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# INTEGRATED OUTCROP AND SUBSURFACE STUDIES OF THE INTERWELL ENVIRONMENT OF CARBONATE RESERVOIRS: CLEAR FORK (LEONARADIAN AGE) RESERVOIRS, WEST TEXAS AND NEW MEXICO

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# Integrated Outcrop and Subsurface Studies of the Interwell Environment of Carbonate Reservoirs: Clear Fork (Leonaradian Age) Reservoirs, West Texas and New Mexico

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**SEMIANNUAL TECHNICAL PROGRESS REPORT**

for

# INTEGRATED OUTCROP AND SUBSURFACE STUDIES OF THE INTERWELL ENVIRONMENT OF CARBONATE RESERVOIRS: CLEAR FORK (LEONARADIAN AGE) RESERVOIRS, WEST TEXAS AND NEW MEXICO

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## Abstract

Outcrop studies include stratigraphic and petrophysical analysis. Analysis of the detailed sequence- and cycle-scale architecture of the Clear Fork reservoir-equivalent outcrops in Apache Canyon is nearly complete. This work reveals two high-frequency transgressive-regressive sequences (HFS) in the lower Clear Fork composite depositional sequence and three HFS in the basal middle Clear Fork composite depositional sequence. A 1,800-ft transect of 1-inch-diameter samples was collected from one cycle at the Apache Canyon outcrop. The transect was sampled with 5-ft spacing, but there were some gaps due to cover and cliff, resulting in 181 samples. Permeability, porosity, and grain density were measured, and the spatial statistics are being analyzed geostatistically.

Preliminary results of the fracture analysis on cores from the South Wasson Clear Fork field are encouraging. Petrographic evidence is consistent with the formation of many of the fractures visible in core at about the same time as dolomitization, making dolomite a synkinematic cement. A further finding of the core studies to date is that anhydrite postdates fracture opening and is therefore a postkinematic cement. A wide spectrum of macrofracture sizes is present within the core, and microfractures have been observed. Measurements are in progress to quantify the nature of the fracture size distribution.

## Results and Discussion

We have completed the first 6 months of study and are reporting significant progress. This report is concentrated on work done within Task 1, Outcrop Analog Tasks, and Task 2, Subsurface Applications Tasks.

### Task 1a. Construct Model of Outcrop Stratigraphic Framework

Analysis of the detailed sequence- and cycle-scale architecture of the Clear Fork reservoir-equivalent outcrops in Apache Canyon is nearly complete (fig. 1). This work reveals two high-frequency transgressive-regressive sequences (HFS) in the lower Clear Fork composite depositional sequence (L2) and three HFS in the basal middle Clear Fork composite depositional sequence (L3). High-frequency sequences in L2 document progressive transgression and deepening up to the base of the Tubb, which represents a major sea-level fall. Tubb siltstones document shallow-water clastic-rich deposition associated with renewed flooding of the platform following exposure. Overlying middle Clear Fork HFS (L3) demonstrate punctuated but continued transgression and deepening to the top of the outcrop succession. These HFS, which average 50 to 100 ft in thickness, define accommodation trends during Leonardian deposition that can be used to interpret and correlate subsurface reservoir successions.

Cycle-scale studies reveal 5- to 10-ft-thick high-frequency cycles that are continuous for more than 3,000 ft in the transgressive bases of HFS. By contrast, cycles in the upper parts of HFS appear much less continuous. These data on facies dimensions offer important guidelines for constructing subsurface models.

### Task 1b. Construct Model of Fine-Scale Petrophysical Heterogeneity

A 1,800-ft transect of 1-inch-diameter samples was collected from cycle 66 at the Apache Canyon outcrop to complement the 2,700-ft transect previously collected from cycle 62 (Jennings and others, 1998). The transect was sampled with 5-ft spacing, but there were some gaps due to cover and cliff, resulting in 181 samples. These were cut into 455 plugs, of which 113 had visible fractures or vugs. Permeability, porosity, and grain density were measured on the remaining 342 plugs by a service company. The resulting permeability transect is shown in figure 2.

The transect exhibits a high degree of variability with weak spatial correlation, similar to that observed in other carbonate outcrop permeability transects in the RCRL data base (Jennings, 1999). The total variability is similar to that observed in the Apache Canyon cycle 62 transect, and most of the variance is associated with a nearly random spatial pattern whose correlation range is less than 5 ft. However, a significantly reduced variance for the 1-inch separation distance, estimated from multiple 1-inch-long plugs cut from many sample locations, demonstrates that the variability is not simply random measurement error; some correlation structure must exist between the 1-inch and 5-ft scales.

A distinct 180-ft oscillation observed in the cycle 62 transect is not readily apparent in cycle 66. However, additional statistical investigations are planned to determine the likelihood of failing to detect a hypothetical 180-ft oscillation with the more limited and irregularly arranged cycle 66 sample transect.

