A Window into the Proterozoic – Using High-Quality 3-D Seismic Exploration Volumes to Image the Sub-Basement in the Southeast Fort Worth Basin

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1. Abstract:

The Fort Worth Basin is the most fully developed shale gas field in North America. Although imaged by perhaps one hundred 3D seismic surveys, the intense competition for acreage and focus on the relatively shallow, flat-lying Barnett Shale objective has resulted in little published work on the basement structures underlying the lower Paleozoic strata. Major tectonic features including the Ouachita thrust-fold belt, Lampasas arch, Llano uplift and Bend arch surround the southeast Fort Worth Basin. Subtle folds and systems of large joints represent almost all 3D seismic surveys in the Fort Worth Basin with little to no vertical offset. At the Cambro-Ordovician Ellenburger level, these joints are often diagenetically altered, and exhibit collapse features at their intersections. Where the overlying Viola Limestone is absent, these joints and karst represent drilling/completion hazards that will produce water and negatively impact production. In support of our investigation, Marathon Oil Company has provided a high-quality, wide- azimuth survey near the southeast fringe of the Fort Worth Basin. In this research, we use the seismic volume, and integrate it with gravity, magnetic, and geological data to study basement and sub-basement structures in the southeast Fort Worth Basin and how they relate to the Late Paleozoic sequences above it.

2. Tectonic setting and geology of the area

Major tectonic units such as Ouachita Orogenic Belt (OOB), Southern Oklahoma Aulacogen (SOA), and Llano Uplift surround the study area, which lies in the southeast part of Fort Worth Basin (Figures 1 and 2). The Phanerozoic evolution of the area started with Early Paleozoic continental rifting in the context of a Wilson Cycle that formed the SOA and the Early and Middle Paleozoic continental margin along which the OOB developed in the Late Paleozoic (Keller, 2009). During the Paleozoic, the Ellenburger Group, Simpson Group, and Viola Limestone lie beneath a major unconformity and overlain by, the Barnett Shale, and Marble Falls Limestone Group and Pennsylvanian strata were deposited in the FortWorth foreland basin. The entire basin was later unconformably covered by Cretaceous and Quaternary deposits (Figure 3; Burner and Smosna, 2011). Due to these different tectonic events, the Fort Worth Basin formed as asymmetrical and wedge-shaped that pinches out toward the south (Figure 3). The Lower Ordovician Ellenburger Group comprises porous dolomite and limestone with abundant chert and is characterized by karst solution-collapse and brecciated structures (Loucks, 2003). In the central part of the Fort Worth Basin, basement faults have influenced the Ellenburger subaerial karst features, and these features have helped to reactivate the faults (Sullivan et al., 2006). Below the Ellenburger Group lies the basement rocks, which have been mapped primarily as granite, diorite, and metasediments in the Llano Uplift (Figure 2), but no well in the vicinity of the study area has penetrated below the Ellenburger Group. Walper (1982) interpreted some high angle normal faults and graben structures mostly associated with the OOB and the Llano Uplift. Some of these faults are exposed in the surface, but the Quaternary sediments cover most of them.

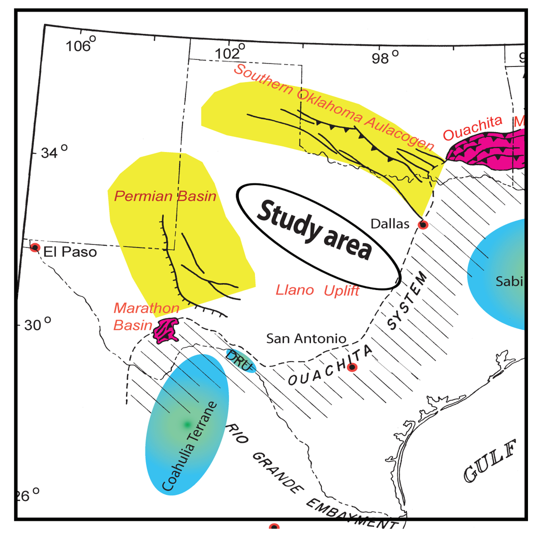

Figure 1: Regional tectonic map of Texas and the Gulf Coast (modified from Keller, 2009). Major tectonic units are shown. The study area lies within the open black ellipse.

