The complexity of micro- to centimeter-scale heterogeneities in geological and geomechanical properties in fine-grained deposits and how to quantify it

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Summary

Recent studies have illustrated that the geological and compositional characteristics of fine-grained deposits, often referred as shales or mudstone to be highly heterogeneous from the millimeter to kilometer scale (e.g., Plint 2014; Birgenheier et al. 2017; Illgen et al. 2017). These heterogeneities are controlled by (1) the processes that deposited the sediment thereby forming sedimentary fabrics, (2) the allogenic and authigenic composition that make up the fabric, and (3) post-depositional modification by bioturbation and diagenesis (e.g., differential cementation) that collectively influences the variability of elemental and geomechanical properties of mudstone deposits. However, studies have focused on the compositional and mechanical properties of mudstone deposits at the meter- to kilometer-scale despite deposits exhibiting heterogeneities down to the laminae. Therefore, the characterization of vertical and lateral sedimentary fabric and elemental variability at the millimeter- to centimeter-scale is needed to better understand how heterogeneities at this scale control the mechanical behavior of mudstone.

Eleven representative samples of three sedimentary fabrics of the Montney Formation in Northeastern British Columbia (massive siltstone, stratified (light- vs. dark-dominated) siltstone, and bioturbated siltstone) were examined using a 1 centimeter by 1 centimeter grid system (*cf.* Venieri et al. 2022) to determine vertical and lateral heterogeneities at a centimeter-scale. Handheld XRF machine was used for elemental composition and a HLD piccolo tool to document mechanical properties. Micro-scale analysis using an SEM was used to characterize microfacies and their respective microfabric makeup (matrix, cement, and framework grains) to better understand the elemental distribution across the sedimentary fabrics.

Based on centimeter gridding and micro-scale analysis, inter- and intra-sample compositional and mechanical heterogeneities exist in the Montney Formation. Sedimentary fabric with the highest centimeter-scale aluminum content from XRF comprises microfacies that are comparatively matrix-rich consist of mica and clay minerals (observed in SEM) and exhibit the lowest hardness values. On the other hand, sedimentary fabric with a higher elemental calcium component comprises microfacies that are matrix-poor, highly cemented by carbonate (calcite and dolomite) and quartz, and overall exhibit a positive trend with hardness measurement. Notably, intra sample heterogeneity is dependent of the scale at which the data was obtained. Handheld XRF machine obtained data at 8 mm radius and thereby averaged the bulk composition and included multiple microfacies, whereas hardness values were collected at 3 mm radius and represent hardness of an individual microfacies.

To relate the elemental and geomechanical proxies to controls on rock mechanics, a total of 75 calcite-filled natural fractures within the studied core intervals were characterized and subdivided based on their orientation: vertical to sub-vertical, bed parallel, and brecciated fractures. Each type of fracture was constrained to a specific sedimentary fabric and commonly bounded by a change in sedimentary fabric. Fractures in massive siltstone (F1) are preferentially horizontal and on one occasion sub-vertical. Whereas fractures in stratified siltstone (F2) are horizontal and bed bounded by the abrupt transition from dark- to light-dominated laminae and vice versa. On the other hand, fractures in bioturbated siltstone (F3) are vertical to sub-vertical. Both centimeter- and micro-scale analysis suggest that the facies and microfacies matrix composition, intergranular cement (carbonate), and overgrowth cement (dolomite and quartz) in addition to the degree of fabric interbedding plays a primary role on the variability in mechanical hardness and the geometry and termination of natural calcite-filled fractures along the cored intervals.

Collectively, these datasets provide insight into the influence that sedimentary fabric and the distribution of elemental composition have on mechanical properties and natural-filled fractures in fine-grained deposits of the Montney Formation, which can then be implemented within reservoir modelling of the unconventional play.

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