Depositional Controls on Distribution and Reservoir Character of Deep-Water Deposits in the Permian Wolfcamp, Bone Spring, and Wolfbone Plays of the Delaware Basin

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SUBSURFACE APPLICATION: The proposed intervals of study form reservoir systems in the study area. Lessons learned can be applied to other similar deep-water systems

STATUS: Ongoing research; One project complete and reported to sponsors

TIMING: 2-4 years upon funding

FUNDING: Seeking funding

Purpose
Deep-water carbonates continue to show economic value as conventional and unconventional hydrocarbon reservoirs. Many of these reservoirs are derived from sediment 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 sediment gravity flow stratigraphy, sedimentology, and reservoir quality within the Permian Wolfcamp, Bone Spring, and Wolfbone (co-mingled 3rd Bone Spring Sand and Wolfcamp) plays in the Delaware basin of western Texas and New Mexico (Figures 1, 2) with the purpose of understanding what processes produce productive zones and areas within the plays. Using core, seismic, and petrophysical data, this project will investigate depositional processes in deep-water gravity-flow deposits as well as the reservoir potential in different settings. 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 provide predictive tools 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 both conventional and unconventional deepwater carbonate reservoirs compels further evaluation of depositional processes and controls, facilitating better understanding and prediction of reservoir properties.

This proposed project is a continuation of our research on Permian basin unconventional plays. An initial study focused on the Avalon Shale (Stolz, 2014). Results of that study are currently available to consortium sponsors and indicate:
1) Sediment gravity flow deposits dominate the carbonates in the Avalon. Grainy, carbonate-rich deposits form poor reservoir, whereas muddy, less carbonate-rich deposits form better unconventional reservoir (e.g. Figure 3).
2) Depositional trends changed throughout Avalon deposition as source direction and deposit types repeatedly changed. Carbonate-rich geobodies have been mapped and there are two phases of fan development, which occurred during regressions and lowstands that are separated by a phase of apron development, which occurred during transgression and highstand.
3) The thickest mudstones, deposited during transgressions and highstands, occur on the margins of fan lobes; these mudstones should be the focus of drilling (Figure 4). The most prospective areas have been mapped.

Similar to the Avalon Shale, Wolfcamp, Bone Spring and Wolfbone deep-water facies consist of organic-rich carbonate and siliciclastic deposits, much of which was transported into the basin. This proposed project will examine deep-water sediment gravity flows (SGFs) to further understand their reservoir properties and their depositional and distributional controls. Hypotheses are aimed at answering several general questions:

1) What influences source, dispersal, and geobody configuration of SGF deposition (e.g. sea level, cyclicity, source of detritus)?
2) What controls the porosity and occurrence of the SGFs?
3) Are these deposits suitable reservoirs and how does geobody type and distribution affect reservoir potential?
4) Which rock properties lead to better reservoir?
5) How can controls on depositional system and rock properties lead to prediction of the best economics in each play?

Previous research projects on deep water deposits in the Delaware Basin have 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. These include both conventional and unconventional reservoirs. Deposition occurs in sheet-like deposits (Hobson et al., 1985), channelized deposits (Silver and Todd, 1969; Harris and Wiggins, 1985; Loucks et al., 1985; Mazzullo and Reid, 1987, 1989; 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 stratigraphic units are productive conventional reservoirs (i.e., Hobson, et al., 1985; Mazzullo and Reid, 1987; Saller et. al., 1989; Cook and Mullins, 1983) whereas other similar deposits are unconventional reservoirs or poor reservoirs. Despite the previous studies, depositional details of the Wolfcamp, Bone Spring and Wolfbone are lacking and warrant further study, especially considering that carbonate content in the Avalon shale is negatively correlated with the improved reservoir properties (Stolz, 2014).

Methods and Deliverables
1. **Determine rock properties and establish correlations to reservoir quality.** This goal involves measurement of TOC, porosity, permeability, mineralogy, and physical properties to evaluate fundamental controls on reservoir quality (e.g., Figure 3). Data will depend on partnership with sponsors and access to core data.

