CSPG

TOURMALINE
OIL CORP.

CORE*CONFERENCE*

16-17 May 2019 • AER Core Research Centre • Calgary, AB
Celebrating 50 Years

Faults and Natural Fractures in Clearwater and Wabiskaw Caprocks in an Athabasca Oilsands SAGD Project

Kevin Gillen[1], Patrick McLellan[2]
[1]Vox Terrae
[2]McLellan Energy Advisors Inc.

Summary

In-situ thermal recovery projects such as steam-assisted gravity drainage (SAGD) and cyclic steam stimulation (CSS) require a sufficiently thick, intact, impermeable and strong shale caprock to minimize the risk of steam escaping into overlying strata. For many years SAGD operators in the Athabasca Oilsands have been characterizing the Clearwater and Wabiskaw caprocks that overlie the McMurray Formation where steam is injected and from which bitumen is produced (McLellan et al, 2014, Chou et al, 2016, Stabb and Webb, 2018). Both core and formation image logs have principally been used for this scale of investigation to ascertain the degree of faulting and natural fracturing present. This core conference presentation will feature one caprock core obtained from the Athabasca Oilsands region, as well as the accompanying image log, and other structural features and in-situ stress indicators from other cored and logged wells in the region.

The calculated Discrete Fracture Network (DFN) metrics, P_{10} and $P_{32,}$ are shown for lithologic subdivisions of the caprock. This parameter can be used for DFN modelling of the fault and fracture network, and hence such questions, as whether a connected pathway is likely to exist across the caprock interval, can be tested. DFN modelling can also be used to estimate natural fracture and fault sizes, and spatial concentrations of weak discontinuities in a caprock, however these will not be shown in this presentation.

Accounting for natural fractures, faults and bedding plane discontinuities in a caprock for application in geomechanical simulation, is a classic upscaling problem that has been addressed in the mining and tunnelling industries. Several methods of accounting for rock mass properties, that make use of DFN characteristics from the type of core and log analyses described in this study are briefly described and compared in the accompanying poster.

Methodology

In stiffer clastic and carbonate rocks, naturally occurring fractures can be recognized by the presence of such indicators as mineralization, slickensides, dissolution along fracture planes, etc.

In the absence of such indicators (which is the case for the bulk of core examined in this study), one must also utilize fracture shape and surface texture to distinguish natural and induced fractures (Fig. 1). Data logged in core were combined with those obtained from image logs run in the same borehole using the methods described by Chou et al.(2016).
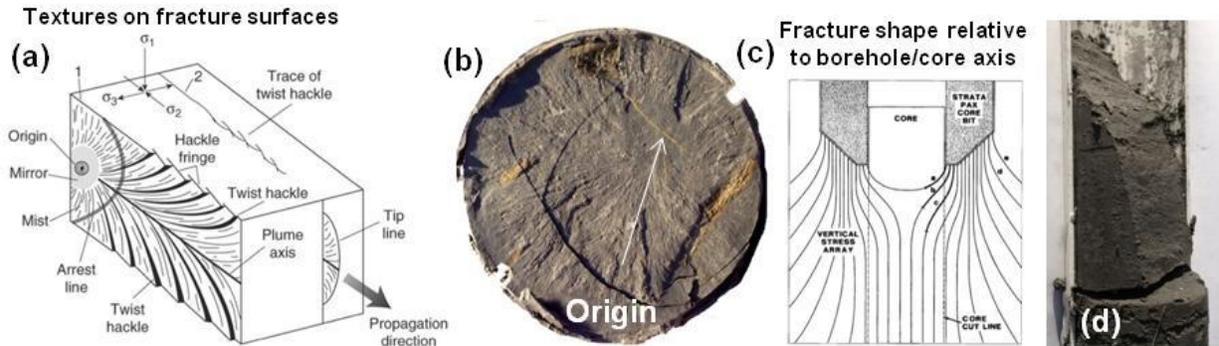

Fig. 1: Examples of fracture characteristics used to assess natural vs induced origin. (a) Plumose patterns on natural fractures (van der Pluijm & Marshall, 1997). (b) Coring induced horizontal fracture in the Lower Clearwater at 69.17mKB. (c) Induced fractures resulting from coring can exhibit shapes which relate to the stress field at the bit (Lorenz et al., 1990). (d) Petal-like induced fracture in the Lower Clearwater at 69.94mKB.

