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A Regional Geomechanical Study of the Duvernay Formation in Alberta, Canada

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Summary

Geomechanical studies can provide important information for reducing costs during drilling and optimizing hydraulic fracturing and production in unconventional plays. This paper reviews the results of a regional geomechanical analysis of the Duvernay Formation in Alberta. The study included the characterization of mechanical rock properties and natural fractures, determination of in situ stresses and analysis of drilling and fracturing experience. The results show that maximum horizontal stress is largely influenced by the presence of the Leduc reefs, which explains significant differences in natural fractures and drilling experience throughout the large study area. In situ stress, natural fractures and pore pressure all appear to play an important role in early production results from the Duvernay.

Introduction

The development of unconventional plays in recent years has brought with it a renewed interest in geomechanics and its application in horizontal well drilling, hydraulic fracturing design and diagnosis, well placement and production optimization. The complexity of operations in unconventional plays, together with the complicated nature of these rocks, requires that geomechanical studies be conducted in a way that integrates data and results of analyses from other disciplines such as geology, geochemistry, petrophysics, and geophysics. In 2014 Canadian Discovery, together with partners Graham Davies Geological Consulting Ltd. and Trican Geological Solutions Ltd., performed a regional analysis of the Duvernay resource play from developing a regional stratigraphic framework to determining in situ stresses and examining their implications for drilling and completions. Some of the key geomechanical components of the study included a review drilling experience, rock properties analysis, image log analysis, in situ stress characterization, wellbore stability modelling and fracture fabric characterization. This paper provides a general review of the data, methodologies, results and conclusions of the geomechanics part of the study and demonstrates the types of insights that come from a geologically integrated approach to understanding a play.

Methodology

Geology and Hydrogeology

The stratigraphic framework for the Duvernay was developed through detailed sampling and analysis of nearly 900 m of full core from 29 wells throughout the play. Core analysis was also an important part of characterizing the stratigraphic and geographic distribution of sedimentological and mechanical features, such as natural fractures. A petrophysical model was developed for 241 wells, and the Passey-Schmoker technique was used to construct total organic carbon (TOC) maps for all seven Duvernay units. Detailed analysis and screening of Rock-Eval data allowed for kerogen typing. Temperature data were used to help understand condensate and gas liquids ratios and shallow- and deep-cut yield trends. The hydrogeology of the Duvernay was determined using 84 quality-ranked reservoir pressure data points.

Geomechanics and Rock Properties

Vertical stress (overburden) in the study area was calculated by integrating 153 quality-screened density logs. Minimum stress values were derived from minifrac and DFIT tests as well as hydraulic fracture stage data. All non-confidential Duvernay completions available at the time of the analysis were included (a total of 73 data points). The orientation and magnitude of the maximum horizontal stress was determined through the modelling of stress-induced, mechanical wellbore failure (induced tensile fractures and breakouts). The resulting geomechanical model was then verified against drilling experience.

The geomechanical analysis also included an investigation of rock mechanical properties from both core tests and log data. The relationship between rock properties and mineralogy, natural fractures and induced fractures was then examined. The concept of rock "brittleness" was examined using four approaches to determine the mechanical stratigraphy of the Duvernay for hydraulic fracturing (Soltanzadeh et al., 2015).

Coulomb failure analysis was also performed to determine the mechanical state of pre-existing fractures and faults in the current geomechanical setting, which has implications for fracture permeability and fault stability (Zoback, 2010).

Results

Geology and Hydrogeology

As a result of the study, the Duvernay has been subdivided into three internally multi-cyclic units: the A Shale at base, a middle B Carbonate, and an upper C Shale. The underlying Majeau Lake and overlying Ireton Formations have very different geomechanical properties than the Duvernay units, and variation is seen within the Duvernay units themselves.

Three types of natural fracture fabrics were observed in the Duvernay core: bedding parallel parting (induced by removal of the core from confining stress), polished slip faces (and associated low-grade metamorphic cleavage), and high-angle natural fractures.

The hydrodynamics analysis showed that the majority of the Duvernay formation is located within the "overpressured" Deep Basin setting, the onset of which is indicated at a pressure-depth ratio of 10 kPa/m. Overpressure is seen to reach in excess of 19 kPa/m. Overpressuring is conducive to high productivity and has a significant influence on geomechanical parameters including rock properties and in situ stresses, which in turn influence drilling and production experience. Normally pressured to underpressured Duvernay is generally constrained to areas where Duvernay kerogens are immature.

