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Black shale or mud aggregate sandstone? Depositional processes of a world-class source rock

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Summary

Processes that control the deposition and preservation of organic-rich mudstones are still poorly understood despite their economic importance. Recent studies show that mud can be transported as aggregates by bedload processes under current velocities that would transport and deposit sand, and contain sedimentary structures characteristic of varying depositional processes. Thus, one should expect mudstones to have a similar degree of facies heterogeneity as their coarser-grained siliciclastic and carbonate counterparts. This study utilizes a world-class dataset in order to characterize the microfacies and lithofacies of the organic-rich Belle Fourche and Second White Specks formations. The most organic-rich lithofacies is the coarsest-grained of the succession as it is composed of cross-laminated medium sand-sized mud aggregates. Although compositions vary, depositional processes did not change throughout the study interval as indicated by mud aggregates, as well as evidence of wave- and current-reworking occur in every lithofacies.

Introduction

In the past decade, sedimentological studies of fine-grained successions have identified textures and bedforms characteristic of a wide-variety of depositional processes. This contradicts the traditional view that mudstone intervals were dominantly deposited by suspension settling under low-energy conditions (e.g. Potter et al., 1980). Laboratory experiments and studies of ancient deposits revealed that under traction currents that would transport and deposit sand, clay is flocculated and is transported as bedload (e.g. Macquaker and Keller, 2005; Schieber et al., 2007; Schieber and Southard, 2009; Macquaker et al, 2010; Plint et al., 2010; Schieber, 2011; Aplin and Macquaker, 2011). Recognizing these processes has important implications for hydrocarbon exploration, as it provides mechanisms for characterizing and predicting the heterogeneity of mudstones. The three-dimensional facies variability in fine-grained sedimentary rocks is not well documented in comparison to coarser-grained siliciclastic and carbonate successions.

This study characterizes the lithofacies and multiscale heterogeneity of the Late Cenomanian to Turonian Belle Fourche and Second White Specks formations. The Second White Specks Formation is a world-class source rock and unconventional play that spans thousands of square kilometres across the Western Canada Sedimentary Basin. Several vertical wells have each produced over 1 million barrels of oil from the study interval; however, there has not been repeatable success when targeting this interval. The unpredictable nature of the productivity demonstrates the importance for understanding the 3D heterogeneity of this organic-rich mudstone.

Geological Background

The interval of interest was deposited within the Canadian portion of the Cretaceous Western Interior Seaway. The mixing of cold, nutrient-rich Boreal seawaters with warm, southern Tethys seawaters resulted in increased organic productivity, especially in the form of calcareous coccoliths and foraminifera (Schröder-Adams et al., 1996) that are abundant within the Second White Specks Formation. The study area is located in the Deep Basin of west-central Alberta along the edge of the fold and thrust belt deformation front.

Method

Multiple wells targetting the Belle Fourche and Second White Specks formations have produced over a million barrels of oil each, making the study interval a prospective play in the Alberta Basin. Although this play is often dismissed as being unpredictable, it is being studied due to access to a diverse and high-quality dataset, as well as it being analogous to other organic-rich mudstone successions. Typically, sedimentological studies of fine-grained successions is limited to taking thin-sections from weathered outcrop or core in order to see detailed textures and composition; however, this study incorporates data from two, >100m long, continous cores in pristine condition where detailed sedimentology can be described from hand-sample. Thin section analysis, RockEval, X-ray Diffraction (XRD), X-ray Fluoresence (XRF), CT scan data, and outcrop descriptions are also incorporated in order to characterize the heterogeneity of these deposits both vertically, and laterally, at the milimetre to metre scale.

Conclusions

Described microfacies and lithofacies reveal that although there is a lithology change between the formations of interest, similar depositional processes acted upon the entire study interval. All facies contain sedimentary structures that indicate wave and/or current influence on the seafloor including: gutter casts, scours, HCS, wave ripples, lags, combined-flow and current ripples, starved-ripples, and sharp based graded beds. Silt- to medium sand-sized mud aggregates also occur in all facies. The most organic-rich facies appears as a homogenous ‘black shale’ in core and outcrop, but thin section analysis reveals it is composed of cross-bedded, medium sand-sized grains composed of mud aggregates indicating relatively high-energy deposition. Additionally, all facies contain varying degrees of bioturbation and benthic bivalve shell fragments indicating that long-lived bottom water anoxia was not a main control on the organic richness of this unit. Results from this study indicate that the heterogeneity of the system is due to the input of multiple sediment types from varying sources, rather than significant changes in depositional processes.

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