Mudstone Facies, Diagenesis, and Sequence Stratigraphic Interpretation for Caprock Integrity Assessment of the Upper Morrow Shale and Atokan Thirteen Finger Limestone, Farnsworth Unit, Texas

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ABSTRACT

We present a caprock integrity assessment of a combined EOR-C02 storage site, focusing on impacts of mudstone diagenesis on sealing capacity and potential seal bypass systems. The driving research is to understand how diagenetic changes may interact in a complex way with emergent large-scale properties on net sealing behavior. Diagenetic changes may act to improve capillary sealing mechanisms by reducing pore throat sizes while also altering stiffness and other properties that may lead to fracturing. We examine the upper Morrow shale and Atokan Thirteen Finger Limestone intervals that compose the primary caprock units at the Farnsworth Unit (FWU), Texas. The FWU is an active, mature waterflooded oilfield that is transitioning to C02 flooding for enhanced oil recovery (EOR). The Southwest Regional Partnership on Carbon Sequestration (SWP) is characterizing reservoir and caprocks and monitoring C02 storage at the site as part of a DOE-sponsored project on carbon capture and storage.

Over 780 ft of core from three new wells spanning the reservoir and caprock sections were characterized for sedimentary and fracture attributes, subdivided into lithofacies and interpreted in a sequence stratigraphic context. Sedimentary core descriptions were aided by petrographic, petrophysical, and geomechanical analyses. Lithologies include limestones and mudstones that overlie the uppermost Morrowan sand unit, referred to as the Morrow B, and mudstone that underlies the Morrow B. The Morrow B is the target unit for injection and production at FWU.

The upper Morrow shale is between 52-58ft thick and consists of three principal lithofacies. Lowermost is a friable, bioturbated fine sand-to-fine mudstone (Mfms), interpreted to have been deposited in an estuarine environment as part of a transgressive systems tract (TST). This is overlain by black, finely laminated, fine-to-medium mudstone (Mfrn) containing local calcite concretions and pyritized fossil fragments. This facies represents a transition from estuarine to marine deposition, contains a marine flooding surface (MFS) and the initiation of a falling stage systems tract (FST). The FST continues into the uppermost facies of the Morrow shale, a friable, splintery carbonaceous mudstone (Me). A 3 inch section within facies Me was well indurated with irregular upper and lower bounding surfaces is interpreted as a shallow marine hardground. This section contains abundant foraminifera, gastropods, ostracods, bryozoans, mollusks, and fish bones. The same sequence of strata comprising facies Me, including the hardground section, is present in all three characterization wells, despite a 3.5 mile separation. The top of facies Me is a sequence boundary and marks the top of the Morrowan sequence and the base of the Atokan series.

The Atokan interval of the cores is between 88 and 130ft thick and consists of two distinct lithofacies: a pyrite fossil and coal bearing, massive to laminated, fine to medium mudstone (Mfmc), and a carbonate cementstone (Cc). Coals within facies Mfmc represent the lowstand system tract (LST), and the transition to the TST. Black, finely laminated pyrite and fossil bearing mudstones were deposited under euxinic marine conditions within the TST. Bedding perpendicular fibrous veins often termed "beef" are found within facies Mfmc and have been linked to hydrocarbon expulsion during periods of overpressure. TOC measurements from this facies measured above 45%.

The Thirteen Finger Limestone interval contains 60-70 individual "limestone" beds, comprising 55% of the section. Petrographic analysis of these beds indicates that they are for the most part not primary depositional features, but rather are of diagenetic origin and more properly termed cement stones. They consist dominantly of 0.03-0.06 mm dolomite rhombs, with some dedolomite. Many have calcite-filled fractures. Cement stones are believed to form below marine flooding surfaces during periods of low net sedimentation that causes extended residence periods near the sediment-water interface. This facies within the Thirteen Finger interval suggest low net sediment accumulation, and the rhythmic facies transitions represent high frequency cycles associated with the late Pennsylvanian climate. The cemenstones can have extremely high capillary intrusion pressures (e.g., still no intrusion at 60,000 psig) and thus very high capillary sealing capacity. The cement stones also exhibit large differences in mechanical properties than the surrounding fissile mudstones.

The characterization cores recovered from the FWU provided insight into the depositional and diagenetic features of the upper Morrow shale and Thirteen Finger Limestone, which until recently have been overlooked, but are currently important units as caprock intervals for CCUS, and potential unconventional reservoirs.

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