Integration of Seismic and Log Data of a Deep Borehole in the Basement Rocks of Northeastern Alberta

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Summary

Existing heat flow and geothermal gradient studies suggest that deep drilling into the basement rocks is required for the extraction of geothermal heat for oil sands processing in Northern Alberta. The target temperature for the geothermal reservoir is 80°C in order to heat water for oil sands recovery. As an alternative to burning natural gas for hot water towards oil sands processing, a feasibility study on geothermal energy development in Alberta is currently being investigated under the research collaboration between the Helmholtz-Association of German Research Centers and the University of Alberta.

The extraction of geothermal heat from the crystalline basement rocks would require the use of Engineered Geothermal System (EGS) technology due to the low permeability of the granitic basement rocks. Hence, it is important to perform a detailed subsurface characterization of the basement rocks using a combination of geophysical logs and seismic methods. Part of the feasibility study for geothermal development in Northern Alberta consists of investigating the presence of subsurface fluid pathways in the Precambrian basement. A deep borehole located west of Fort McMurray has a depth of 2.36 km, where the largest oil sands deposit in Alberta is located (**Figure 1**). It is by far the deepest well drilled into the Precambrian basement below the sedimentary successions in Alberta, and can provide valuable information for geothermal investigations.

This presentation includes the processed and interpreted data sets from this deep borehole, with a focus on identifying any geological features such as zones of fractures in the crystalline basement rocks that could act as indicators of enhanced fluid potential – a necessary component for any geothermal systems to be viable.

Downhole Logs

To achieve a better understanding of the physical properties of the basement rocks, a series of logs were acquired in the open hole section of the borehole in the crystalline basement rocks to highlight zones of interest. **Table 1** lists some of the applications of the logs that could be of relevance to the development of EGS in Alberta. With the limited cores available for the well, formation microimager (FMI) logs acquired by the well owner are used to correlate some of the structural heterogeneities identified in the recently acquired logs to natural and drilling-induced fractures (**Figure 2**). The orientation of principal stresses can be inferred from the borehole breakouts and tensile fractures.

Table 1.

Type of Log	Observation	Relevance to EGS Development
Thermal	Rapid drop in water level (70 m over a few hours)	Presence of fractures
	Temperature gradient at 21.2°C/km	Reflects the variations in fluid properties with depth
	Bottom hole temperature at 47.5°C	To estimate the required depth required for extracting geothermal heat toward heating water for oil sands processing using bottom hole temperature and temperature gradient
Natural Radioactivity	Increase in the concentration of radioactive elements	To identify zones with heat generation and fractures
Resistivity	Separation between deep and shallow curves	Different current geometry possibly due to presence of fractures
	Low resistivity spikes	Increase in water content or total amount of dissolved solids can be associated with geothermal activity
Magnetic Susceptibility	Sudden increase at 1760 m with increase in density values	To provide in-situ estimates of mineral content and narrow down the origin of radiogenic heat sources based on the changes in geochemistry and mineralogy related to metamorphic processes and hydrothermal alteration of rocks

Aside from the conventional borehole logs, analysis of full waveform sonic (FWS) data was also performed (**Figure 3**). The velocity and energy content of the FWS data is inversely correlated to the permeability of the subsurface. The processed data are used to identify the presence of fractures based on the attenuation and interference patterns of the waveforms.

Seismic Methods

Two 2D seismic reflection profiles are re-processed and interpreted to identify any geological structures and features viable for hosting geothermal systems and controlling fluid flow in the subsurface. Dipping reflectors are interpreted in the profiles and can be related to shear zones containing fractures. To differentiate between true seismic reflectors and multiple reverberations in the 2D seismic reflection profiles, a zero-offset vertical seismic profile (VSP) was processed. The higher-frequency VSP data has the resolution in identifying fracture zones based on the upgoing tube waves (**Figure 4**). Data quality becomes increasingly poorer as depth increases due to the poor geophone coupling to the borehole wall in an open hole environment.

A walk-away VSP survey was acquired at the 800 m and 1780 m section of the well to analyse the overall anisotropy of the basement rocks around the well. Fractured rocks are known to cause velocity variations in seismic data which is dependent on the crack density, degree of preferred orientation, and also on the degree of fluid saturation that can exhibit seismic anisotropy for wave propagation. The walk-away VSP data is processed and the degree of seismic velocity anisotropy is calculated. Between the ground surface to 800 m depth, the P-wave velocity anisotropy was calculated to be in the range of

9 to 11 %, and 11 to 14 % from 800 m to 1780 m depth, which indicates an increase in anisotropy with depth. The degree of seismic velocity anisotropy can be attributed to geological heterogeneity and metamorphic foliations and lineations due to the preferential alignment of minerals in the crystalline basement rocks.

Conclusions

The joint assessment of geophysical methods reveals the complexities of the crystalline basement. Strong reflectors in surface seismic data, changes in the physical properties of rocks using downhole logs, tube waves from zero offset VSP data, waveform interference in FWS logs, and images from FMI logs are used to verify the presence of fractures in the crystalline basement rocks that are of importance for geothermal exploration. Knowledge of stress orientation from the interpretation of drilling-induced tensile fractures in the FMI logs help to orient future wells along the direction with optimal fluid flow for geothermal development. Uncertainties for the subsurface characterization of the Canadian Shield are minimized when there is an agreement across multiple geophysical data sets.

Acknowledgements

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Figure 1: The deep borehole (marked by yellow star) used in this study is located west of Fort MuMurray in Twp 89, Rge 10, W4M.

