Imaging Sub-basement Structures in Southeast Fort Worth Basin using High Quality 3D Seismic Exploration Volume

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1. Abstract:

To understand the setting and behavior of a reservoir, it is equally important to know what kind of structural and tectonic control is in the sub-basement and how they relate to the reservoir. Although the Late Paleozoic sequences of the Fort Worth Basin is well imaged and studied amid flat lying Barnett Shale gas production, the Lower Paleozoic and Proterozoic basement and sub-basement structures are ignored at large. Complex tectonic units such as Ouachita thrust-fold belt, Llano uplift, Lampasas Arch, and bend Arch surrounds the southeast Fort Worth Basin. These tectonic units have introduced subtle folds, large joints, some normal and thrust faults, and many collapse features in the reservoir level.

In this research, we use high quality seismic volume, and integrate it with gravity, magnetic and geological data to answer what kind of structures lies in the sub-basement of 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 tectonics 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 (see figure 1). This whole system started as a continental rifting in the Early Paleozoic age in the context of Wilson Cycle and then failed and formed the SOA and OOB (Keller, 2009). Later in the late Paleozoic era, the Ellenburger Limestone, Viola Limestone, Forrestberg Limestone, Barnett Shale, Marble Falls Limestone Group was deposited in the foreland basin of the Laurentia. The whole basin was later unconformably covered by Cretaceous and Quaternary deposits missing upper Paleozoic rocks (figure 3) (Burner & Smosna, 2011). Due to these different tectonic activities, the Fort Worth Basin formed as asymmetrical and wedge shaped that pinches out toward southeast portion (See figure 2). The Lower Ordovician Ellenburger Group comprises porous dolomite and limestone with abundant chert and is characterized by karsts, solution-collapse, and brecciated structures (Loucks, 2003). Below the Ellenburger Limestone lies the basement rocks which has been interpreted as granite-diorite metasediments(?) but no well in the vicinity of the study area has penetrated below the Ellenburger Limestone. 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 while most are covered by the Quaternary sediments.

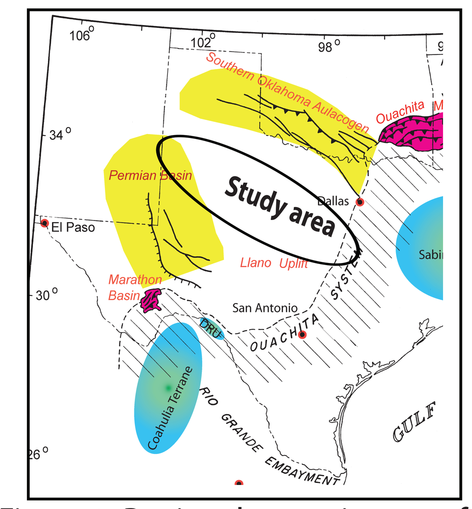

Figure 1: Regional tectonic map of Texas and Gulf Coast. Major tectonic units are shown in the figure (modified after Keller, 2009). The study area lies within the open black ellipse.

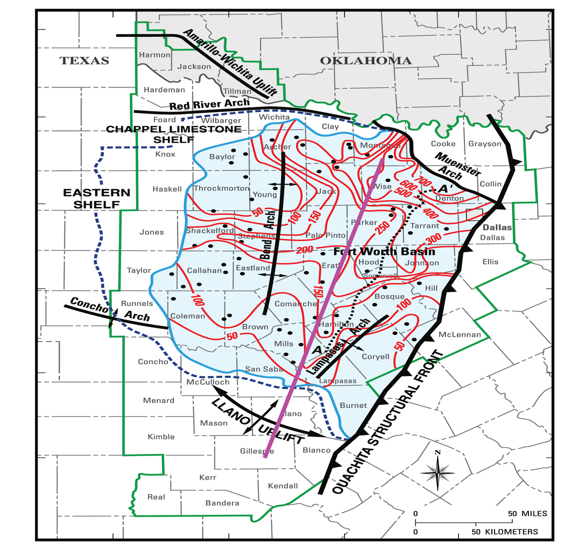

Figure 2: The extent of Barnett Shale in the Fort Worth Basin. Major structural units surrounding the basin are shown in the figure.Burner & Smosna, 2011).

