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The Duvernay Formation- the application of structure and simultaneous inversion for reservoir characterization and induced seismicity

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Summary

This abstract describes the analysis of multi-component inversion data integrated with structural interpretation. This workflow is used for characterizing a low permeability unconventional reservoir, both in a structural and lithologic sense. This includes the determination of a time-depth relationship using synthetic seismograms, generation of seismic derived structural maps, and the determination of inversion based parameters of density, shear wave, and p wave velocity. The model based procedure includes poststack (acoustic) inversion, AVO prestack inversion, and joint PP-PS inversion. With these rock properties determined, calculations are made to determine Young's Modulus, Poisson's Ratio and brittleness. Faults are mapped based on time slices, isochrons and observing correlatable vertical displacements. Seismic derived attributes, when combined with structural mapping can highlight zones most favorable to hydraulic fracturing. The mapping of structural discontinuities can also lead to an understanding of zones of preexisting weakness, and an understanding of induced seismicity risk

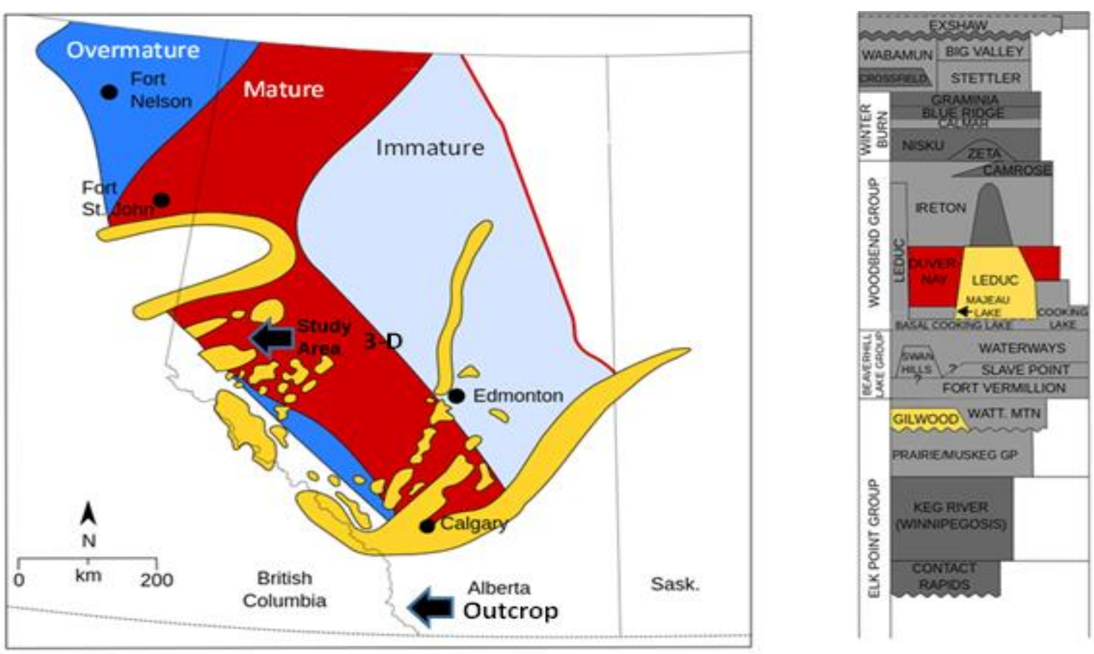

Figure 1. Hydrocarbon maturity windows for the Duvernay petroleum system (modified from Creaney et al., 1994), showing location of the study area. Table on the right (adapted from Core Labs, 2017) shows Middle and Upper Devonian regional stratigraphic nomenclature, highlighting several units that are discussed here.

Introduction

We will show how a 3-D,3-C seismic data can be used to evaluate the Duvernay unconventional hydrocarbon play in West central Alberta Canada. The depositional environment of the Duvernay Formation varied depending on where it was situated with respect to the Leduc reef margin. Factors that influenced the depositional environment included tides, storms and sea level changes. Inter-reef areas were protected from waves and tides, so that sediments in these regimes were deposited in a low-energy environment. In the subsurface, five lithofacies have been identified from cores (Dunn et al., 2012); these are argillaceous mudstones, bioturbated limestones, organic rich siliceous mudstones, siliceous organic-rich mudstone and mixed siliceous mudstones.