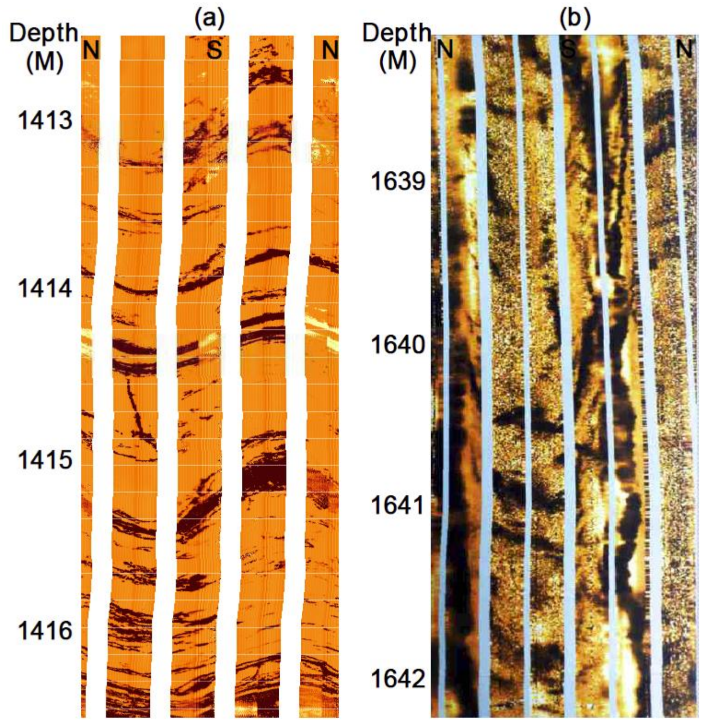

Figure 2: Example of fractures in FMI logs. Lighter colour in the logs represent higher resistivity values. (a) Natural fractures that are more electrically conductive than their surrounding rocks. (b) Drilling-induced fractures along the NE-SW direction.

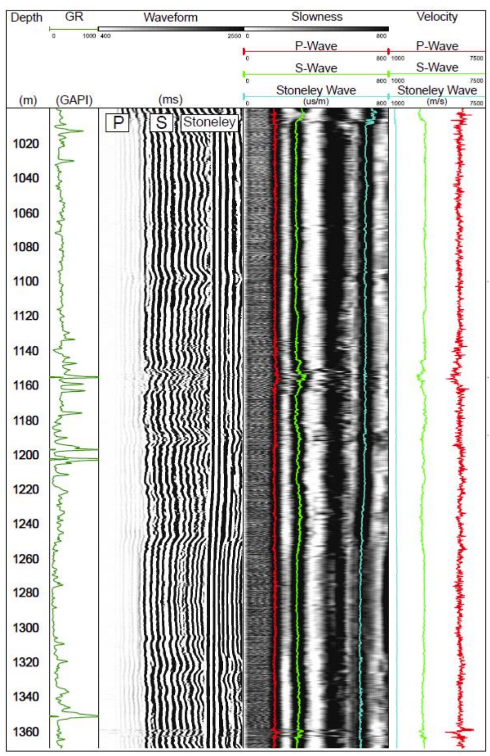

Figure 3: Example of FWS data. Gammra ray (GR), variable-density plot of data, semblance processing, and interpreted velocities for P-, S-, and Stoneley waves. Dark bands in semblance image indicate high correlation between far- and near-offset receivers.

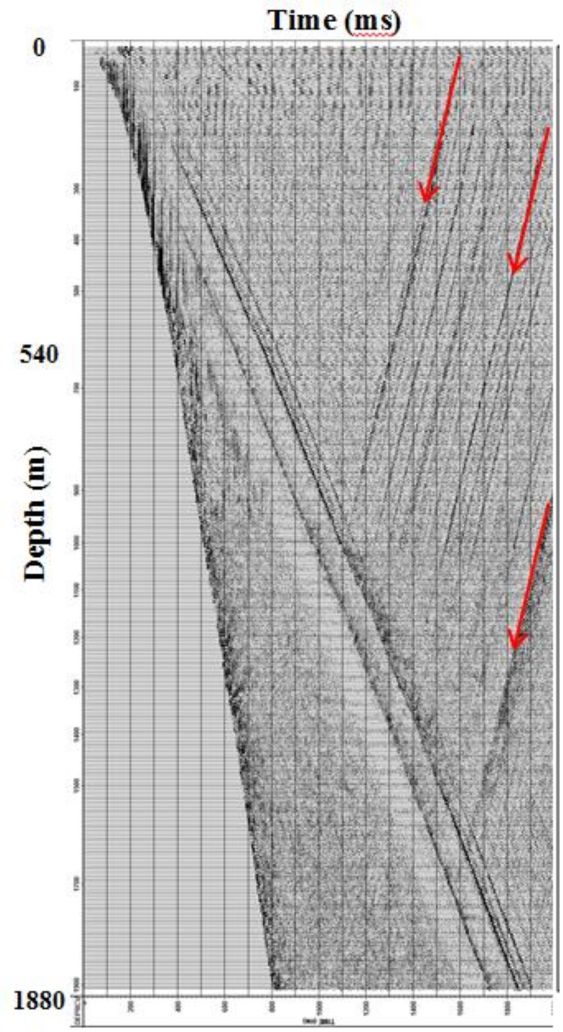

Figure 4: Processed zero-offset VSP data. Three of the interpreted upgoing tube waves are indicated by the red arrows.