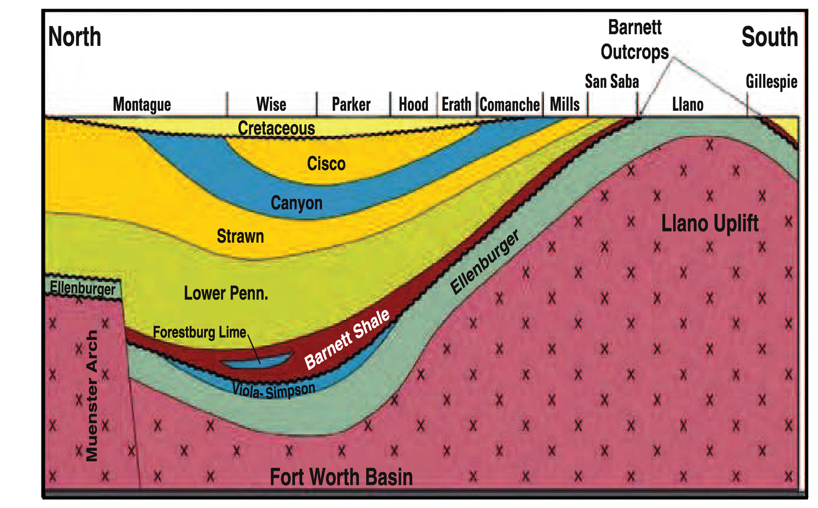

Figure 3: Geological cross-section of the Fort Worth Basin along the North-South trending purple line shown in figure 2. Normal fault and uplift on the basement is observed (Burner & Smosna, 2011).

3. Sub-basement structures in the seismic volume

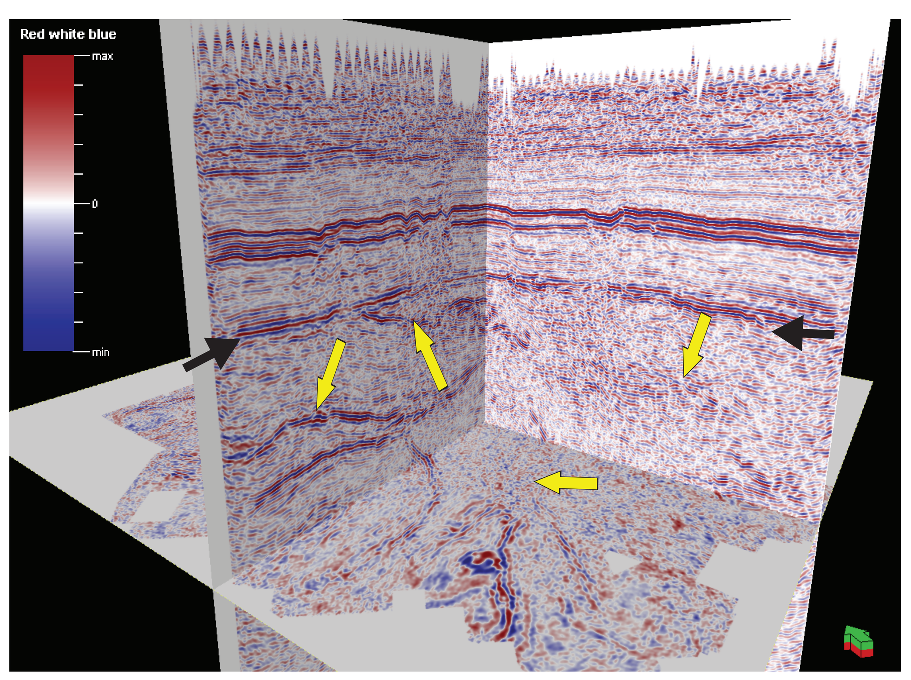

Figure 4: 3D seismic data in the study area with vertical exaggeration of 7.5. Black arrows are showing the possible top of the basement (the Ellenburger Limestone). Below it are the sub-basement reflectors with subtle folding, possible thrust, and collapse features (shown in yellow arrows). The time section at 1400 ms shows some coherent reflectors.