A rock with a high brittleness index (BRI) will necessarily have a low Poisson's Ratio (PR), and a high Young's Modulus (E). Within an established lithofacies framework, a strong correlation exists between quartz content, total organic carbon (TOC) and brittleness of the Duvernay Formation (Dunn et al., 2012). The higher silica content of the Duvernay comes from deposition at the more distal, low-energy areas. Soltanzadeh and Fox (2015) provided evidence that clay content also plays a significant role in the brittleness of the Duvernay and Ireton Formations; moreover, hydrocarbon generation has changed the rock properties such that the high TOC Duvernay tends to be more brittle (Soltanzadeh et al., 2015). We will show how prestack seismic inversion is a useful tool in extracting reservoir properties such as PR, E, and BRI.

Structural Mapping

A time -depth relationship was established using a nearby synthetic seismogram tie. Time-structure maps were created throughout the data volume for all the horizons listed in figure 2. The time-structure map of the Gilwood horizons are shown in Figure 3.

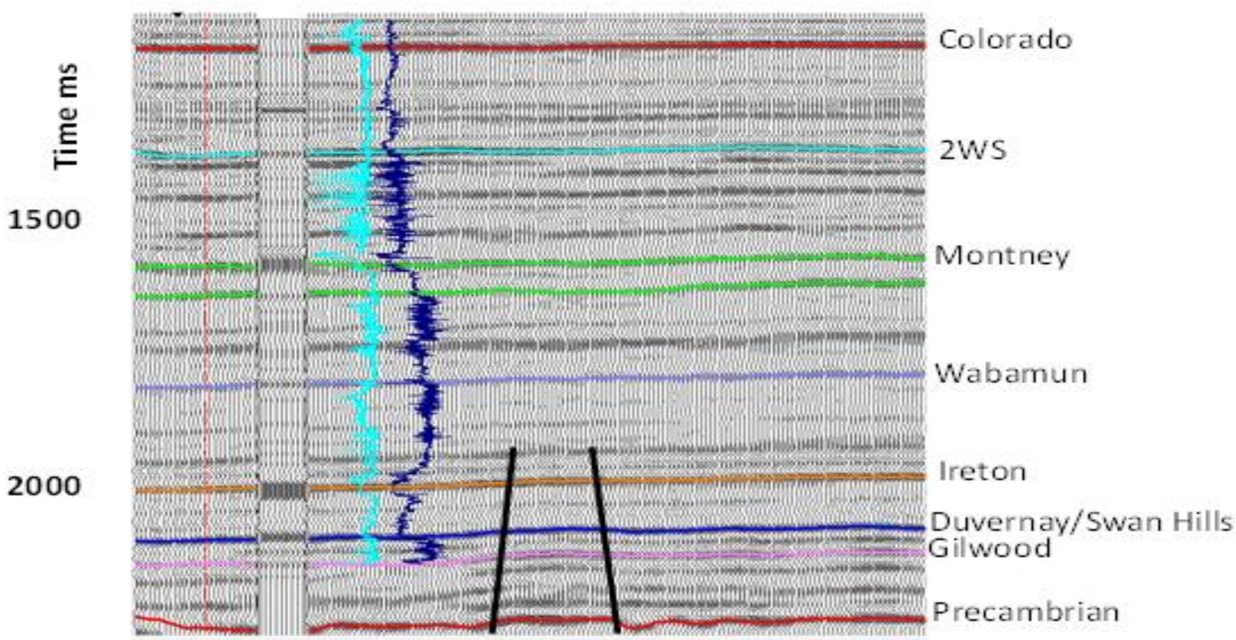

Figure 2. West-East seismic profile extracted from the PP data volume, showing the integrated sonic log correlation with the mapped seismic horizons., the Δt (sonic) and ρ (density) logs are shown. The well is located 8 Km. SE of the line along structural strike. Two interpreted basement faults are displayed showing vertical and lateral displacement in the Gilwood, formation.

The Gilwood member of the Watt Mountain Formation is a clastic unit that was deposited during uplift of the Peace River Arch (O'Connell, 1994). Seismic mapping of this unit reveals a conspicuous feature that is interpreted as a meandering river channel that may represent a drainage system that is linked to uplift of the Arch. These features help to elucidate the meandering channel-like feature, which is cross-cut by a prominent N-S linear feature. We interpret this feature as a possible strike slip fault with left-lateral displacement. Based on the channel offset, the net displacement along the fault appears to be about 1 km.