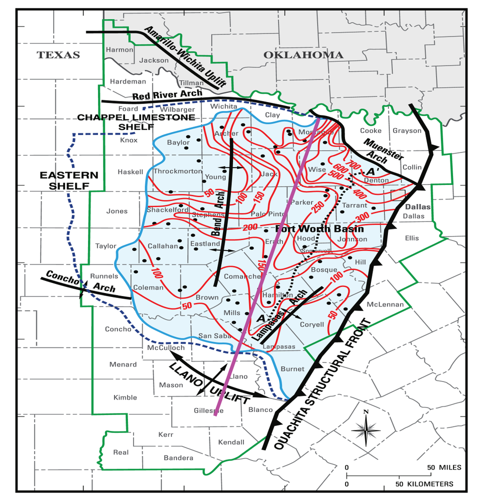

Figure 2: The extent of the Barnett Shale in the Fort Worth Basin. Major structural units surrounding the basin are shown in the Figure. Red contour lines represent the Barnett Shale thickness in the area. The N-S trending purple line is the cross-section across the basin shown in Figure 3 (Burner and Smosna, 2011).

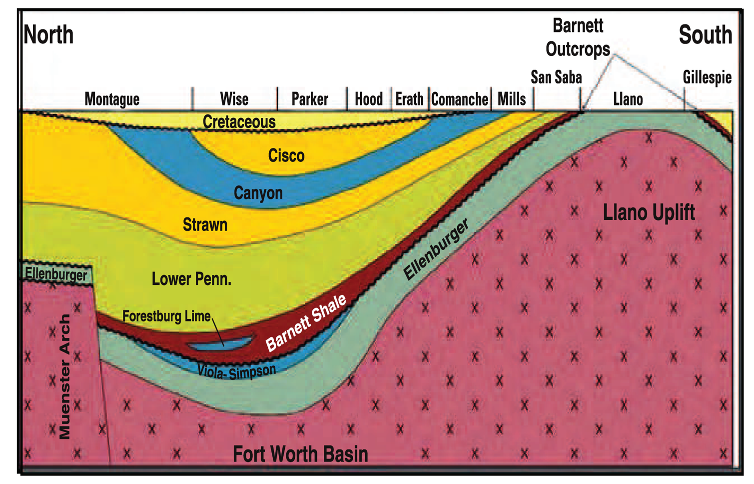

Figure 3: Geological cross-section of the Fort Worth Basin along the northeast-southwest trending purple line shown in Figure 2. Normal faults and uplift on the basement are observed (Burner and Smosna, 2011).

3. Analysis of gravity and magnetic data to provide regional context

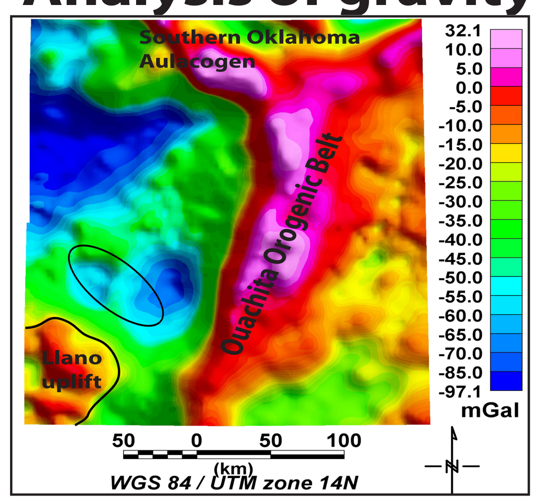

Figure 4: Complete Bouguer anomaly map of the study area. Strong gravity highs are related to the Llano Uplift, the Ouachita Orogenic belt and the Southern Oklahoma Aulacogen. The study area lies in a large gravity low shown in the black ellipse. The gravity anomalies vary by almost 130 mGal in the region.