Most oilsands caprock evaluation boreholes are vertical and hence subject to directional sampling bias. The common Terzaghi (1965) bias correction tends to overcorrect fracture intensity (or frequency) where fractures are close to parallel to the borehole or core axis (Davy et al., 2006). Although Terzaghi-corrected fracture and fault intensities are calculated in this study, they are not relied upon as the most accurate reflection of fracture intensity for fractures and faults dipping greater than 80°. However, features dipping more shallowly than this are expected to yield reliable values.

All fracture intensity data were converted to P_{32} values to compensate for directional sampling bias using the method of Wang (2005). Although not applied here, discrete fracture network (DFN) modeling techniques can also be used for this purpose (Dershowitz and Herda, 1992).

Examples

This core conference presentation will feature one core from a borehole penetrating Clearwater and Wabiskaw caprocks in an Athabasca Oilsands SAGD project area. Interpretations are strengthened by offset core and log data from multiple locations in the same vicinity.

All natural fractures and faults observed in the presented core are unmineralized (Fig.2a). The bulk of natural fractures seen in the FMI image logs are electrically conductive, i.e., consistent with fractures which are not filled with mineralization (Fig.2c). There are a few which are electrically resistive, however these do not appear to be mineralized in core. Their resistive expression in the image log is believed to be due to an inversion of resistivity between the formation and drilling fluid, where the formation resistivity becomes so low that drilling fluid-filled features appear resistive.

Many of the discontinuities interpreted as faults in image logs are confirmed by the presence of a fault with a similar dip magnitude at the corresponding depth in core (Fig. 2b). However, more than half of the faults observed in core from this and nearby boreholes do not appear to have any expression in the associated image log. The lack of a counterpart in the image log suggests that these faults are not open (i.e., they are not electrically nor hydraulically conductive) at the borehole wall. In addition, this may reflect negligible offset (below the resolution of the tool) or possibly a lack of any bedding features necessary to identify offset.
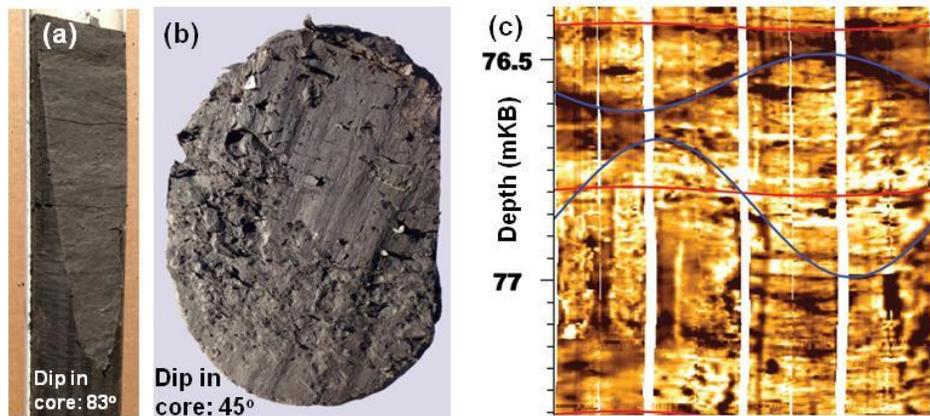

Fig. 2: Examples of natural faults and fractures in the Lower Clearwater from the presented borehole. (a) Steeply dipping natural fracture at 70.95mKB. (b) The footwall of a fault at 68.19mKB. Slickenlines directed down dip are visible. (c) Natural fractures in the borehole FMI image log at 76-77mKB.

