

Characterization of Mass Transport Deposit Using Seismic Attributes: Upper Leonard Formation, Midland Basin, West Texas

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Summary

The Leonardian Series of the structurally complex Permian basin had shelf to open marine depositional environment with many sedimentary features. Previous studies show the sediments were deposited as a large basin-floor submarine fan system and are commonly interpreted as deposits of turbidity currents. A different mechanism was observed on 3D seismic that is representative of a mass transport deposit. We interpreted the source of sediments coming in from the North and prograding into the basin. The feature mapped in the study area is 5 miles wide and extends 14 miles basinward. Seismic attributes such as a coherence and structural curvature are used to map the discontinuous mass transport deposit along with the lateral extent of the feature.

Introduction

In the early Pennsylvanian, uplift of the matador arch as well as aeolian processes provided the source of sediments for the Spraberry (Henry, 1988). During the Leonardian Series (280 Ma years ago), these sediments were deposited from the North into the Midland Basin. Previous studies, using well logs and core analysis, show the sediments were deposited as a large basin-floor submarine fan system which are commonly interpreted as deposits of turbidity currents and debris flow (Handford, 1981).

Mass transport deposits (MTDs) are characterized as remobilization of sediments as a result of slope failure. The sediments are transported downslope by gravitational processes leading to partial internal deformation of sediments as opposed to turbidite flows. Slope failure can either be caused by loose soil composition, steepness of slope or tectonic movement. Slope failures can also have an impact on hydrocarbon production as they

trigger seal integrity and lead to vertical migration of hydrocarbons (Haflidason et al., 2002).

MTDs have the potential to alter original lithological composition of reservoir intervals thereby affecting porosity and permeability of sediments (Martinez, 2010). Spraberry rocks (siltstones and fine grained sandstones) have porosities averaging 8-10% and permeabilities of less than 1 mD (Elkins and Skov, 1963).

In this paper, we characterize the mass transport deposit observed within the Upper Leonard formation and understand its internal architecture with the help of coherence and structural curvature attribute. Such attributes are a great tool in understanding the extent of the discontinuous MTD and the direction of sediment influx by studying the chaotic seismic reflectors.

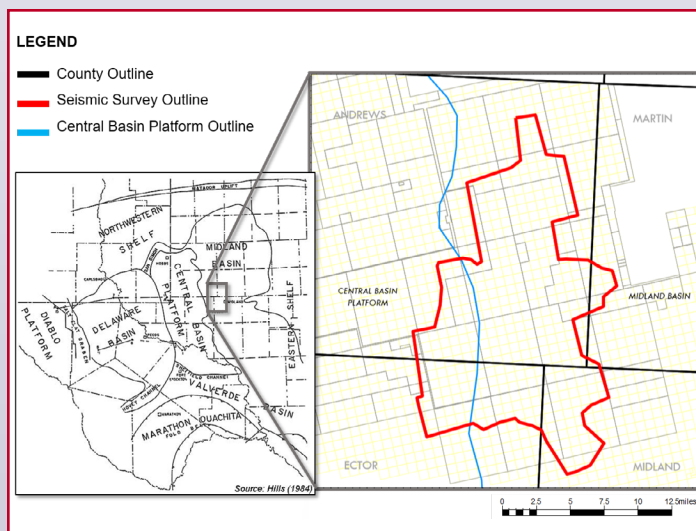


Figure 1. Paleogeography of Permian Basin region in Early Permian (modified after Hills, 1983). Right: Location of the study area. County sections and blocks are represented by yellow and grey respectively.

