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STATUS: Focused-term project in progress
TIMING: Year 2 of 2
FUNDING: KICC and ConocoPhillips Fellowship

Purpose
Deep-water carbonates continue to show economic value as conventional and unconventional hydrocarbon reservoirs. Many of these reservoirs are derived from sedimentary gravity flows that redistributed shelf and slope material. These accumulations are complex, heterogeneous deposits, which must be understood for effective exploration and development.

This project explores sedimentary gravity flow deposits within the Avalon Shale play (Upper Permian) of southeastern New Mexico and western Texas with the purpose of understanding what processes produced productive zones within this play. Using core, seismic, and petrophysical data, this project will investigate the Avalon Shale to understand the depositional processes and controls on deep-water gravity-flow deposits as well as the reservoir potential of accumulations from different flow types. This study will allow enhanced prediction of productive zones and the heterogeneity within these deposits. Ultimately improved knowledge of the distribution and heterogeneity within these systems will allow predictive tools and an analog for better exploration and characterization of hydrocarbon-bearing deep-water deposits elsewhere.

Project Description
Slope and basinal carbonates are complex, heterogeneous deposits that are poorly understood compared to both their shallow water and siliciclastic counterparts (Cook and Mullins, 1983; Playton et al., 2010). Playton and others (2010) provided an excellent summary of what is known about deep-water carbonates, noting that the variations and controlling factors in small-to-large scale architecture need further elucidation. Continued discovery of hydrocarbons within these units compels further evaluation of their depositional processes and controls, facilitating better understanding and prediction of the these systems.

This project examines deep-water sedimentary gravity flows (SGFs) in the Avalon Shale (Figure 1) to further understand their reservoir properties and their depositional and distributional controls. Hypotheses are aimed at answering several general questions:

1) *What influences SGF deposition (e.g. sea level, cyclicity, source of detritus)?*
2) *What controls the nature and occurrence of the SGFs?*
3) *Are these deposits suitable reservoirs and how does flow mechanism (see Mulder and Alexander, 2001) affect reservoir potential?*
Current exploration has targeted SGFs within the Avalon, providing new data from which to study these deposits and their reservoir potential. Previous research on other units in the Delaware Basin has identified numerous examples of SGF deposits (Silver and Todd, 1969; Harris and Wiggins, 1985; Hobson et al., 1985; Mazzullo and Reid, 1987; Saller et al., 1989; Leary and Feeley, 1991), which include thick debris flows, thin turbidites, and other grain-flow accumulations composed of shelf-derived debris. Deposition occurs in sheet-like deposits (Hobson et al., 1985), channelized deposits (Silver and Todd, 1969; Harris and Wiggins, 1985; Leary and Feeley, 1991), and complex channel-wedge systems (Mazzullo and Reid, 1987) that accumulated during both highstands (Silver and Todd, 1969; Saller et al., 1989) and lowstands (Leary and Feeley, 1991). Many of these units are productive reservoirs (i.e., Hobson, et al., 1985; Mazzullo and Reid, 1987; Saller et. al., 1989), with better permeability reported in turbidites (Cook and Mullins, 1983). Of the aforementioned reports, Harris and Wiggins (1985) reported diagenetic differences between shelf and basinal strata. Additionally, Mazzullo and Harris (1991) documented multiple diagenetic phases affecting Bone Spring deposits. The depositional and diagenetic features of the Avalon Shale are unknown, making it a poorly understood reservoir.

Methods and Deliverables

1. **Decipher the depositional processes of units within the Avalon Shale.** This aim involves core descriptions and combination with stratigraphic data from objective two. Available data include core from recent exploration and the Texas Bureau of Economic Geology (number and location of cores dependent on access and availability from industry partners). Core description at a bed-by-bed scale will document the thickness, continuity, and contact of bedding units, the size, composition, and distribution of grains, along with bedforms and sedimentary features (e.g. grading and sorting). Additionally, thin sections of SGF units will be analyzed to examine microscopic features in these deposits. These descriptions will allow interpretation for both the deposition of the Avalon Shale as well as the flow mechanism (classification by Mulder and Alexander (2001)) for SGF units. The core is expected to contain grainy beds of sorted-to-unsorted shelf-derived debris (SGFs) interbedded with organic-rich, lime mudstone. The vertical succession of deposits will be evaluated for cyclic deposition throughout Leonardian-Early Guadalupian time (Figure 2) associated with sea-level fluctuations.

2. **Determine the vertical and lateral stratigraphic architecture of the Avalon Shale.** This objective defines the stratigraphic framework for this project and allows subdivision and description of the play. Where available, core data (Objective 1) will be compared to geophysical log data to calibrate log signatures with subsurface lithology. Geophysical logs and borehole data will be correlated to develop a stratigraphic model to evaluate for thin, widespread debris aprons and thick channelized SGFs are expected to occur in the Avalon Shale.

3. **Determine spatial relationships between SGFs and the location of faults and paleotopographic features.** To explore if paleotopography and faulting acted as a control on SGF deposition (i.e. location, orientation, thickness, flow mechanism), fault locations and paleotopographic data will be extrapolated from seismic profiles (availability, location and resolution of seismic is dependent on access and availability from industry partners). Structure maps constructed from well log data will also be integrated with seismic to identify paleotopographic features and faults. Abrupt structural changes (linear
trends of closely spaced contours) are indicative of faulting (Groshong, 2008). These
trends do not pin point a fault’s exact location but serve as guides for identifying the
geometry and region of a fault or faulted zone. The location and orientation of structural
and paleotopographic features will be compared to the location, orientation, thickness and
inferred flow mechanism of SGFs, as these features may affect deposition in a variety of
ways. Tectonic features or paleo-highs may source density flows. Changes in gradient
due to fault scarps or topographic changes may induce deposition or increase flow
velocity, potentially changing flow mechanism. Alternatively, these same features may
deflect flow, causing flow direction to change, or focus flow, preventing deposition over
a wide area. Focusing flow can potentially alter line source derived flows up-dip on the
slope to point source derived flows down-dip.

4. Compare petrophysical features across varying types of SGFs to determine if flow
mechanism is the primary control on reservoir quality. Porosity and permeability data
from SGFs throughout the three recently acquired cores will be compared to evaluate
their reservoir properties. Differences are expected from varying sedimentologic
properties across flow types along with varying degrees of diagenetic alteration (e.g.
Mazzulo and Harris, 1991; Flügel, 2004) such as compaction, cementation, and
dissolution.

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Figure 1. Stratigraphic chart of basinal Permian strata in the Delaware Basin. The Avalon Shale play of the Delaware Basin lies within the 1st Bone Spring Carbonate (top) of the Bone Spring Formation (Figure 1) (Hardie, 2011; Worrall and Krankawsky, 2011), which has been correlated across the Delaware Basin and Northwestern Shelf (Figure 2) (Mazzullo (1987), Kerans et al. (1994), and Montgomery (1997)). The Avalon Shale was deposited adjacent to a high-energy shelf (Mazzullo, 1987) in Late Leonardian to Early Guadalupian time (Kerans et al., 1994) and ranges from 275-520 meters (900-1700 feet) thick (Hardie, 2011; USDOE, 2011).
**Figure 2.** Correlation chart of the Permian Bone Spring Formation and bounding strata within the Delaware Basin and Northwestern Shelf. Dashed lines show approximate locations of boundaries. Modified from Saller et al. (1989), Kerans et al. (1994), and Hayes (1964).