Oriented natural fracture and fault data from both the Lower Clearwater Shale and the Wabiskaw A Shale in the presented and surrounding boreholes are portrayed in Fig. 3. Although a slight NE-SW trend is visible in the strike data from both units, previous experience of the authors in other caprock settings suggests exercising caution in the interpretation of the significance of directional trends in the early stages of a study. Some degree of order can be visible on the individual borehole scale which often does not translate to surrounding boreholes. The portrayed plots reflect data from only seven boreholes. Initial trends may not hold as the study progesses and additional boreholes are added.
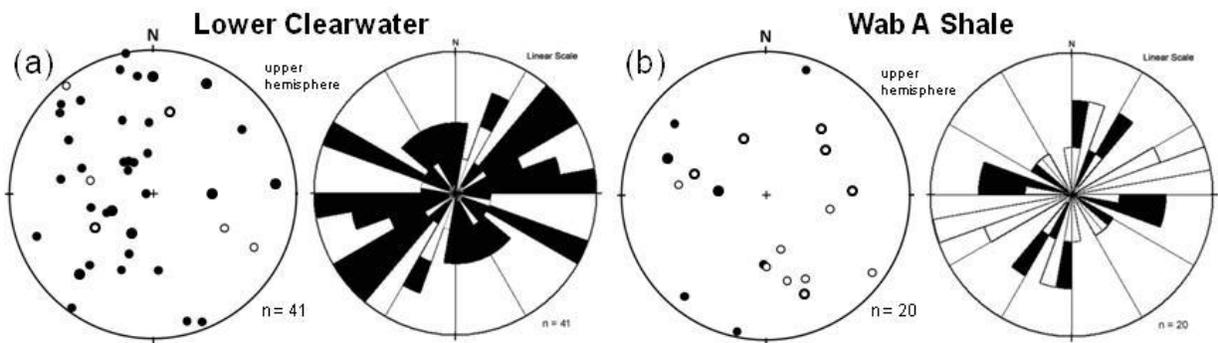

Fig. 3: Stereonet of poles and roseplot of strike for all oriented natural fractures (filled symbols) and faults (open symbols) in the (a) Lower Clearwater (b) Wabiskaw A Shale.

Fracture and fault development with depth through the caprock is pictured in Fig.4. The observed frequency (i.e., the #/m or so-called P_{10}) is portayed along with two approaches intended to correct for directional sampling bias associated with this vertical borehole (Terzaghi correction and the Wang conversion to P_{32}). Due to the variations in confidence levels for the determination of fracture origin, a range of intensity estimates are presented.
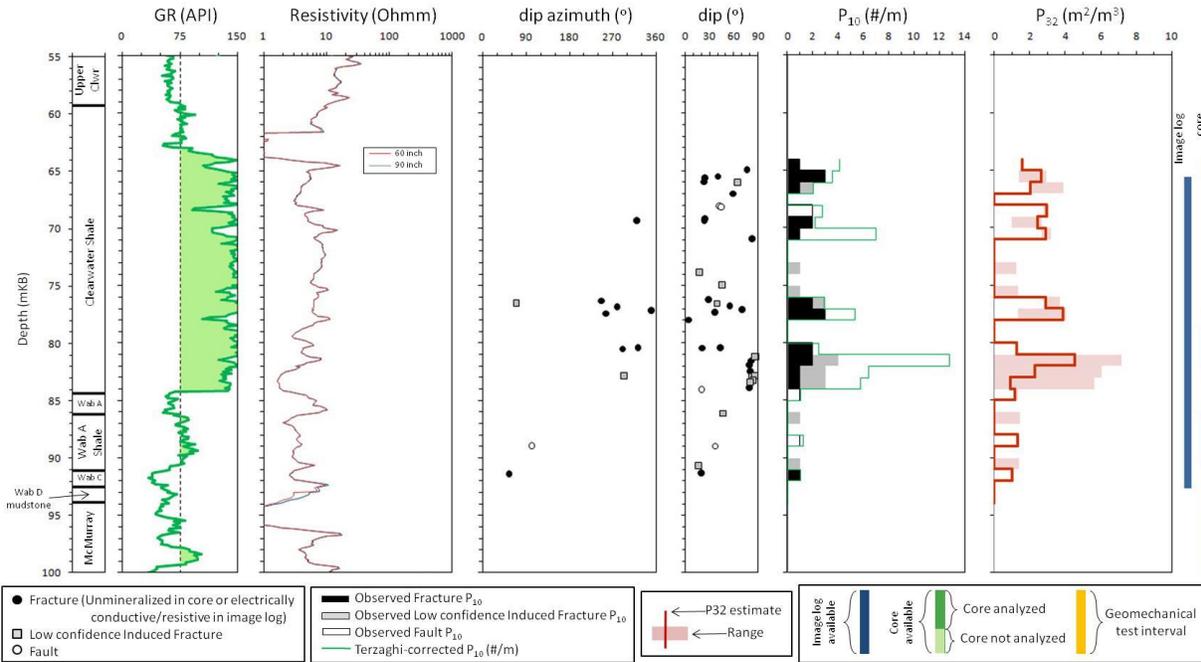