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Geology of the Study Area

The Permian Basin is a structurally complex sedimentary basin that began forming as many as 1.3 billion years ago as tectonic shift started molding the basin as we know of it today. Throughout its history of structural deformation, the Permian Basin was divided into 2 main basins: the Delaware Basin and the Midland Basin along with the Central Basin Platform as an uplifted basement block. Our study area spans across Andrews, Ector, Midland and Martin counties in the Midland Basin (Figure 1). The study area is within the Spraberry trend which is currently being studied by the Bureau of Economic Geologist (BEG) and accounts for one of the largest plays in the world both conventionally and unconventionally. The Upper Leonard is considered to be equivalent to the Glorieta on the platform (Handford, 1981; Figure 2).

| STRATIGRAPHIC CHART | | | |
|---------------------|-------------|------------------------|---------------|
| System | Series | Central Basin Platform | Midland Basin |
| PERMIAN | OCHOA | DEWEY LAKE | DEWEY LAKE |
| | | RUSTLER | RUSTLER |
| | | SALADO | SALADO |
| | GUADALUPIAN | TANSILL | TANSILL |
| | | YATES | YATES |
| | | 7 RIVERS | 7 RIVERS |
| | | QUEEN | QUEEN |
| | | GRAYBURG | GRAYBURG |
| | | SAN ANDRES | SAN ANDRES |
| | LEONARDIAN | GLORIETA | U. LEONARD |
| | | U. CLEARFORK | U. SPRABERRY |
| | | TUBB | L. SPRABERRY |
| | | L. CLEARFORK | DEAN |
| | WOLFCAMP | WOLFCAMP | WOLFCAMP |

Figure 2. A simplified stratigraphic chart correlating shelf to basin facies (modified from Handford, 1981).

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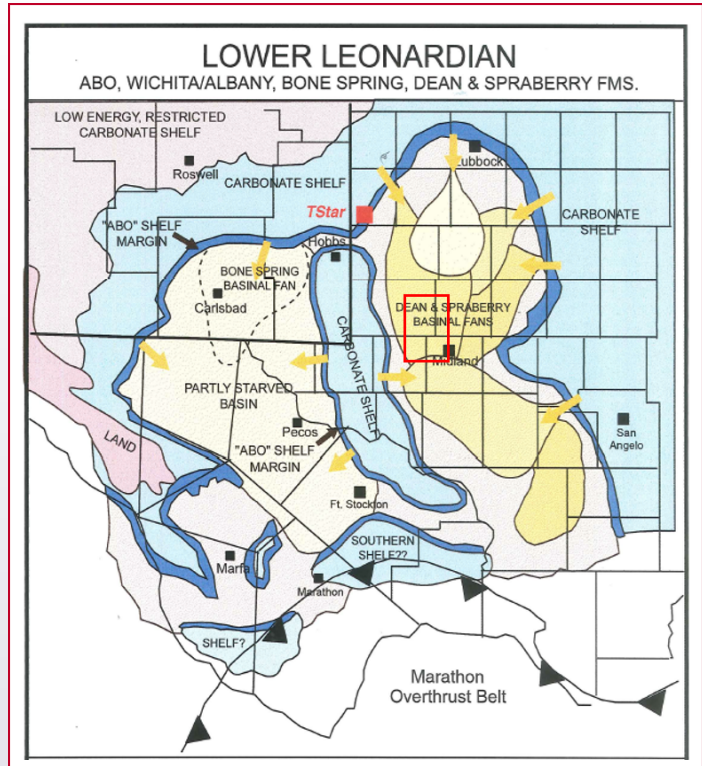


Figure 3. The influx of sediments coming from North and the Central Basin Platform during Spraberry time. Red box is the study area (Gibbs, 1996).

During the time of deposition (Upper Leonardian), the sediments are believed to be coming in from the North and pro-grading into the Midland basin (Figure 3). The Spraberry can be delineated by three sand bodies in the upper Spraberry and four in the lower Spraberry. The upper and lower Spraberry sands can be separated by 250 feet of limestone. This cyclic repetition of terrigenous clastics and carbonates and shales identifies primarily carbonate or clasticly dominated shelf. Central Basin Platform also contributed to the sediment influx from the west, although this was relatively flat and consistent. Figure 4 illustrates a cross sections running W-E showing the distribution of sediments during Spraberry time. Figure 5 shows a regional N-S cross section indicating sediment influx from the northern slope and the distribution of different lithologies.