Geomechanics and Rock Properties

The stress modelling determined that, in general, the study area is in a strike-slip stress regime where the maximum and minimum principal in situ stresses are horizontal, and the overburden is the intermediate stress. The absolute magnitudes of the stresses, particularly the maximum horizontal stress, however, do vary significantly over the study area and appear to influence the presence or absence of particular fracture types; where maximum horizontal stress is lower, which is east of the main Leduc reef trends, polished slip faces are rarely observed in core (figure 1). The stress distribution also has important influence on drilling experience and required mud weights. Where maximum horizontal is higher, mechanical wellbore instability problems are more severe, and significantly higher mud weights are needed. Finally, the results of modelling suggest that there is a pore pressure transition zone in the lower part of the Ireton where pressure is influenced by the overpressured Duvernay.

Analysis of directional anisotropy in rock properties showed little directionality in the plane of bedding but significant differences between properties measured parallel versus perpendicular to bedding, confirming that both the Duvernay and Ireton may be considered transversely isotropic. A strong correlation was observed between Young's modulus and percentage of clay, where the modulus decreased as clay volume increased. Correlations were also observed between Poisson's ratio, quartz content and TOC. Comparison of four types of rock "brittleness" indices determined that plane-strain Young's modulus and clay mineralogy are better indicators of mechanical difference between stratigraphic units than the commonly used Poisson's ratio−Young's modulus based calculation or brittle mineralogy (Soltanzadeh et al., 2015).

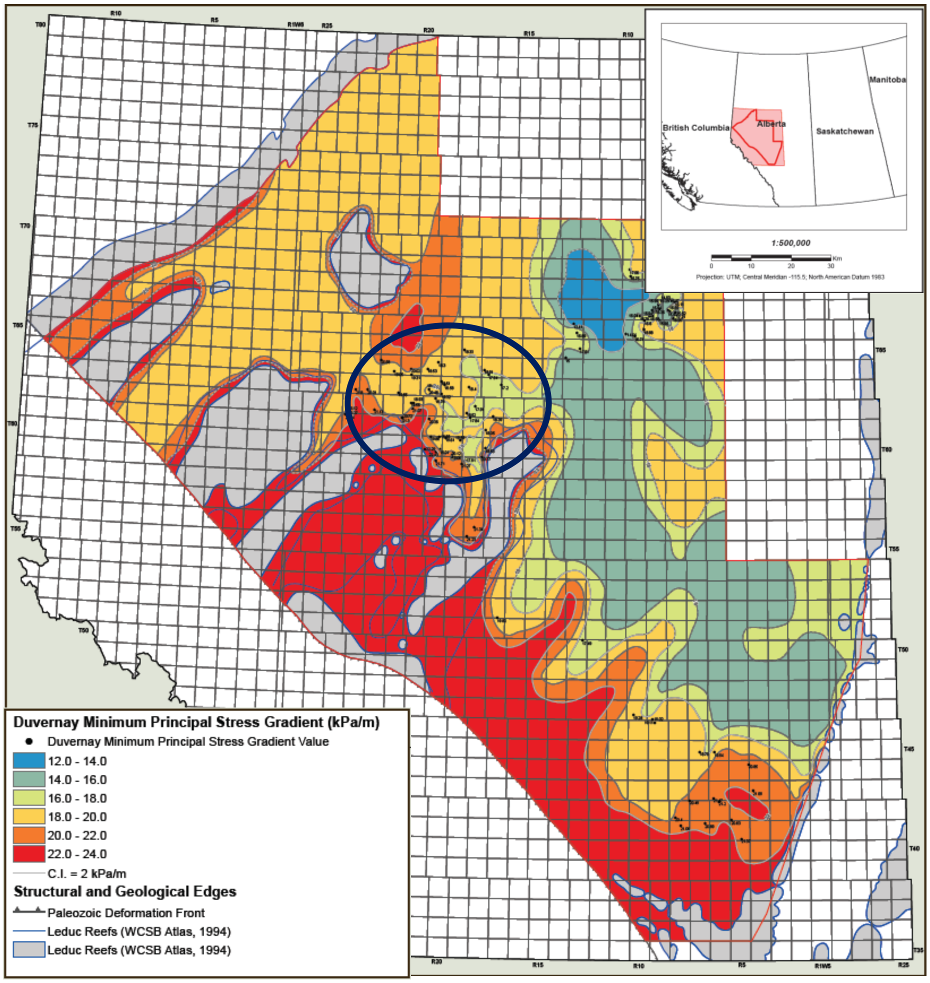

Figure 1. Map of minimum horizontal stress magnitude in the Duvernay Formation. The black oval indicates the region where maximum horizontal stress is relatively high compared to the rest of the study area. In this area, lower mud weights are used to drill, and fewer drilling problems are encountered than in other parts of the study area, and polished slip faces are not observed in core.

