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Thermal maturity and geochemical compositional controls on geomechanical properties in Upper Devonian Duvernay Formation, Western Canada Sedimentary Basin

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Summary

Shale reservoirs, characterized by low matrix permeability, require effective geomechanical models to optimize drilling and hydraulic fracturing strategies. Previous studies suggest that geomechanical properties in shale reservoirs are controlled by the rock geochemical composition and subsequent diagenetic processes, such as mechanical compaction, carbonate and quartz cementation. The Upper Devonian Duvernay Formation, Western Canada Sedimentary Basin spans a wide range in rock compositions and thermal maturity and therefore provides an excellent opportunity to study how shale composition and thermal maturity control the geomechanical properties. Major element chemical analysis, X-ray diffraction analysis and LECO combustion were used to determine mineralogy, bulk rock chemistry and total organic carbon (TOC) content. Core hardness measurements and dipole sonic and density log data were used to characterize the geomechanical properties. Scanning electron microscopy (SEM) images with complementary energy-dispersive spectroscopy (EDS) maps were obtained for representative samples to document the rock fabric and distribution of organic matter and minerals.

Hardness and Al_2O_3 concentrations are strongly negatively correlated in all cores, regardless of thermal maturity, suggesting that clay mineral content is the most significant factor controlling geomechanical properties. The positive correlations between CaO content and hardness in all cores suggest that carbonate minerals contribute to brittle behavior.

TOC content is negatively correlated to hardness in immature samples but is uncorrelated to hardness in oil window and gas window samples. We propose that this is a result of (1) increased stiffness of organic matter; and (2) partial conversion of kerogen into expelled hydrocarbons that reduces the load-bearing function of the organic matter.

Quartz in the Duvernay Formation exists as detrital silt, authigenic overgrowths on the detrital silt grains, pore-filling cement in the intragranular pores (e.g. radiolarian and styliolinid chambers) and microcrystalline quartz distributed throughout the clay-size matrix. The positive correlation between calculated biogenic SiO_2 and authigenic quartz content from point-counted SEM-CL images indicates that dissolution and re-precipitation of biogenic silica from radiolaria and sponge spicules was the principal source for quartz cementation in the Duvernay Formation. Biogenic silica is positively correlated to hardness. Detrital silica is negatively correlated to hardness, an artifact of the positive correlation between detrital clay minerals and detrital quartz. We conclude that quartz cements sourced from biogenic silica rather than smectite-to-illite transition strongly contributed to the rock strength in the Duvernay Formation.

Increased thermal maturity from immature to oil window results in greater hardness for rocks of similar geochemical compositions, largely because of greater mechanical compaction for oil window samples. Beyond oil window, thermal maturity does not exert a major control on the rock strength, e.g. there are no significant changes in hardness between samples from oil window and dry gas window.