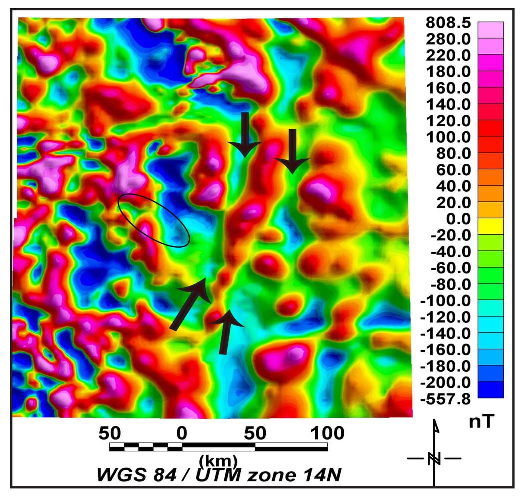

Figure 5: Total magnetic intensity map of the study area after Reduction-to-the-Pole and application of a 25 km upward continuation filter. Pairs of black arrows show the boundaries of the Ouachita Orogenic belt. The open ellipse (in black) outlines the low magnetic anomaly that coincides with the low Bouguer anomaly in Figure 4. The magnetic anomaly in the area varies by almost 1500 nT.

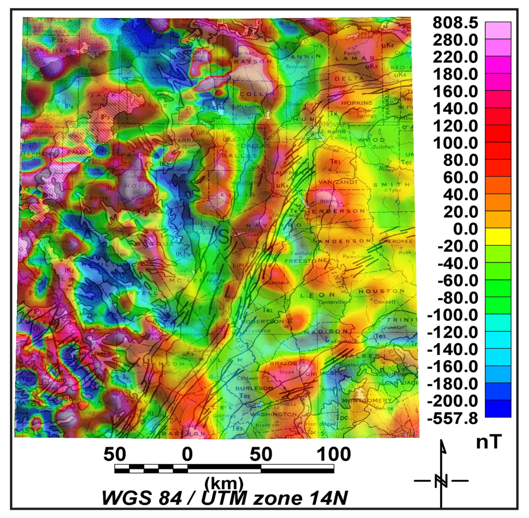

Figure 6: A co-rendered image of Figure 5 with a tectonic map of the study area (King, 1989).

4. Basement structures in the seismic volume

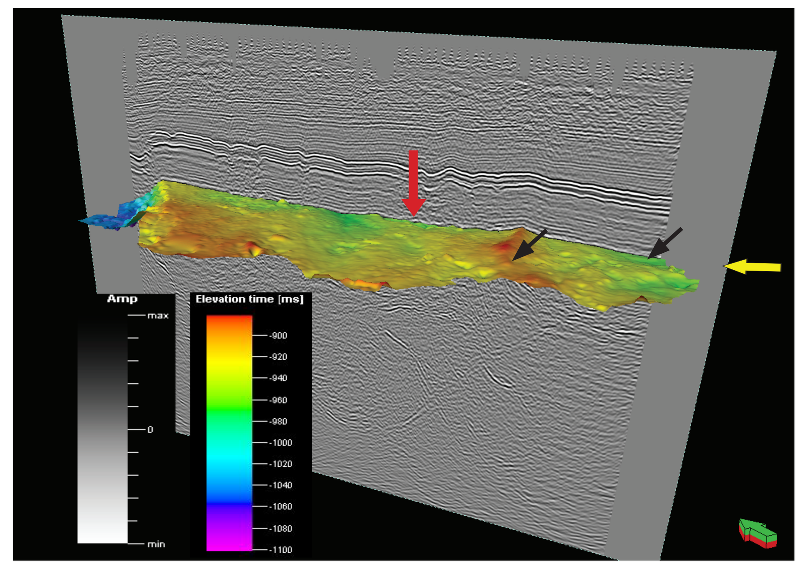

Figure 7: Picked top of the basement surface (yellow arrow) on the seismic section shown with a seismic crossline. The basement surface is relatively flat having only about 200 ms of relief. Black arrows indicate the karst features that extend down from the carbonate rocks above. Red arrow indicates the possible collapse features most likely related to basement faults.