Stratigraphy

The midland basin is characteristic of shallow marine shelf to shelf margin carbonates but shelf

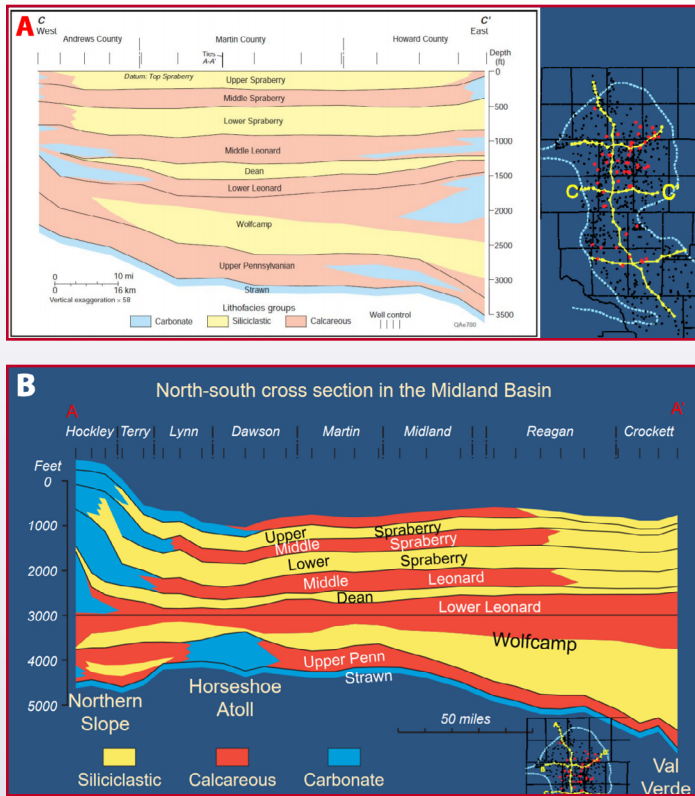


Figure 4. (a) Map showing Regional W-E cross section CC' showing Lower Permian stratigraphy and lithology in central part of Midland Basin. (b) Regional N-S cross section AA' showing sediment influx from the northern slope and lithology distribution (Hamlin, 2013).

to basin correlation is difficult because of abrupt changes in facies type, high relief topography, and inadequate well control. The Spraberry is considered to be equivalent to the Glorieta and/or Upper Clearfork on the platform (Handford, 1981; Figure 2).

The Spraberry formation strata consist of interbedded organic rich shales, and low-permeability, naturally fractured siltstone and sandstones. The Spraberry silty sandstone can be characterized by containing quartz (35-65%) with minor feldspars (10-15%) and clays (10-13%). These individual sandstone beds can be 3 inches to 9 feet thick. The lower sections of the sandstone beds contain fluid escape structures and become more laminated going up section (Murphy 2015). The sandstone beds are well cemented by either calcite, dolomite, or quartz. Within the terrigenous clastics, two primary vertical sequences can be

identified. First is discrete fining-upward interval characterized by turbidity flow. Second is a coarsening upward sequence (Fisher 1988). Most sedimentologic evidence suggest that these terrigenous clastics were deposited by density current deposits as opposed to turbidity currents.

Seismic attribute analysis

Seismic and Well log data

The mega merge 3D survey consists of more than five different 3D surveys acquired over last two