Fig.4: Natural fracture and fault data from the presented borehole.

Conclusions

- The characterization of discontinuities in these caprocks is improved by combining data from core and image log in the same borehole. Multiple boreholes form a more representative depiction than a single well.

- Natural fractures appear unmineralized in all cores examined.

- Data from the presented core combined with surrounded boreholes shows that natural fractures are primarily developed in the muddier sections of the caprock represented by the Lower Clearwater Shale and the Wabiskaw A Shale.

- Faults are confined to the Lower Clearwater Shale and the Wabiskaw A Shale in the presented and surrounding boreholes.

- Fault characteristics are consistent with a gravity-driven process such as normal faulting.

- No natural fractures or faults are observed in the Wabiskaw D mudstone.

Acknowledgements

References

Chou, Q., A. Altosaar, K.P. Gillen (2016): Predicting Clearwater Formation Natural Fracture Intensity, Athabasca Oil Sands Area, Presentation at the AAPG Annual Convention and Exhibition, Calgary, Alberta, June 19-22.

Davy, P., C. Darcel, O. Bous, R. Munier, and J.R. de Dreuzy (2006): A note on the angular correction applied to fracture intensity profiles along drill core, Journal of Geophysical Research, v. 111, p. B11408.

Dershowitz, W.S. and H.H. Herda, (1992): Interpretation of fracture spacing and intensity., In 33rd US Symposium on Rock Mechanics, Santa Fe, NM, pp.757-766.

Lorenz, J. C., J. F. Sharon, and N. R. Warpinski (1990): Significance of coring-inducing fractures in Mesaverde core, northwestern Colorado: AAPG Bulletin, v. 74, p. 1017–1029.

McLellan, P.J., K.P. Gillen, and S. Rogers (2014): Essential Elements of Caprock Integrity Assessment for Thermal Recovery Projects, Poster presented at the AAPG CSPG Oil Sands and Heavy Oil Symposium: A Local to Global Multi-disciplinary Collaboration, Calgary, Alberta, October 2014.

Stabb, G.T. and M. Webb (2018): Geologic Considerations of Shallow SAGD Caprock; Seal Capacity, Seal Geometry and Seal Integrity, Athabasca Oilsands, Alberta Canada, CSPG Core Conference, May 10-11, 2018.

Terzaghi, R. D. (1965): Sources of error in joint surveys, Geotechnique, v. 15, p. 287-304.

van der Pluijm. B. and S. Marshak (1997): Earth Structure: An Introduction to Structural Geology and Tectonics, WCB/McGraw-Hill, New York, 495 p.

Wang, X. (2005): Stereological Interpretation of Rock Fracture Traces on Borehole Walls and Other Cylindrical Surfaces, PhD dissertation, Virginia Polytechnic Institute and State University, Blacksburg, Virginia (September 2005).