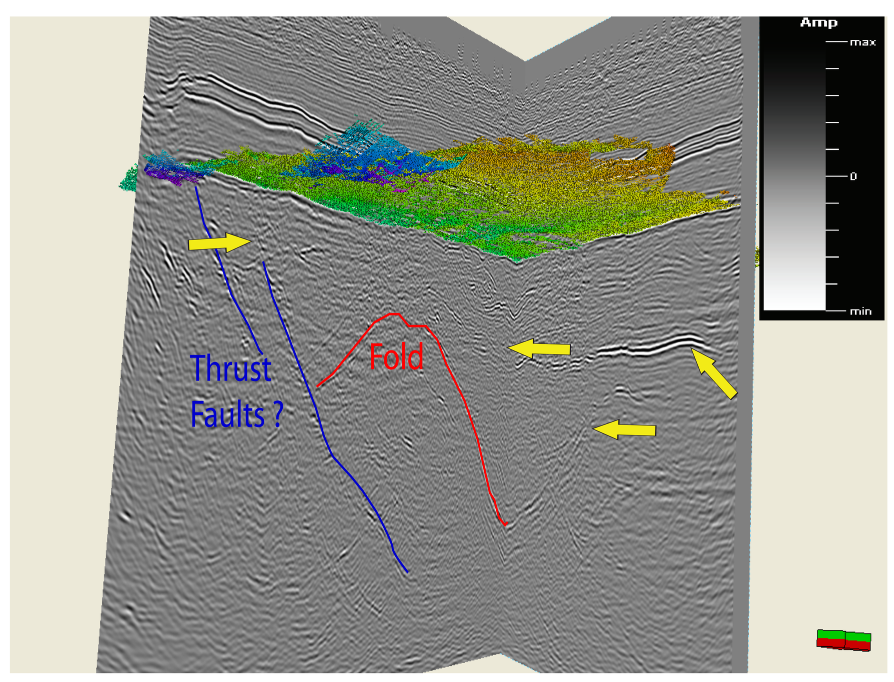

Figure 5: 3D seismic data in the study area with top of the basement horizon picked at about 1000 ms. Some folds, and possible thrust-faults are visible in the seismic sections. Yellow arrows indicate some of the strong reflectors, and possible collapse features extending below the basement. The vertical exaggeration in this figure is of 10.

4. Analysis of gravity and the magnetic data in the regional context

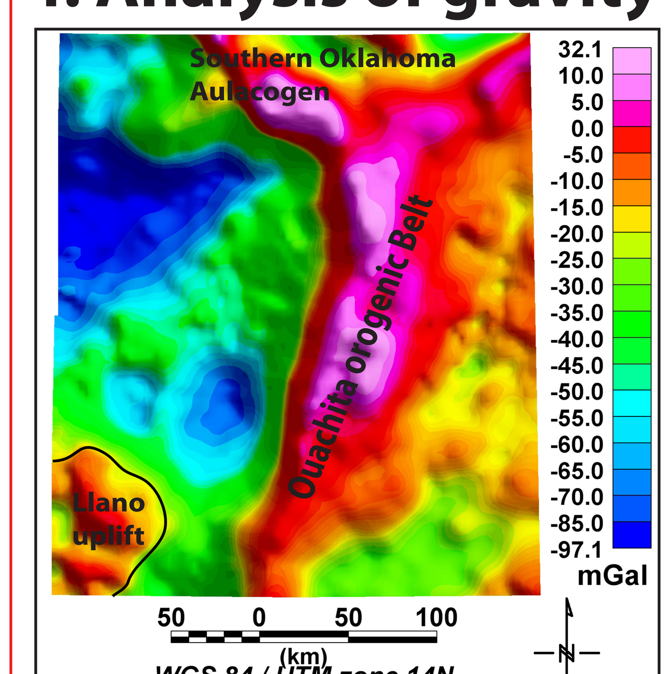

Figure 6: Complete Bouguer Anomaly map in the regional context of the study area. The gravity high related the Llano Uplift, the Ouachita Orogenic belt and the Southern Oklahoma Aulacogen are observed. The gravity anomaly varies by almost 130 mGal in the area.