The identification of natural and induced fractures in core and image logs from 2 key wells allowed for the identification of intervals with particular rock properties and mineralogy that are more prone to fracturing and even to containing specific fracture types. Fractures tended to not be observed in rock that is either too strong or too ductile. Natural fractures tend to occur in rocks with fast shear and compressional wave velocities, low TOC, high Young's modulus and plane-strain Young's modulus, high Poisson's ratio, high clay-based brittleness index and low total or Uranium-free spectral gamma. Polished slip faces tend to occur in rocks with high TOC, slower velocities, low Young's modulus and plane-strain Young's modulus, intermediate Poisson's ratio, low clay-based brittleness index, intermediate total spectral gamma and low Uranium-free spectral gamma. Bedding-parallel partings are common in rock with properties between these two end members.

Critically-stressed natural fractures and faults are those on which the shear stress is relatively high compared to the effective normal stress. On a Mohr diagram, these fractures fall above the line defined by the coefficient of sliding friction. When a fracture is in this particular state, it is expected to have experienced shear displacement in recent geologic history, and/or it will do so in the present under minor stress or pore pressure variations. Such fractures tend to be important for fracture permeability. In the central part of the study area, for example, there is a large potential population of critically-stressed fractures dipping more than about 30° with strikes between about 10° and 100° (figure 2). Fractures at other orientations require up to 35 MPa of additional pressure to become critically-stressed, a mechanism that may account for seismic and microseismic events that can occur during hydraulic fracturing.

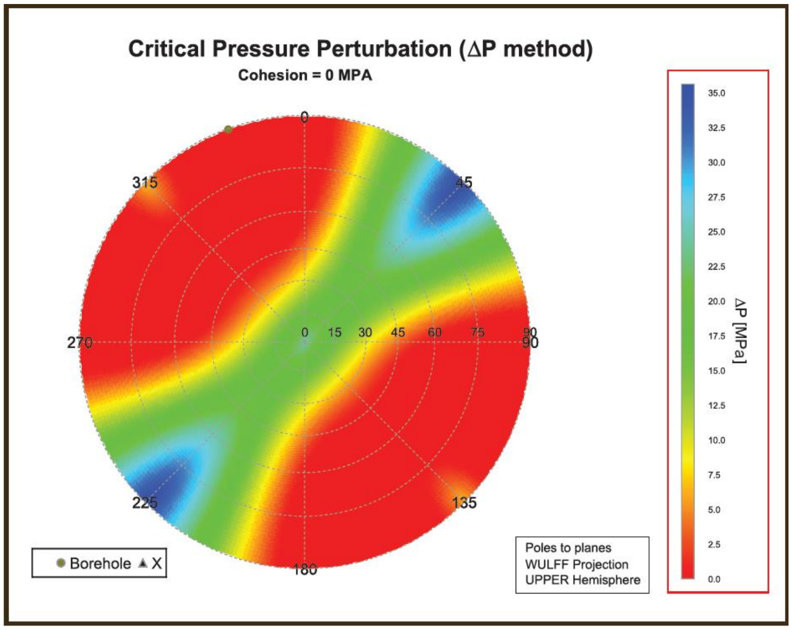

Figure 2. Upper hemisphere stereoplot of poles to natural fracture planes coloured by the excess pressure needed to reduce the effective normal stress on the fracture and cause it to become critically-stressed. Red zones indicate potential fractures that are naturally critically-stressed under in situ geomechanical conditions.

Conclusions

The Duvernay study offered a unique opportunity to add geomechanics to a regional geological and hydrothermal understanding of an important, growing resource play. Both high pore pressure in (and just above) the Duvernay and regional changes in horizontal stress both play an important role in wellbore instability problems observed in Duvernay wells. These problems can be minimized by using appropriate mud weights and careful planning of casing set points. Detailed studies on the key wells with extensive data sets (core, image logs, dipole sonic logs, lab tests, etc.) showed strong correlations between geomechanical and mineralogical properties of the rock, which proved useful in distinguishing specific intervals that are prone to the occurrence of the different types of fractures in the Duvernay. While production results were sparse at the time the study was conducted, areas with higher reservoir pressure and lower effective horizontal stress appear to be associated with improved production outcomes, CDL has observed similar relationships in other Western Canada plays such as the Second White Specks. The presence of critically-stressed fractures may also contribute to production from the Duvernay. Finally, studies such as this can provide important, calibrated input parameters for hydraulic fracture and reservoir modeling.

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