Quasi Seismic-Scale Modeling of the Montney Formation from Well Log Data: A Quick Look Technique for Assessing Reservoir Heterogeneity and Geomechanical Characteristics

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Summary

The extent to which resource plays are homogeneous or heterogeneous is often debated among Engineers, Geologists, and Geophysicists. To address this discussion, detailed geological characterization and reservoir modeling are typically performed, however, these can be inherently arduous and time-consuming tasks. The large number of wells being drilled in shale and tight plays present opportunities for exploring new ways to gain an insight on reservoir characteristics in these plays before committing time and capital to detailed studies. We present in this paper our exploration of well log data inversion into seismic-scale properties to gain a high-level insight into regional-scale heterogeneity and geomechanical characteristics of the Lower Triassic Montney Formation. The Montney interval is ~200 m thick and contiguous over our ~1,100 km^2 study area in west-central Alberta. (**Fig. 1**). Our inverted seismic results demonstrate that the Montney shows sub-regional to regional-scale variations in petrophysical and rock elastic/geomechanical properties in our study area, with local paleostructural controls. This finding is consistent with literature and our outcrop observations of meter to decameter-scale reservoir heterogeneity in the Montney-equivalent, Sulphur Mountain Formation in Alberta. Our methodology introduces a cost-effective, time-efficient technique to gain an initial reservoir insight, prior to performing a more detailed subsurface characterization for planning pad placement, selecting landing zones, and placing hydraulic fracture stages in the Montney Formation.

Fig. 1. Study area (red box). The limit of the Montney play (black outline) was modified from NEB (2013)

Method

We utilized the structural framework process in Petrel^{TM} to define a geometry and volume of interest for the well data inversion. We interpreted formation tops in 88 vertical wells and gridded the well tops to generate structure depth maps for Top of the Cretaceous Colorado Group (used for shallow horizon definition), Top of Montney, Top of Lower Montney, and Top of Belloy Formation. The volume of interest was defined between 0 and 3000 mTVDSS to enable quality control outside of the Montney interval and geometry definition (limits) was defined by the Top Montney Horizon. Using the bulk density (RHOB), compressional and shear velocity logs (derived from Sonic logs) from 4 vertical wells, we populated our volume of interest (Top Montney to Top Belloy interval) with RHOB, Vp, and Vs volumes using triangulation method and linear interpolation between wells. 7 wells initially used yielded similar results and some wells were removed for blind-testing. The RHOB, Vp, and Vs volumes were subsequently converted to seismic cubes using property operations in Petrel™. With RHOB, Vp, and Vs available as seismic volumes, we calculated elastic and rock mechanical properties using established relations between RHOB, Vp, Vs and rock mechanical properties (Smith, 2015; Vishkai et al., 2017). These properties were evaluated for general trends and compared with dynamic elastic properties computed from well logs. We also used 4 learning and 2 cross-validating wells as neural network inputs to generate a porosity (Phi) seismic cube from the RHOB seismic volume through genetic inversion, a neural network-assisted seismic inversion process. The Phi seismic cube was used as an input in genetic inversion to generate a permeability (K) cube.

Results and Discussion

The Phi and K inversion results volumes are shown in tracks 6 and 7 from the left in a cored blind test well (**Fig. 2)** and compared with core and log Phi-K (tracks 4 and 5). The seismic Phi-K had 0.67 and 0.87 correlation in blind test wells (respectively) and capture the general vertical and lateral property trends observed in wells in the study area. The higher correlation for K stems from a relatively higher correlation of Phi with K because the K log was derived using a relationship between slip and overburden stress-corrected core Phi-K derived from a well in our study area.