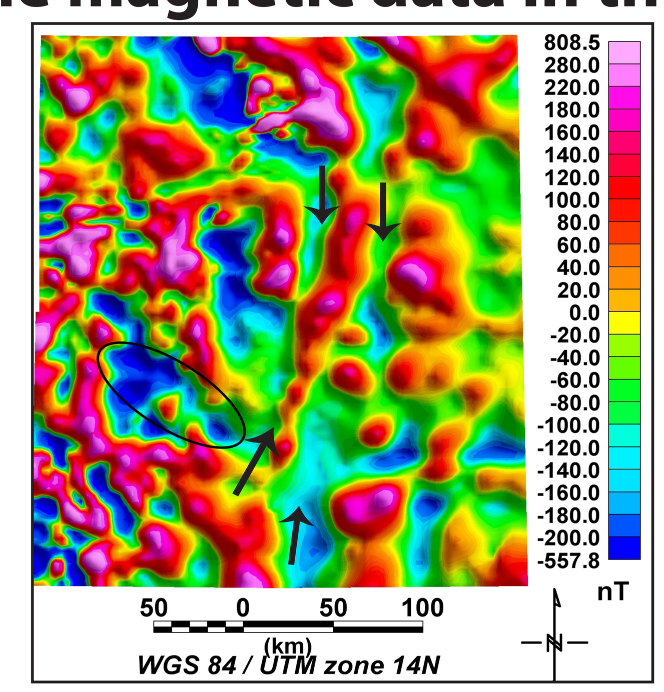

Figure 7: Total magnetic intensity map of the study area after reducing to North Pole and applying Butterworth bandpass filter. Sets of black arrows show the boundaries of the Ouachita Orogenic belt. The open ellipse (in black) shows low magnetic anomaly which matches with the low Bouguer Anomaly from figure 6. The magnetic anomaly in the area varies by almost 1500 nT.

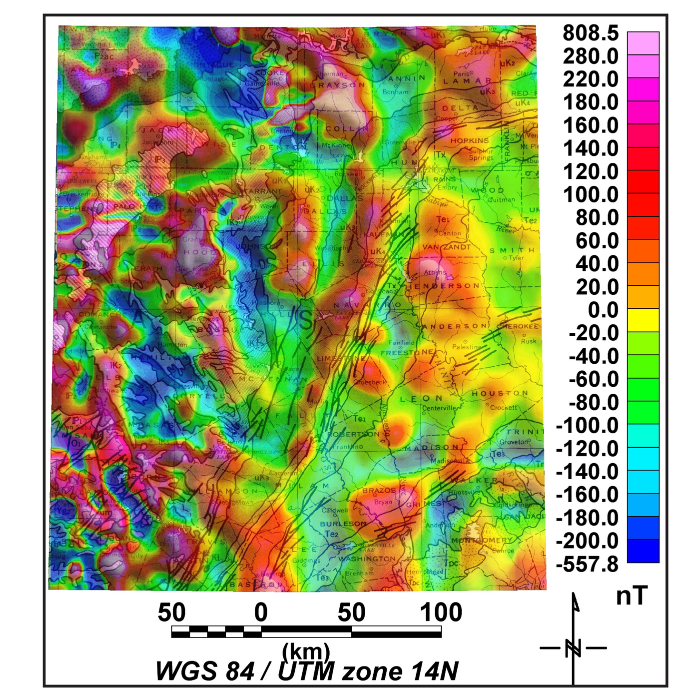

Figure 8: The co-rendered image of figure 7 with geological map of the study area (King, 1989). The thrust fault system of the Ouachita Orogenic Belt matches well with the related magnetic signatures from figure 7.