2. **Decipher the depositional processes of units within the Wolfcamp, Bone Spring or Wolfbone.** This goal involves core descriptions combined with stratigraphic data from objective three (below). The number and location of cores are dependent on access and availability from industry partners. Core description at a bed-by-bed scale will document the thickness, continuity, and contacts of units, the size, composition, and distribution of grains, along with sedimentary structures. Additionally, thin sections of SGF units will be analyzed to examine textures and origin of grains. The core is expected to contain grainy beds of sorted-to-unsorted shelf- or slope-derived debris (SGFs) interbedded with organic-rich, mudstone. The deposits will be evaluated for cyclic deposition throughout the succession associated with sea-level fluctuations or other controls.

3. **Determine the vertical and lateral stratigraphic architecture.** This objective defines the stratigraphic framework for this project and allows subdivision and description of the play. Where available, core data will be compared to geophysical log data to calibrate log signatures with subsurface lithology.

4. **Provide maps and geobody model for sweet spots in each play.** Geophysical logs and borehole data will be correlated to develop a stratigraphic model to map geobody type and distribution. The rock property data will be used to map the best economics in each play.

**References**


MAZZULLO, S.J., AND REID, A.M., 1989, Lower Permian platform and basin depositional systems, northern Midland basin, Texas, in P. D. Crevello, J. L. Wilson, J. F. Sarg, and
J. F. Read, eds., Controls on carbonate platform and basin development: SEPM Special Publication 44, p. 305–319.


### Wolfbone Play in the Delaware Basin (West Texas) Stratigraphic Column

**Horizontal Targets**

- **Avalon Shale**
  - Depth: 7,900′ – 8,300′ (Oil Window)
  - Density Porosity: 12-14%
  - Thickness: 300-500 ft.
  - Normal Pressure (0.45 psif/ft)
  - Total Organic Carbon (TOC) 5-8%
  - XRD: 15-20% clay and 40-60% silica
  - IP: 100-270 Bbl/day 200-1,200 Mcf/day

- **1st and 3rd Bone Spring**
  - Density Porosity: 10%
  - Thickness: 100 ft.
  - Normal Pressure (0.45 psif/ft)
  - IP: 10-600 Bbl/day 500-2,500 Mcf/day

- **Upper Wolfcamp**
  - Depth: 10,500′ – 10,600′ (Oil Window)
  - Density Porosity: 10%
  - Thickness: 280-350 ft.
  - Geopressure (0.7psif/ft)
  - IP: 121-900 Bbl/day 250-3,300 Mcf/day

- **Middle Wolfcamp**
  - Depth: 11,500′ – 12,000′
  - Density Porosity: 12-15%
  - Thickness: 200-300 ft.
  - Geopressure (0.7psif/ft)
  - Total Organic Carbon (TOC) 2-4%

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**Figure 1.** Stratigraphic chart highlighting Bone Spring and Wolfcamp reservoirs in the Delaware Basin.
Figure 2. Map showing trends of stratigraphic zones in the Delaware and Midland basins.

Figure 3. Plot showing porosity in relation to carbonate content in the Avalon Shale. Porosity is shown to increase with decreased carbonate, illustrating the poorer reservoir properties of carbonate-rich strata.
Figure 4. Block diagrams showing the development of “sweet spots” in the Avalon Shale. A) shows toe-of-slope area decreasing in gradient out into basinal areas with no deposition. B) shows the development of large submarine fans (blue), sourced from the Northwestern Shelf, in toe-of-slope and basinal areas. C) Fan deposition has ceased and relief has been created that limits the lateral extent of SGFs sourced from other areas. Thus subsequent SGFs from other source areas are deposited on the margins and slopes of submarine fans lobes. This results in carbonate deposits from other source areas (orange) to be deposited on the lobe margins with better reservoir quality mudstones (brown) from distal SGFs deposited in slightly up-dip locations where flow is more restricted. Once the relief is filled carbonate SGFs can be deposited over areas previously restricted by fan lobe.