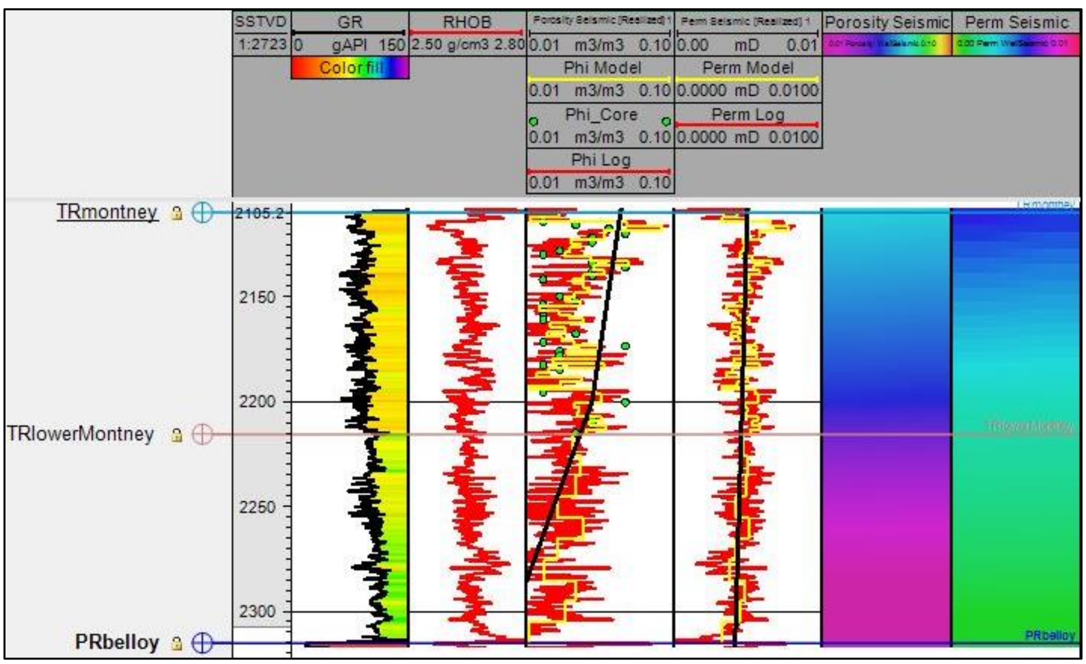

Fig. 2. Cored well inverted seismic Phi-K along with Phi-K from well log, core and 3D geomodel (included for context). The black curve in log tracks 4 and 5 from the left represent the Phi and K seismic displayed as a log along the well shown.

By overlaying the generated seismic Phi, K and rock elastic properties over the top structure maps for Top of Montney, Top of Lower Montney and Top of the Permo-Triassic unconformity (which is marked by the Top Belloy horizon), we observed NW-SE trends in attributes for all the maps, an early indicator of potential underlying geologic and geomechanical controls on where and in which orientation operators are choosing to drill producing wells in the study area (**Fig. 3A - 3K**).

A depocentre likely exists in the south-central portion of the study area (**Fig. 3F and 3G)**. This depocentre is flanked by contour deflections on the structure maps, interpreted to result from lineaments (see outlines in **Fig. 3A - 3K**) which are associated to Leduc reefs and reactivated Paleozoic faults around the Southern Peace River and Gold Creek paleohighs which are in the vicinity of our study area (Davies et al., 2018; Iwuoha et al., 2018; Zonneveld & Moslow, 2018). We utilized 3rd order paleostructure mapping to better highlight the limits of the south-central depocentre and other paleolows in the study area and demonstrate their control on reservoir and geomechanical heterogeneity. Lineament orientations were further investigated using seismic attributes analysis.