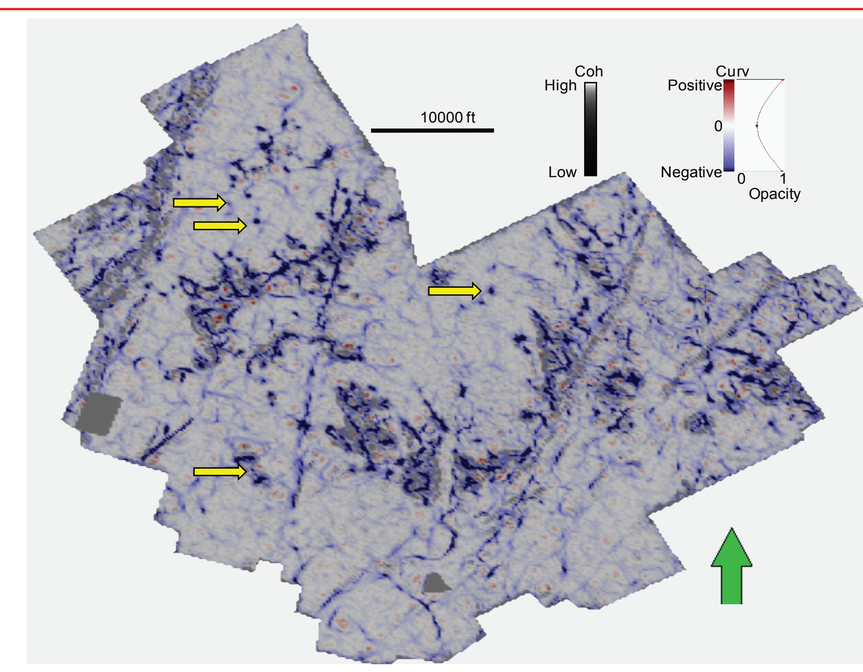

Figure 8: Co-rendered horizon slices along the top Ellenburger dolomite through coherence and most-negative principal curvature volumes. Collapse features appear as black circles as indicated by the yellow arrows. Note the control of the collapse features by negative curvature lineaments which we interpret to be diagenetically-altered fractures.