5. Volumetric multi-attribute analysis of the sub-basement structures

(Note: the color bar used for figure 12 through 14 are same)

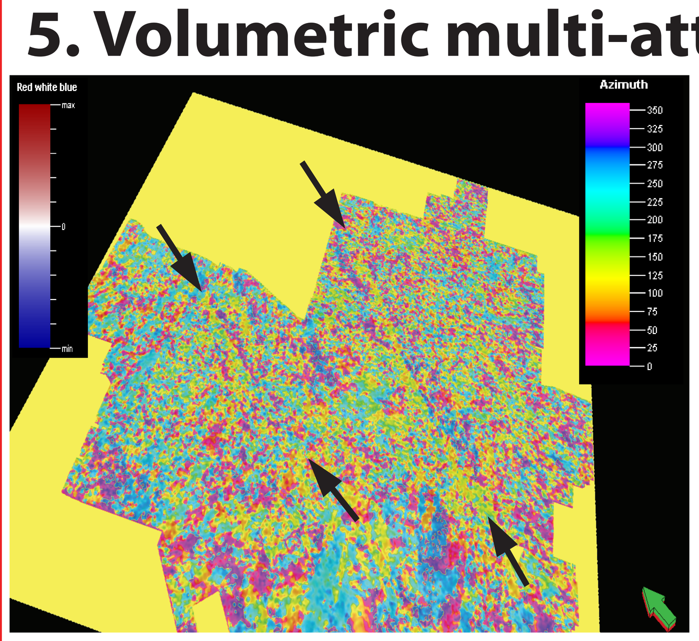

Figure 9: Co-rendered time slice of the volumetric attributes at 1400 ms. Convergence azimuth and convergence magnitude of the curvature, **K**1 and **K**2 principal curvatures are used in this image. The sets of black arrows are showing some linear trend of structures which is most likely faults in the sub-basement.

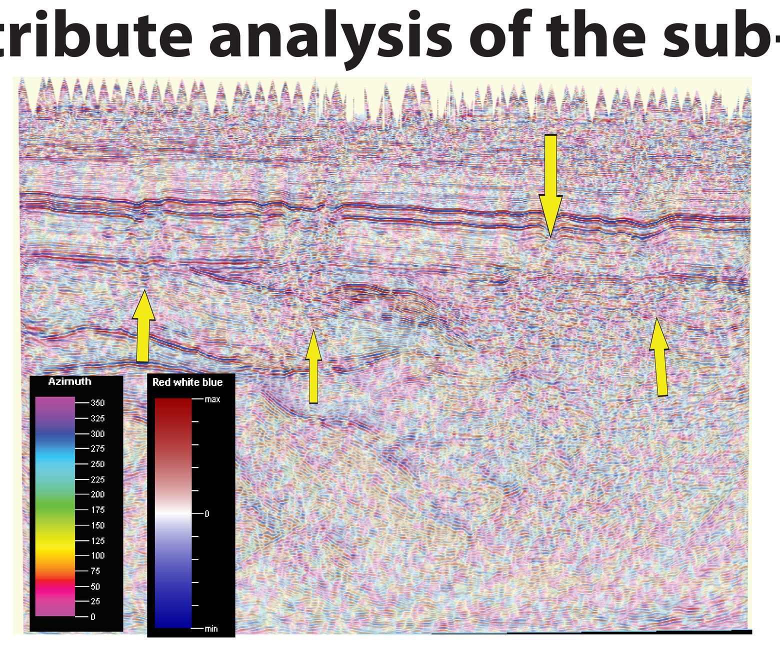

Figure 10: Co-rendered image of inline seismic section with convergence azimuth and convergence magnitude of the curvature help to visualize the linear extent of sub-basement structures. The yellow arrows indicate the collapse features and its vertical extent.

