2010). Analysis was performed on the statically-normalized Formation MicroImager (FMI) logs (Figure 3). These image logs allow us to identify the presence of fractures with consistent strike and dip throughout the borehole according to the contrasts in conductivity between the fractures and the changes in rock composition. Colour display changes from light to dark brown that corresponds to changes from low to high conductivity. The nature, orientation, spacing and density of the fractures can further be extracted from the image logs. The FMI logs for this borehole reveal zones of fractures at 1406-1424 m and 1461-1471 m. Both of these intervals correlate to relatively higher bulk density, lower resistivity and higher magnetic susceptibility values, which indicate the presence of conductive alteration minerals in the fractures. Further interpretation and processing are required for the FMI logs to distinguish between the different planar structures (such as open fractures versus closed fractures, faults, drilling-induced fractures), the direction of maximum horizontal stress, and to further enhance sections of the image logs with poor resolution.

Conclusions

A comprehensive suite of geophysical logs has been compiled for a deep borehole that reaches the crystalline basement rocks located west of Fort McMurray. The data was quality-checked and depth-corrected to allow proper correlation across separate log runs. Interpretations made from these logs reveal possible correlation of conductive, fractured zone with the dipping reflectors in the 2D seismic reflection profile. Vertical seismic profiling (VSP) data is also available and has yet to be processed at the time of abstract submission. However, the processed VSP data will become useful in characterizing different fracture properties by identifying and analyzing the tube waves in the seismic section.

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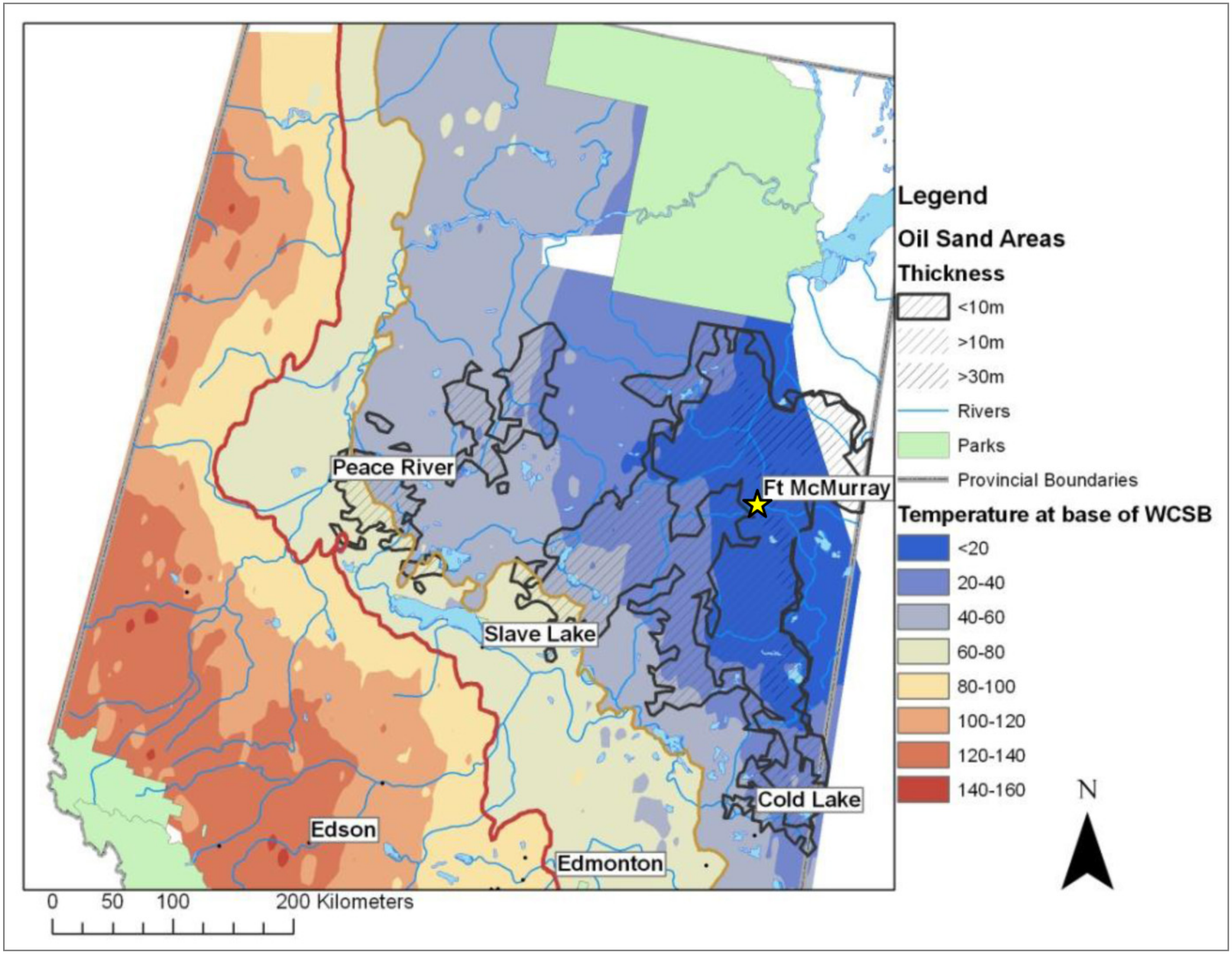