5. Volumetric multi-attribute analysis of the basement structures

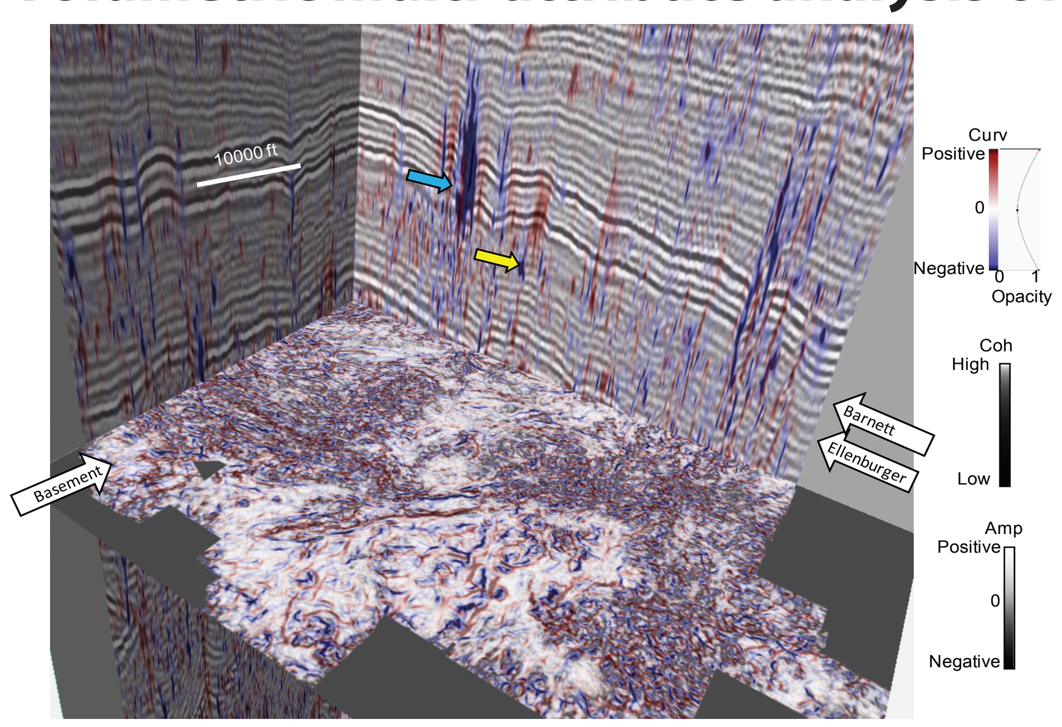

Figure 9: Illustration of geometric attributes using a 3-D chair diagram showing vertical slices through seismic amplitude and a time slice at 0.980 s (approximate basement) through coherence co-rendered with most-positive and negative principal curvature. Blue areas (such as indicated by the cyan arrow) highlight valleys and bowls, while red areas (such as indicated by the yellow arrow) highlight ridges and domes. Note the complex deformation of the basement that controls the collapse features the shallower Ellenburger do-

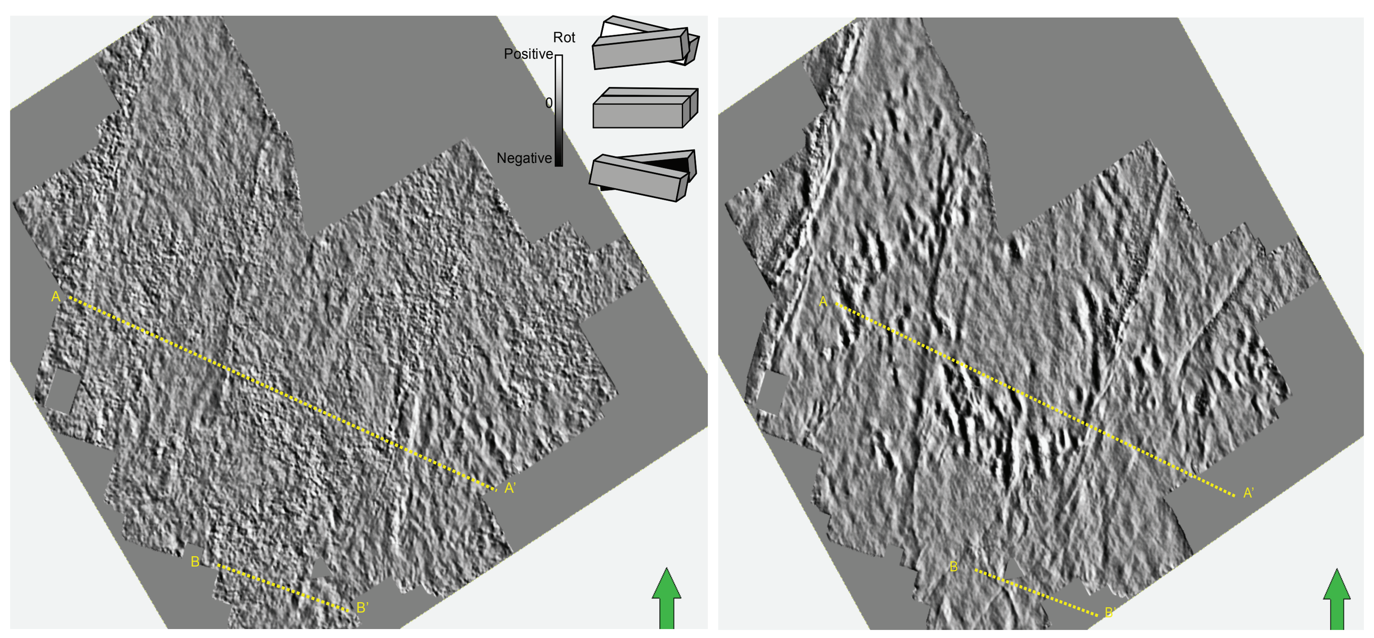

Figure 10: Time slice through the reflector rotation time slice at (left) t=0.980 s (approximate top Ellenburger) and at (right) t=0.700 s (approximate top basement) showing a strong NNE-SSW-trending fabric consistent the magnetic basement anomalies shown in Figures 4-6. White lineaments are down to the right (clockwise rotation) while black lineaments are up to the right (counterclockwise rotation).