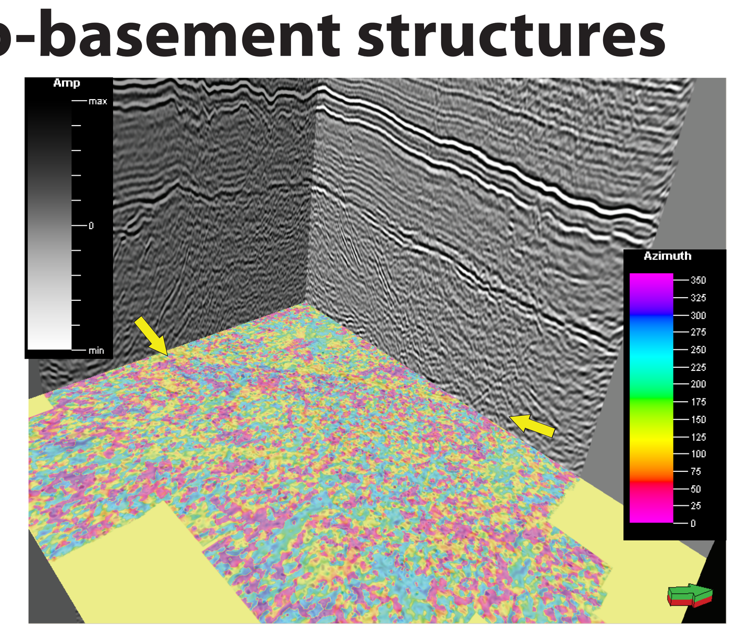

Figure 11: Co-rendered time slice of the convergence azimuth and convergence magnitude of the curvature, **K**1 and **K**2 principal curvatures at 1400 ms plotted with the seismic sections. The yellow arrows indicate possible fault as discussed in figure 9 which match with the fault observed in the seismic section at the corresponding offsets.

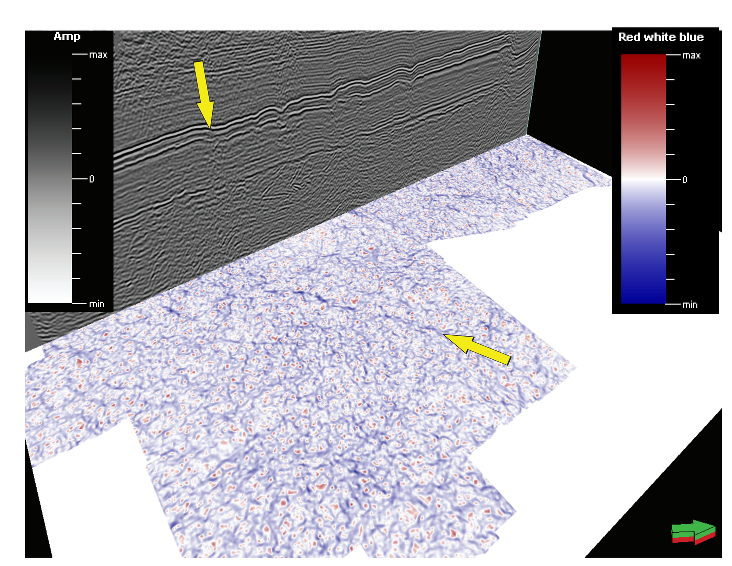

Figure 12: Co-rendered time slice of coherent energy with **K**1 and **K**2 principal curvatures at 1400 ms plotted with a seismic cross line. The yellow arrow in the time slice indicates a linear trend which matches with a probable fault in the seismic section which extends all the way up to the Barnett Shale and Marble Falls Limestone also indicated by the yellow arrow.