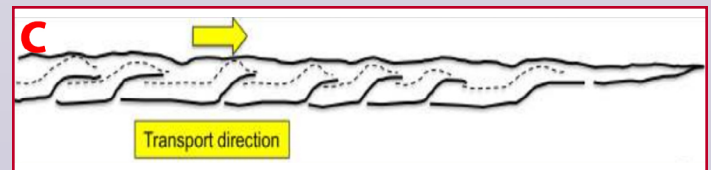
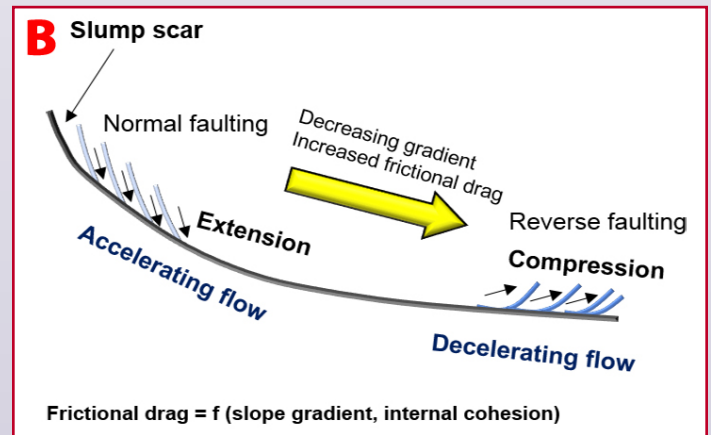
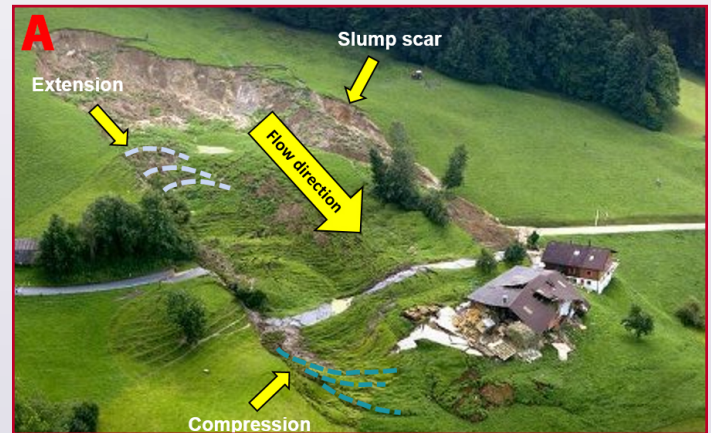


Figure 5. a) A small mass transport deposit observed in Bernese Oberland region, Switzerland; b) Compression and extension associated with mass transport deposit; c) Cross section showing sediment deformation within the complex MTD. Modified after Posamentier (2017).