## Task 1c. Construct Model of Fracture Porosity and Permeability

Plan-view patterns of fractures in Clear Fork outcrops have been identified on air photographs, and the stratigraphic context of outcrop fractures has been thoroughly documented. Field sampling of the outcrop reservoir analog for fracture and microfracture analysis will be undertaken within the next month.

## Task 2a. Select Subsurface Study Area

This task has been completed with the selection of the South Wasson Clear Fork field as the primary subsurface study area. Comparison of core and outcrop descriptions suggests a similarity in sequence stratigraphic setting, platform position, and facies tracts. The quality of reservoir data is excellent, and a 3-D seismic data set is available. Altura Petroleum Company, the operator for this field, has been very cooperative in the past and is planning to use the results of our characterization study in the construction of a reservoir model. The production history does not suggest a major fracture component to well performance. However, there are small open fractures in the cores, which may contribute to the performance of this reservoir.

Task 2b. Gather Subsurface Data

Microfracture analysis and study of relations between microfractures and macrofractures has focused on the core collection from the reservoir interval of the South Wasson Clear Fork field. Macroscopic fractures in one long core have been described in detail, including systematic documentation of fracture shapes and internal structure. The distribution and attributes of fractures with respect to sedimentary facies are being documented. Extensive sampling has been carried out to assess the mineralogy and structure within large fractures and to document the attributes of associated microfractures.

Preliminary results of the core analysis are encouraging. Petrographic evidence is consistent with the formation of many of the fractures visible in core at about the same time as dolomitization, making dolomite a synkinematic cement in the terminology of Laubach and Milliken (1996). These fractures are lined by dolomite but at the end of dolomitization retain significant fracture porosity, even at small fracture apertures (less than 1 mm). A wide spectrum of macrofracture sizes is present within the core, and microfractures have been observed. Measurements are in progress to quantify the nature of the fracture size distribution. Together, these observations are consistent with a model of syndiagenetic regional fracture formation that produces both small and large open fractures. Such a pattern is necessary for the success of an analysis method based on systematic analysis of microfractures and diagenesis patterns. This result also supports the possibility that the outcrops of the Clear Fork can be used effectively as guides to subsurface fracture patterns because the core fractures have distinctive shape and size patterns that can be sought in outcrop samples.

A further finding of the core studies to date is that anhydrite (and possibly ferroan dolomite) postdate fracture opening and are therefore postkinematic cements. Anhydrite that lacks crack-seal structure or other evidence of precipitation during fracture opening is found filling or partly filling fractures. Because anhydrite is a common but highly variably distributed cement in the Clear Fork, its distribution in the rock pore space could be a direct indicator of the degree to which natural fractures have been occluded, thus providing an indication of natural fracture quality in areas where macrofractures have not been sampled. Owing to the complex dolomitization and anhydrite precipitation/reprecipitation history these rocks have undergone, this interpretation needs further testing and refinement.

Preliminary core studies also suggest that natural regional fracture networks most likely had low mechanical connectivity shortly after formation. Subsequent diagenetic effects will mostly further reduce connectivity. Reservoirs having such patterns are unlikely to have production responses that closely resemble fractured reservoir models that postulate infinite (perfectly connected) fracture arrays.

## Conclusions

1) The project is progressing at an acceptable pace, and no problems have been encountered.

2) The outcrop stratigraphy is nearly completed. The next activity is defining and collecting geometric data on rock-fabric facies.

3) Detailed petrophysical data have been collected and remain to be analyzed.

4) Initial data from fracture descriptions suggest that we will be able to evaluate the impact of fractures on production performance in the South Wasson Clear Fork field.