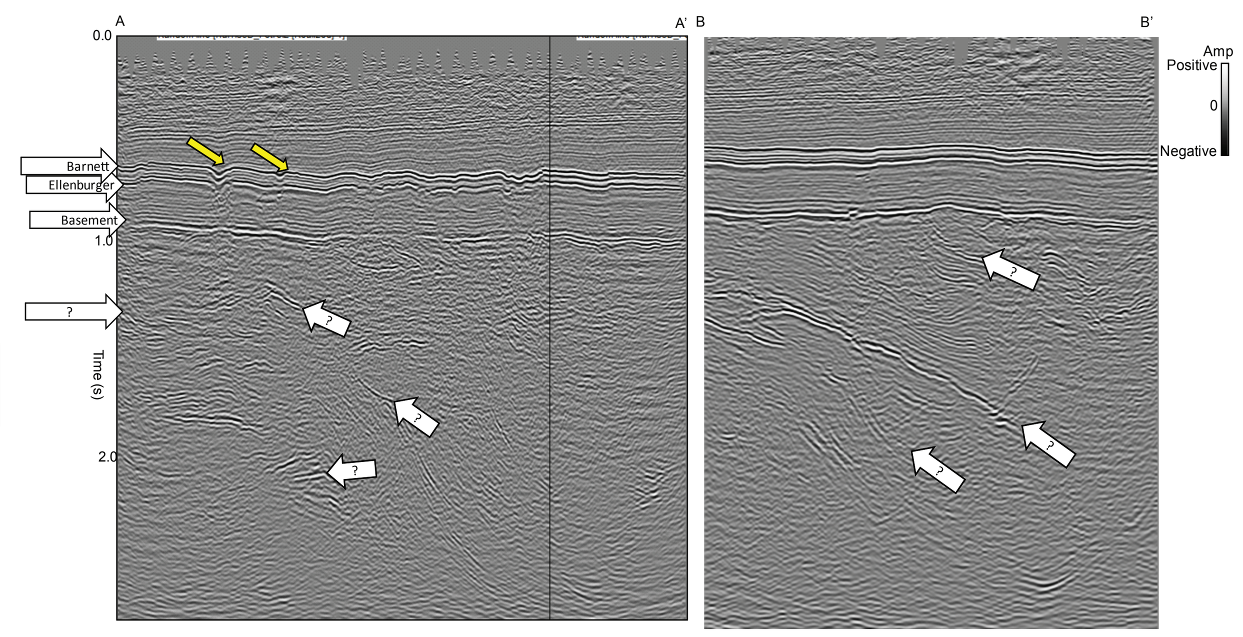

Figure 11: Vertical slices through seismic amplitude along line AA' and BB' chosen to be perpendicular to the structural fabric seen in the previous image (Figure 9) showing key Paleozoic horizons as well as unidentified Proterozoic reflectors. We suspect some of these reflectors are thrust faults, others to be volcanic dikes and sills, still others sedimentary or metamorphic horizons. Yellow arrows indicate collapse features seen within the Ellenburger dolomite. These two features do not appear to be controlled by basement deformation.