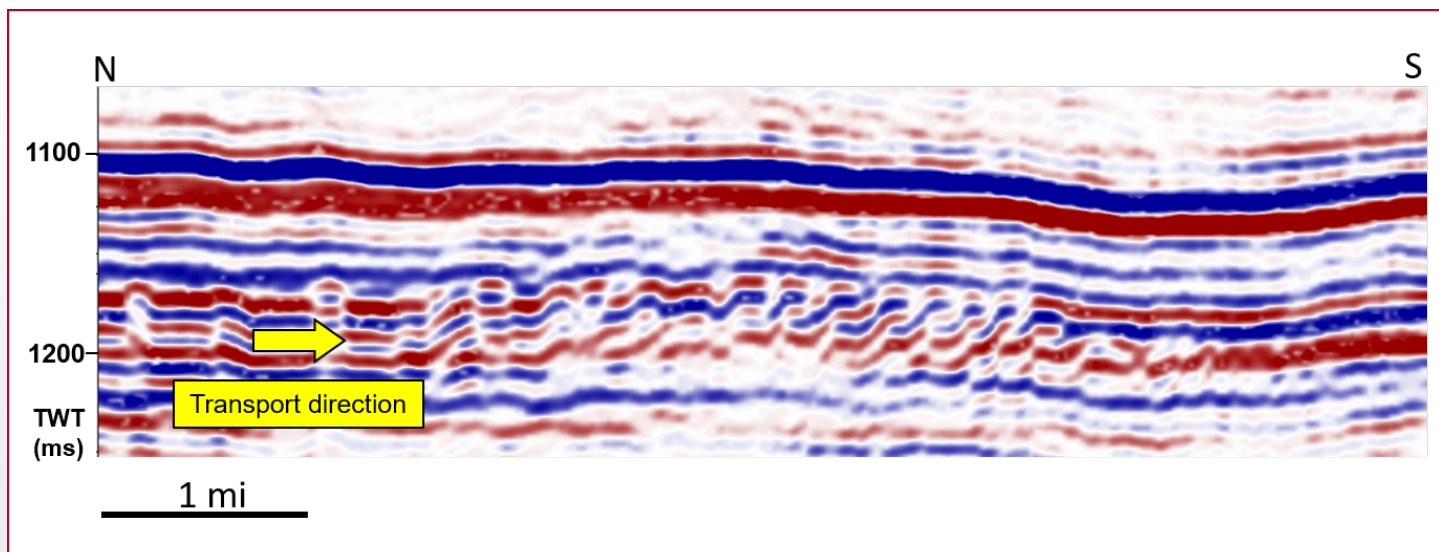


Figure 6. Seismic N-S cross section running across the MTD. The chaotic seismic reflectors indicate the partial internal deformation of sediments within the complex MTD. Notice the similarity between the model proposed by Posamentier and the pattern observed in the dataset

decades. The mega merge was processed after combining all the data together with a sample rate of 2ms and processed with a bin size of 110ft x 110ft. The survey area is approximately 400 mi² covering parts of Andrews, Ector, Midland and Martin counties (Figure 1). The dataset came with over 100 wells, out of which 30 wells had sonic and density log and 3 wells with core data. Although well analysis is not included in this study, we expect to use logs and core data to understand the depositional cycles and correlate it with seismic attribute interpretation, and include it in our final presentation.

Mass Transport Deposit (MTD) architecture

Figure 5 shows the architecture of the extension and compression associated with a mass transport sliding. Posamentier (2017) proposed a model of how a debris flow looks like in a slope setting (Figure 5b). The sediment blocks breaks due to slope failure leaving behind a slump scar and causes the sediments to flow down the slope by extensional structures (e.g., normal and listric faults). As the sediments approach the lower slope, frictional drag takes over and decelerates the sediment flow (Posamentier, 2003). As a result, the sediments pile up on top of each other that represents a series of low angle thrust faults (Figure 5c).

A small scale mass transport analog was observed in the Austrian Alps (Figure 5a), where sediments were remobilized towards the toe of the slope due to slope failure. Notice the slump scar and the extensional and compressional faulting associated within the MTD (Figure 5a).

Similar architecture can be seen on the cross section N-S in our study area. We believe the sediments were transported from the North and as frictional drag force took over, sediments started buckling on top of each other, leaving a compressional feature with low angle thrust faults (Figure 6). One can deduce the transport direction by studying the thrust faults orientation.

Structural curvature and coherence

Seismic attributes such as coherence and structural curvature were used to map the MTD seen in the dataset. MTDs are discontinuous in nature and are easily detected by these geometric and structural attributes. Coherence attribute is an edge detection tool that detects the break in reflector configuration or lateral changes in waveform (Qi et al., 2017). It provides enhanced image of the small scale geologic feature and helps in understanding the internal complexity of the MTDs.