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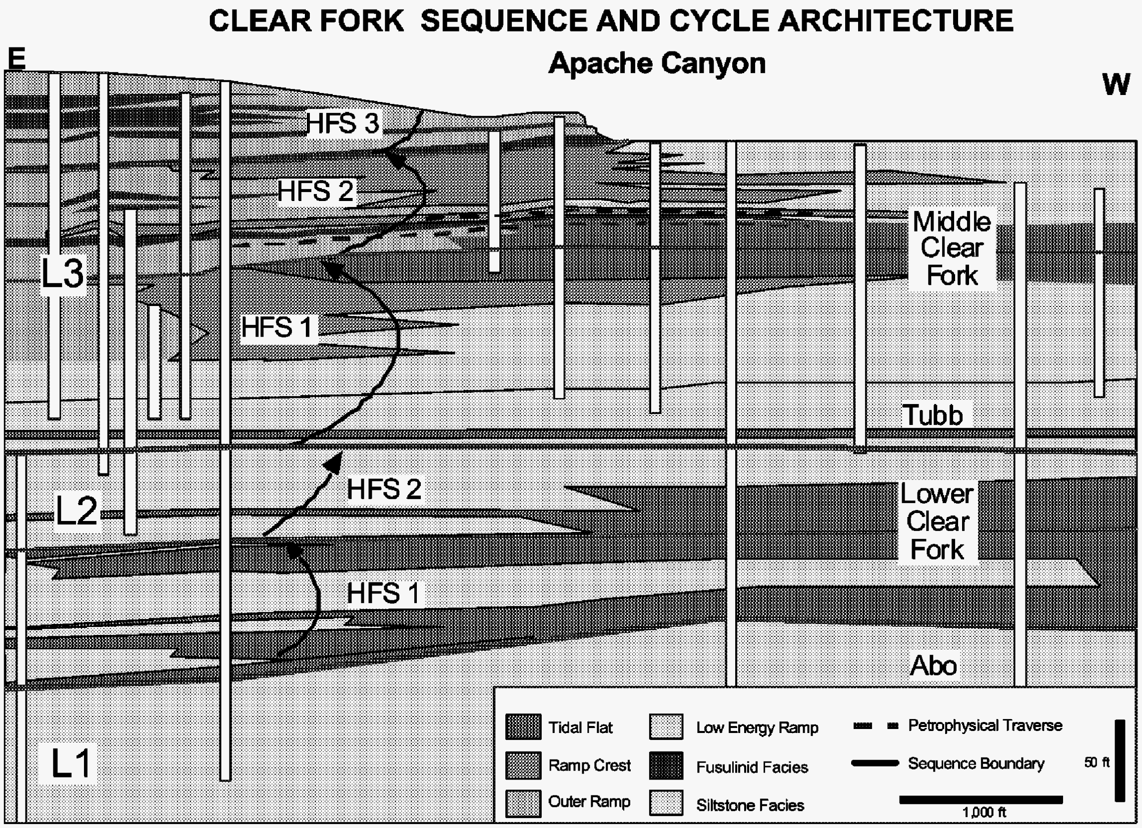


Figure 1. Clear Fork sequence stratigraphic framework, Apache Canyon, Sierra Diablo Mountains, West Texas. One composite sequence and two high-frequency sequences are present in the lower Clear Fork, and one composite sequence and three high-frequency sequences make up the middle Clear Fork exposures. The location of two horizontal petrophysical traverses is show. The upper traverse is described in this report.

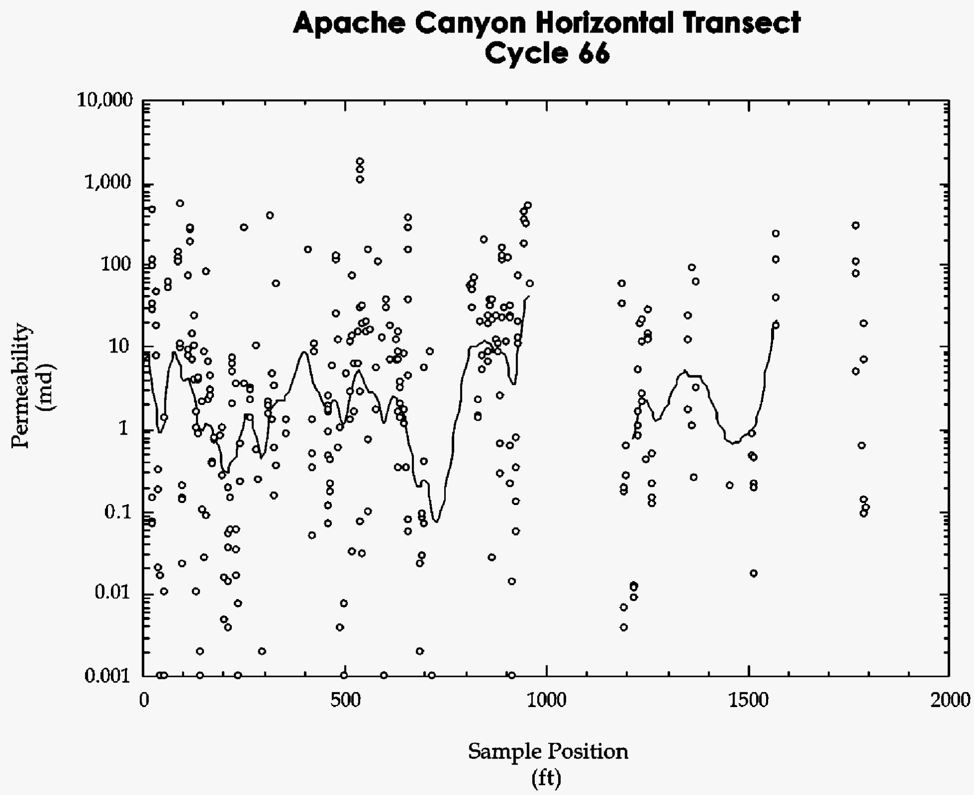


Figure 2. Illustration showing the core-plug measurements (points) and points smoothed into a curve with a tapered digital filter to highlight longer range features (Jennings and others, 1998).