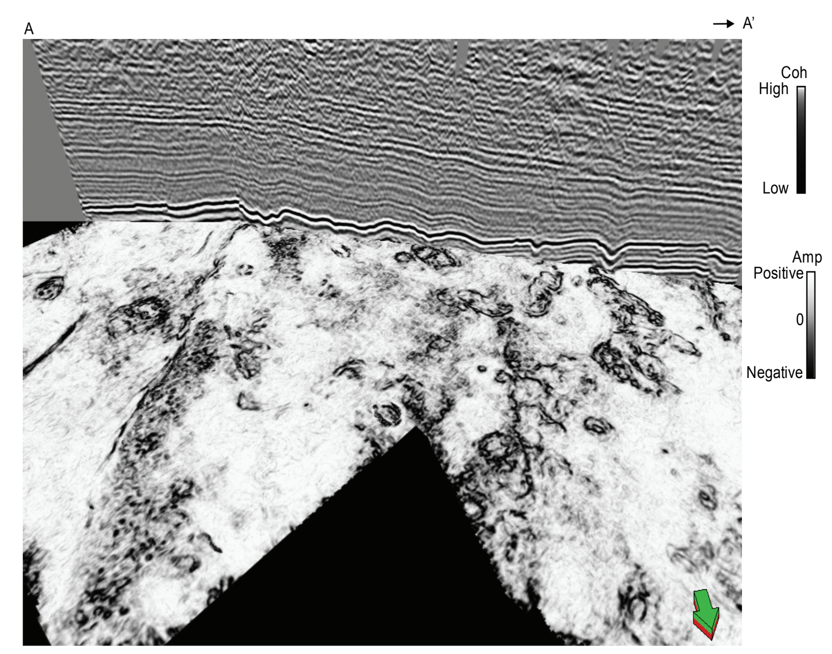

Figure 12: Time slice at t=0.712 s through the coherence volume at the approximate top Ellenburger dolomite showing its correlation with line AA' through the seismic amplitude volume.

6. Discussion of the results

Although the basement and sub-basement reflectors are visible in the seismic section, they are hard to trace throughout the seismic volume. Some of these reflectors are dipping and folded. Some of the probable thrust faults in the sub-basement are visible as deep as 2 s and are pickable (see figure 11). To improve the visibility of these reflectors, we used volumetric seismic attributes. Among them similarity to energy ratio, most positive and negative principal curvatures, and coherence, when co-rendered, helped to identify deep-seated faults and some of the collapse features as shown in Figures 7 through 12. The reflector rotation attribute analysis traced some of the structural blocks well below the Ellenburger dolomite as shown in Figure 10. Karst features that have been mapped in the northern part of the Fort Worth Basin are also seen in the shallower section present in the southeast Fort Worth Basin. The preliminary results from this research show that they extend as deep as 1s (Figure 7 through 12). These features indicate that the structures seen in the Barnett Shale are somehow related with the deep-seated faults, and thrust faults. The initial analysis of gravity and magnetic data shows some promise to further understand the sub-basement structures.

7. Future work

Faults and thrusts in the basement are visible to some extent. We will pick these features with the help of geometric attributes. We will also use structurally oriented attributes to enhance these sub-basement faults, thrust faults and the possible karst and collapse features in the sub-basement. We will use Euler deconvolution deep estimation on the magnetic data and further process gravity data to generate some gravity and magnetic models of the basement and integrate these results with the seismic volume for basement interpretation and control it may exert on the overlying reservoir.

8. Acknowledgement

Many thanks to Marathon Oil Company for providing us with this seismic data and our thanks go to the U. S. Geological Survey and Pan American Center for Environmental Studies (PACES) for making gravity and magnetic data available in the public domain.

9. References

Burner, R. Kathy, and Smosna, Richard, 2011, A comparative Study of the Mississippian Barnett Shale, Fort Worth Basin, and Devonian Marcellus Shale, Appalachian Basin, report of National Energy Technology Laboratory, DOE/NETL-2011/1478.

Keller, G. Randy, 2009 Some Thoughts on the Structure and Evolution of the Ouachita Mountains-Arkoma Basin region, Oklahoma Geology Notes, v 69, no 1.

King, P.B., 1989, Tectonic maps of the United States, National atlas of the United States: Reston, Va., U.S. Geological Survey, 2 sheets, scale 1:7,500,000.

Loucks, R.G., 2003, Origin of Lower Ordovician Ellenburger Group brecciated and fractured reservoirs in West Texas: paleocave, thermobaric, tectonic, or all of the above? : *http://aapg.confex.com/aapg/sl2003/techprogram/paper_78591.htm*, accessed June 2009.

Sullivan, E.C., Marfurt, K.J., Lacazette, A., and Ammerman, M., Application of new seismic attributes to collapse chimneys in the Fort Worth Basin, Geophysics, Vol. 71, No. 4, p B111-B119.

Walper, J.L., 1982, Plate tectonic evolution of the Fort Worth basin, in Martin, C.A., ed., Petroleum geology of the Fort Worth basin and Bend Arch area: Dallas Geological Society, p 237–251.