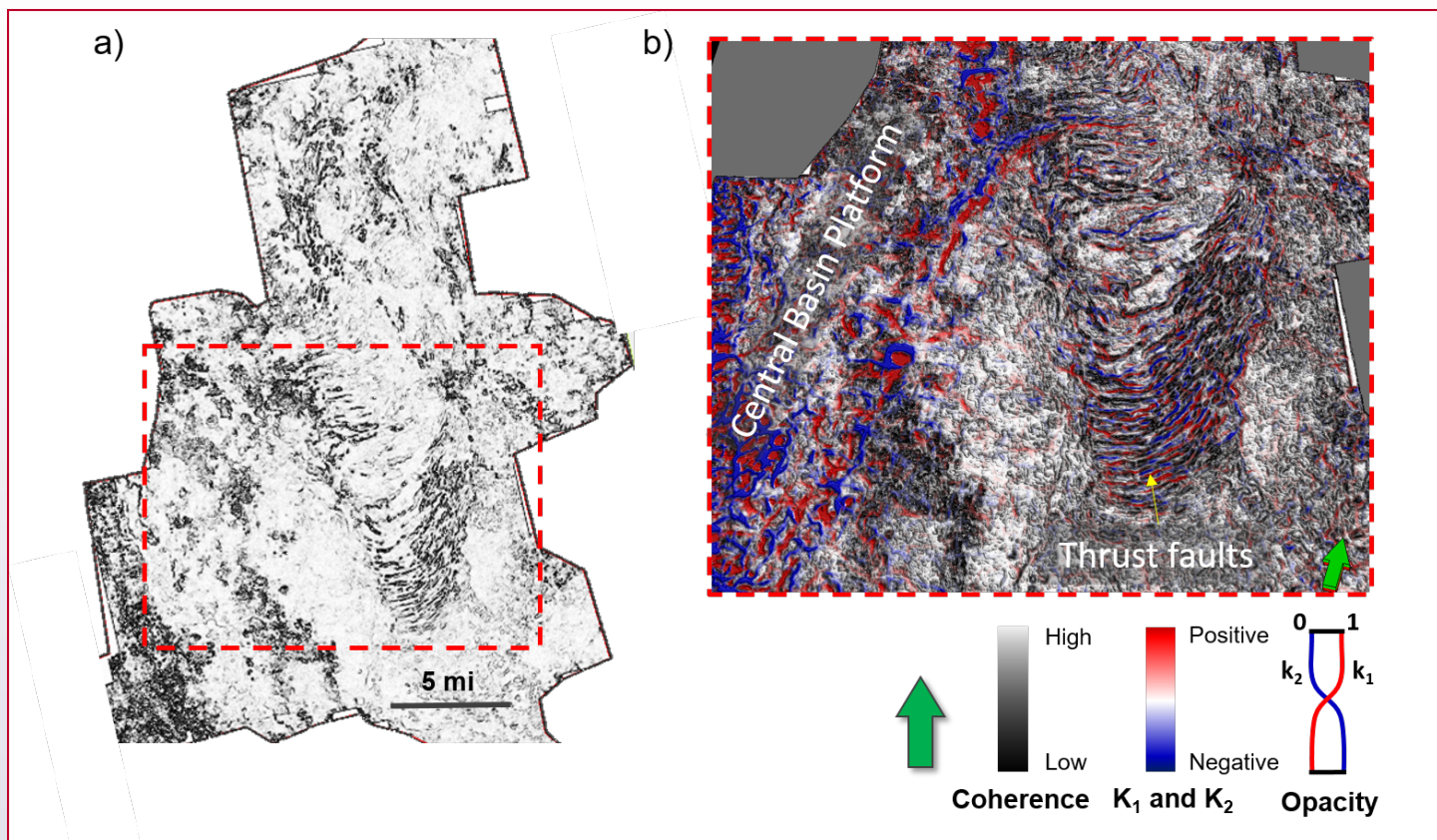


Figure 7. Stratal slice showing the MTD within the Spraberry formation. a) Coherence attribute computed on the stratal slice. Thrust faults are indicated by low coherence values. b) Coherence co-rendered with structural curvature attribute k_1 and k_2 computed on the stratal slice.

These discontinuities were computed on a flattened horizon that are represented by low coherence values indicated by black shown in *Figure 7a*. The discontinuous pattern that is seen in the figure are thrust faults caused by compressional forces as discussed by Posamentier (2017). We also computed structural curvature to understand the geometry of this feature. Blue colors indicate bowl shaped or valley like feature and red color represents dome shaped or ridge like feature (Al-Dossary and Marfurt, 2006; *Figure 7b*). After studying the pattern of these thrust faults, it is believed the sediments must have come from the northern slope, hence leaving an impression like the one observed in the dataset.

Discussion and conclusion

The proposed MTD model agrees with the feature seen on the dataset. After analyzing the extent of the MTD, it is hypothesized that the slope had

a higher gradient effect, thereby increasing flow velocity and making the sediments travel farther. This would have created a high turbulence resulting in better sorting. With the help of seismic attributes, we were able to map the extent of the MTD and understand the internal partial deformation of sediments within the complex MTD. Further work needs to be done to evaluate seal integrity for exploration purposes. The presence of such a geologic anomaly can help interpreters better understand MTDs and its role as a potential hydrocarbon trap.

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