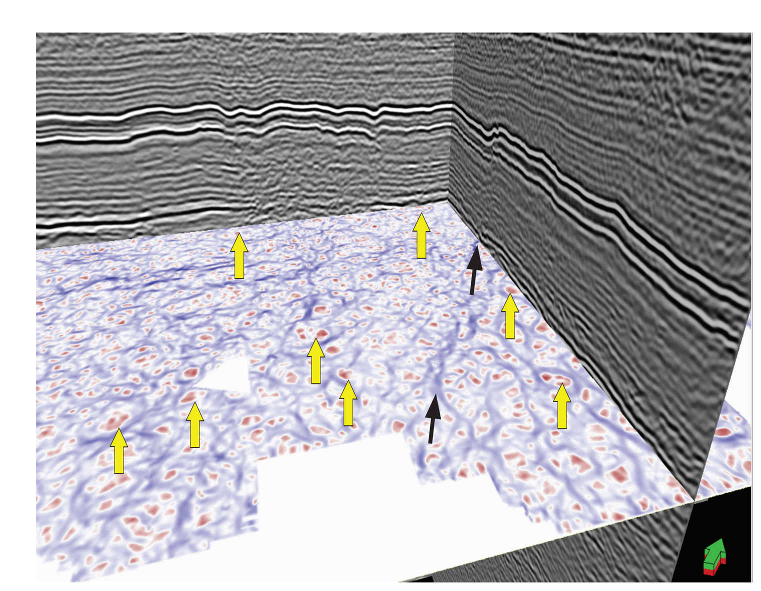

Figure 13: Co-rendered time slice of coherent energy with **K**1 and **K**2 principal curvatures at 1000 ms plotted with seismic lines. The yellow arrows in the time slice are indicating to most probable karsts features. Black arrows are indicating to a linear feature which juxtapose to another fault in the seismic section.

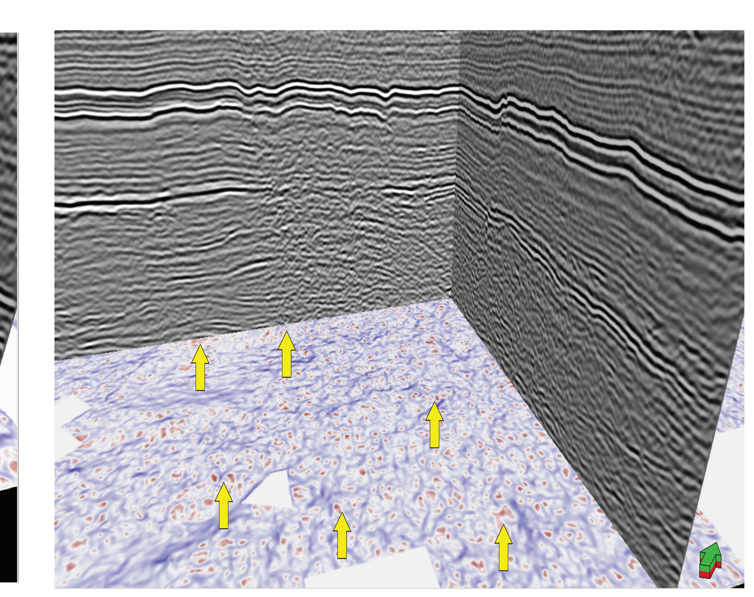

Figure 14: Co-rendered time slice of coherent energy with **K**1 and **K**2 principal curvatures at 1400 ms plotted with seismic lines. Many of the interpreted karsts features in figure 13 extend down to 1400 ms time as shown in the yellow arrows.

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 on the sub-basement are visible and pickable. To improve the visibility of these reflectors, we used volumetric seismic attributes. Among them Coherent energy, K1 and K2 principal curvatures, and convergence azimuth and convergence magnitude of the curvature when co-rendered helped to identify these deep sheeted faults and some of the collapse features as shown in figures 9 through 14. The karsts feature that has been mapped in the northern part of Fort Worth Basin is also seen in the shallower section of the southeast Fort Worth Basin. However the vertical extent of these features and diagenetically altered collapsed features traced through the Ellenburger Limestone is not clear yet. The preliminary results from this research show that they go down up to at least 1400 ms (figure 12 through 14). These features indicate that the structures seen in the Barnett Shale are somehow related with the deep lying faults, thrust faults and collapse features. The initial analysis of gravity and magnetic data shows some promise to further understand the sub-basement structures.

7. Future works

The study is still in the preliminary phase. We will pick basement horizon carefully. Faults and thrusts in the basement are visible to some extent. We will pick these faults and thrust faults with the help of geometric attributes. We will also use structurally oriented attributes to enhance these sub-basement faults, thrust faults and the possible karsts and collapse features in the sub-basement. We will use Euler deconvolution on the magnetic data and further process gravity data to generate some gravity and magnetic model of the sub-basement and integrate these results with the seismic volume.

8. Acknowledgement

Many Thanks to Marathon Oil Company for providing us with this seismic data and our thanks goes to USGS, and Pan American Center for Environmental Studies (PACES) for making gravity, magnetic, and geological data available in the public domain.

9. References

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