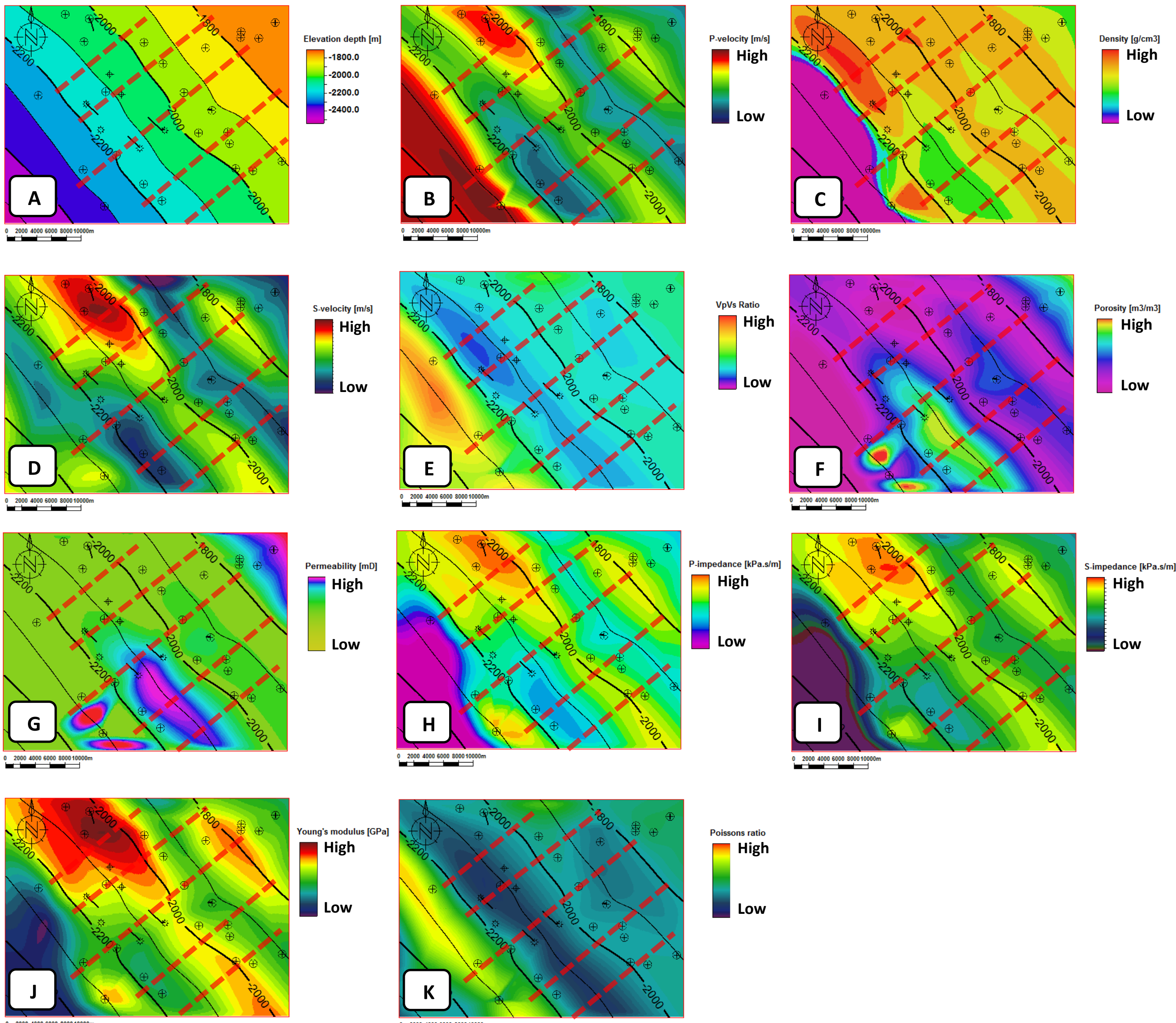

Fig. 3. Structure map of the top of Montney Formation (Fig. 3A). Fig. 3B - 3K show surface attributes of reservoir petrophysical and rock elastic properties from the quasi-seismic volumes. For Fig 3B – 3K, all the attributes were extracted at the top of the Montney horizon. The lineament outlines (red dashed lines) shown above are based solely on the contour deflections seen on the top of Montney structure map. Seismic structural attribute analysis was subsequently used to further evaluate the lineament trends in 3D.

Westward (basinward) of the south-central depocentre, two relatively higher Phi-K trends are observed which may be localized turbiditic or mass wasting events (prominent on **Fig. 3C, 3F, and 3G**). We note that the Upper Member overlying the Lower Montney interval in our study area corresponds to the Smithian-aged Middle Montney, within which turbidites and mass wasting deposits have been interpreted (Davies et al., 2018). Further, the orientation of these likely turbiditic/mass wasting events in our study area is consistent with predominantly NE-SW flow paths of paleostructurally controlled turbidites/mass wasting in the Montney Formation (Davies et al., 2018).

Significance and Novelty

In this paper, we extend the current practice of geological characterization of resource plays by utilizing a relatively simple and yet time-saving approach to gain an initial perspective of large-scale reservoir heterogeneity and geomechanical characteristics of the Montney Formation within our study area. A 3D geological grid is not required to perform this quick look assessment and the resulting time-savings would benefit operators of resource plays who wish to gain an initial opinion of their acreage prior to committing capital towards rigorous reservoir characterization, laboratory measurements, and detailed 3D geological modeling. Further, where seismic data is unavailable, this technique could be used as an option to invert well data and perform a "seismic-type" rock elastic assessment or modeling of reservoir and fluid properties using established theories. We recommend calibrating results against core and field data where and when available.

Acknowledgments

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