Figure 1. Location of the deep borehole (yellow star) (AOC GRANITE 7-32-89-10) west of Fort McMurray marked on the temperature map of the base of Western Canadian Sedimentary Basin (WCSB) in Alberta (after Grey, Majorowicz, and Unsworth, 2012).

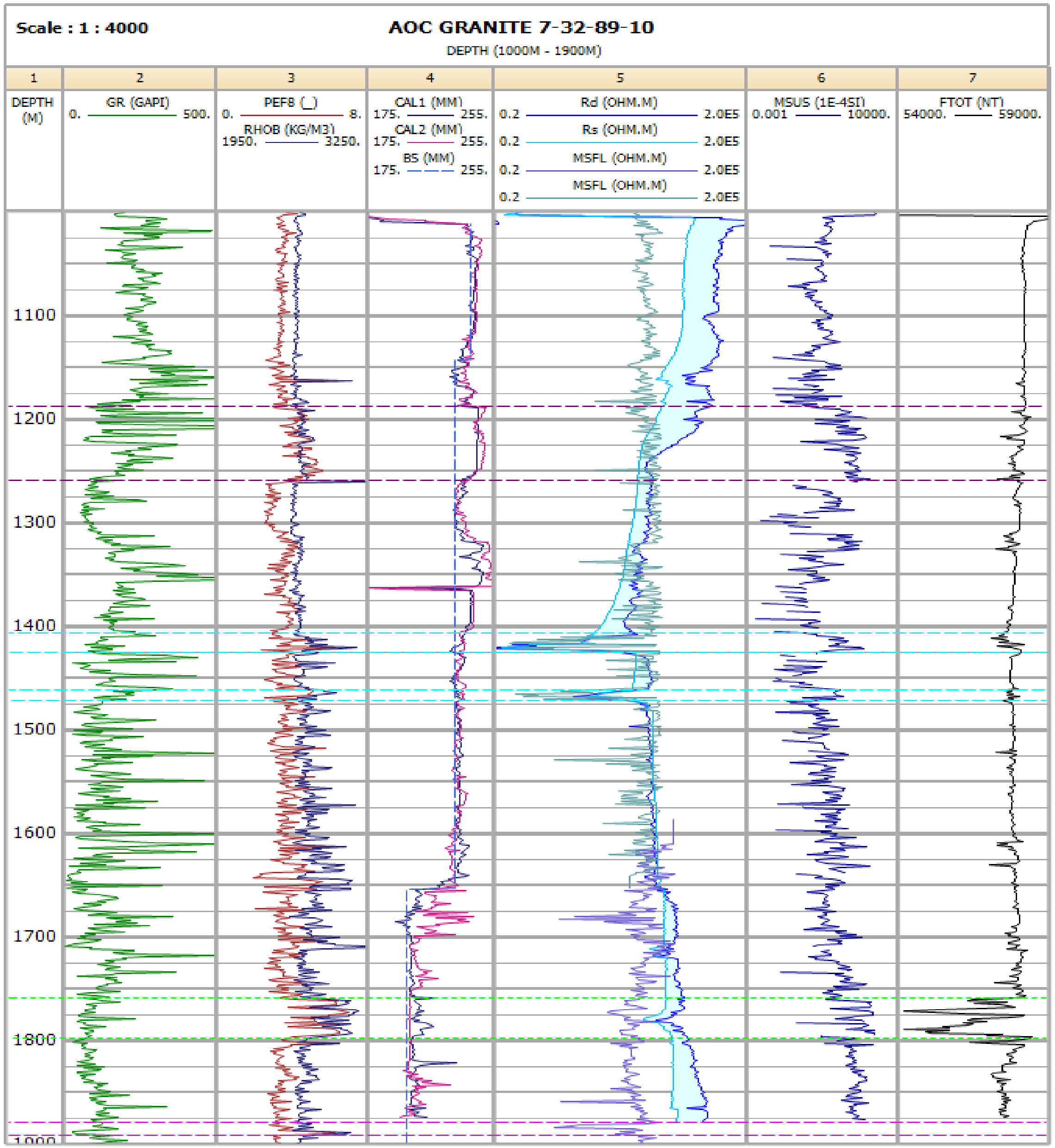

Figure 2. Composite log display of the deep borehole from 1005 to 1880 m. Dashed lines outline zones of interest discussed in this abstract.

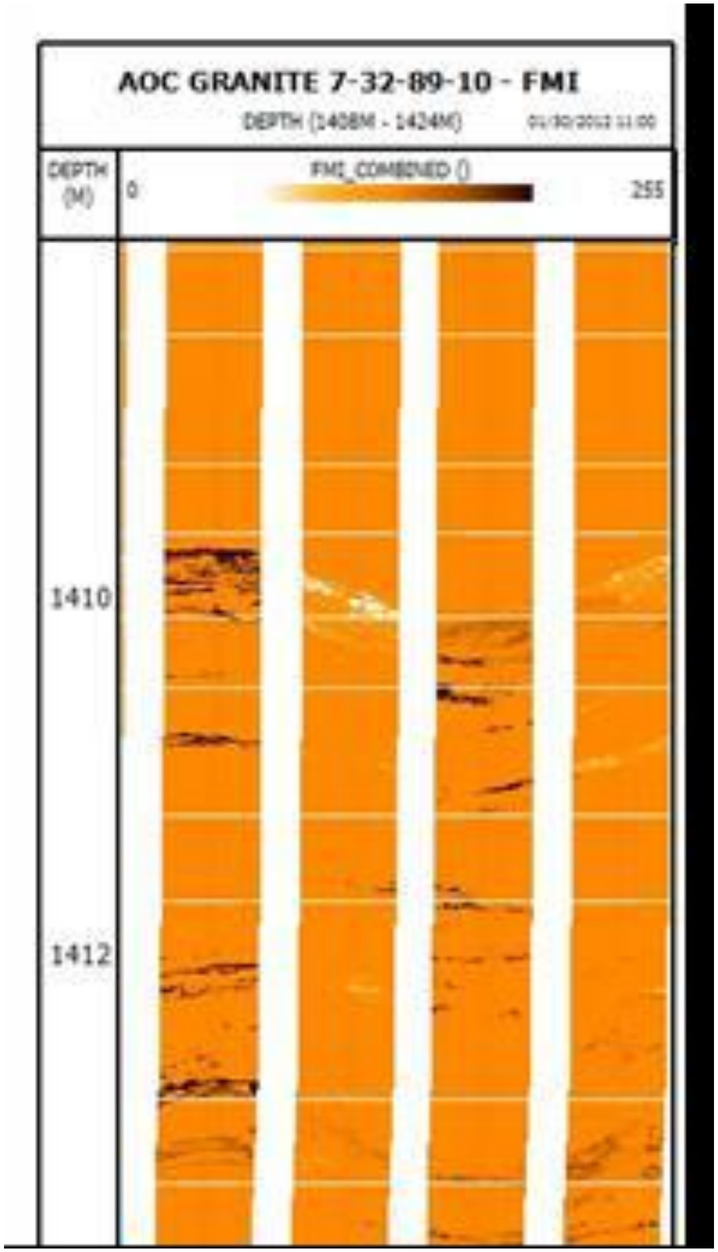

Figure 3. Sample section of FMI log.