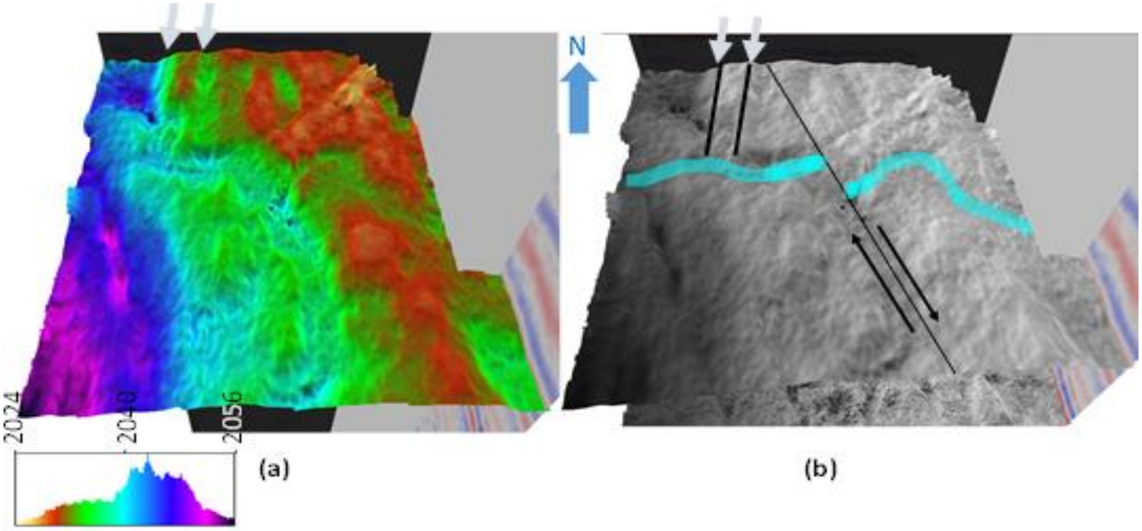

Figure. 3. Gilwood time structure derived from the PP data volume (a). Also shown is the same time structure map (b) in gray scale with interpreted faults and Gilwood Formation channels.

Inversion

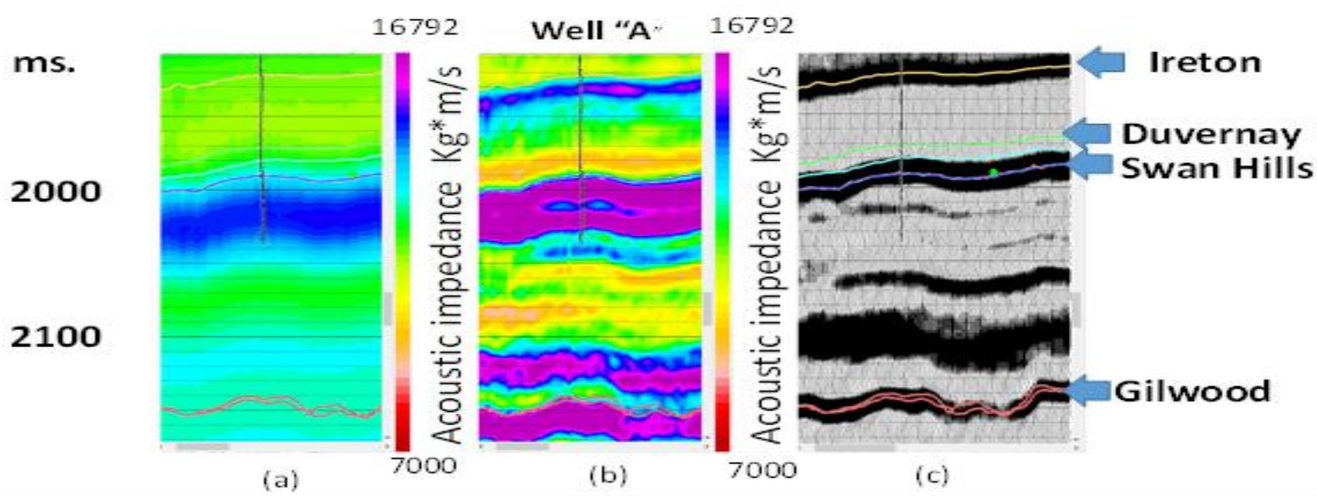

Figure. 4. Small region extracted from poststack inversion of the PP data volume (a) Initial model; (b), inversion output; and (c) input seismic data. Well "A" is a location 8 km SE of this survey.

The data used for the inversion were a 3-D, 3-C data recorded in 2015. Three inversion volumes were processed, a poststack inversion, a simultaneous (AVO) inversion, and finally a joint PP PS inversion. All inversions were model based, constrained by time horizons in conjunction with sonic and density well control. Figure 4 shows the result of the poststack inversion. The model, and the well log ties were also applied to the AVO (prestack) and PP PS prestack volumes.

Results

Using the structure, and extracted reservoir parameters can yield a competitive reservoir picture. Geohazards, and potential thief zones can be identified by fault identification. Areas with a higher BRI are generally thought to be more suitable to hydraulic fracture stimulation, can be mapped with prestack inversion.

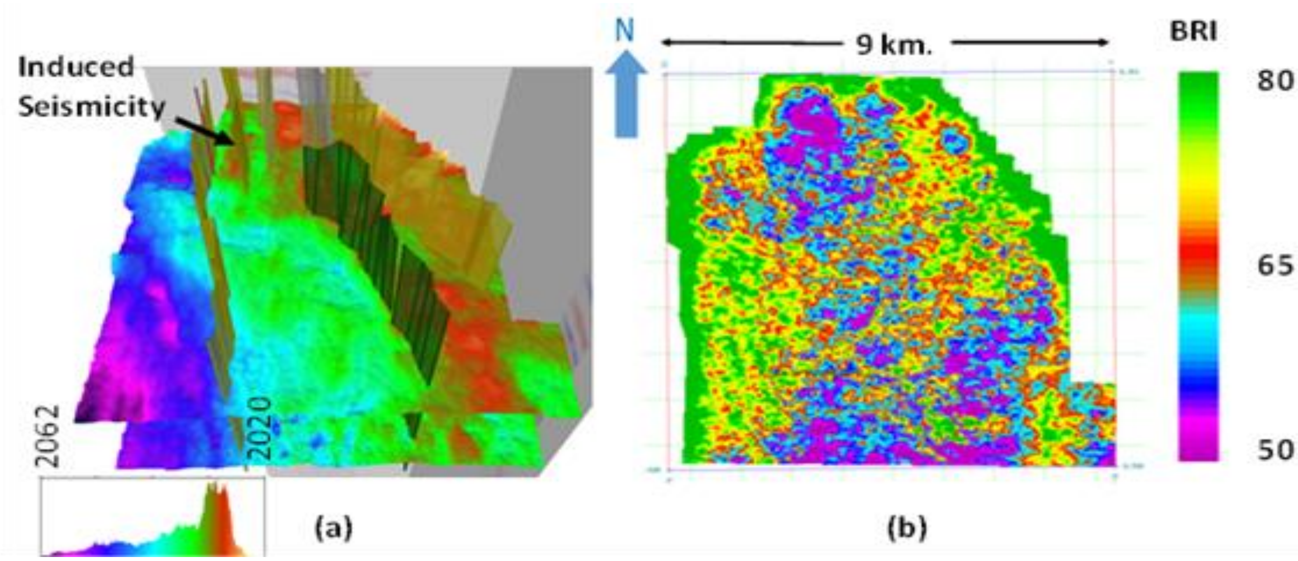

Figure 5. Perspective view showing interpreted basement-rooted, steeply dipping faults (a) as well as Gilwood and Precambrian horizons extracted from the PP data volume. b) Stratal slice showing brittleness index (BI, units percentage) calculated from Young's modulus (E) and Poisson's Ratio (PR) within the Duvernay interval. The interpreted north-south (N-S) faults are marked. The arrow in 17 (a) indicates where induced seismicity has occurred

Conclusions

The Duvernay play is prone to induced seismicity and is likely to exhibit considerable lithologic heterogeneity in the subsurface, at scales that are seismically resolvable. Consequently, we recommend that planning for drilling and hydraulic-fracturing well-completions programs should consider both reservoir facies and present-day fault structure. In this study, we have developed a new workflow for interpretive inversion of multicomponent 3D seismic data, guided by structural analysis. Our workflow requires AVO-compliant data processing and makes use of poststack inversion to obtain an acoustic-impedance volume, followed by correlation of horizons between PP and PS sections and prestack PP-PS AVO inversion. The output parameters from the inversion, consisting of V_P, V_S and ρ, are used to calculate data volumes containing Young's Modulus (E), Poisson's Ratio (PR) and brittleness index (BI) (e.g., Rickman et al., 2008). Various presentation formats for the inversion results, including perspective views and stratal slices, provide insights for geological interpretation of the data.

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