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Investigation of linkages between Precambrian basement structure and Paleozoic strata in the Fort Worth Basin, Texas using high-resolution aeromagnetic data and seismic attributes

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ABSTRACT

Effective hydrofracturing is critical to generating permeability within the Barnett Shale of the Fort Worth basin (FWB). Therefore, knowledge of the nature of the induced and natural fractures, faults, and collapse features that may form conduits to the underlying Ellenburger aquifer is vital. We employ coherence and curvature seismic attributes, which are sensitive to faults, fractures and collapse features to map these features in the sedimentary column. We then integrate high-resolution aeromagnetic (HRAM) data with the seismic attributes extracted along the Ellenburger Formation and the top of basement from the north-central portion of the FWB, thereby linking features in the Precambrian basement to shallower sedimentary structures. HRAM derivative maps designed to enhance basement structures confirm hypotheses made by others that much of sedimentary faulting and diagenesis is basement is basement controlled. Specifically, attribute lineaments are aligned parallel to anomalies identified in the HRAM data. The northeast-southwest and northwest-southeast orientations of sedimentary features are consistently parallel with Precambrian structural fabrics that are associated with structures such as the northeast trending Ouachita orogeny belt and the northwest trending Muenster Arch, which reactivated a late Cambrian/Late Precambrian fault. Mapping such features can aid in the design of the hydrofracture program and provide help in predicting which area of the basin may be more structurally-deformed.

INTRODUCTION

Almost all hydrocarbon production from the Barnett Shale of the Fort Worth basin (Figure 1) requires inducing fractures while avoiding natural fractures, faults and karst collapse features that form conduits to the underlying Ellenburger aquifer. These northwest striking natural fractures and the northeast trending present day stress field and induced fractures are sub-parallel to the Muenster Arch, which is a reactivated basement fault, and the northeast trending Ouachita thrust front respectively (Simon, 2005).

Recent efforts by Montgomery et al. (2005), Sullivan et al. (2006), Aktepe et al. (2008), and Elebiju et al. (2008) have suggest that the Precambrian basement structures may be controlling some of the overlying Paleozoic features such as faulting and karsting of the Ellenburger Formation, and infill by the overlying Barnett Shale.

The existence of links between basement structure, hydrocarbon containers, and structures within the sedimentary section is not a new concept (e.g., Wilson and Berendsen, 1998; Plotnikova, 2006; Berger et al., 2008). Such relationships can be seen in the Paradox, Hardeman, Anadarko, Arkoma, Ardmore (Thomas and Baars, 1992), and Williston basins among others (Gerhard and Anderson, 1988). Structures such as fault zones that can influence the formation of sedimentary basins and mineral deposits are often formed by intraplate tectonism (Barosh, 1995). Such basement structures may be difficult or expensive to delineate using seismic methods.

The objective of this paper is to investigate the use of high-resolution aeromagnetic (HRAM) data to augment seismic images of basement and sedimentary structures within the north-central part of the FWB. We also explore the link and interaction between basement and sedimentary structures. We begin by reviewing the HRAM methods and its link to basement features. Next, we review the tectonic setting of the FWB. Then, we present our methodology of linking HRAM to seismic attributes. Using this methodology, we develop an integrated magnetic and seismic interpretation of the area. We conclude by discussing advantages and pitfalls of our methodology.

We do believe that in areas where seismic data is limited or unavailable, HRAM data can be used to predict the kinds of intra-sedimentary features that may be present serving as an indirect hydrocarbon exploration tool.

This paper presents the results of integrating seismic attributes and enhancement and filtering techniques applied to HRAM data to establish links between Precambrian basement structures and faults in the overlying sedimentary section. The enhancement methods employed were designed to highlight anomalies of potential interest not directly seen in the original data but caused by geological features of interest.

HRAM DATA AND PRECAMBRIAN BASEMENT

HRAM data typically consist of data acquired at flight heights of less than ~800 m, flight line spacings in the range of 145 - 150 m, and a sample spacing of about 15 m along the flight lines with accuracy approximately 0.1 nT (Peirce et al., 1998). The aeromagnetic method has long been recognized as an effective tool for mapping structures within the Precambrian basement rocks because measured magnetic anomalies usually reflect magnetic susceptibility contrasts within the crystalline basement.

Applications of HRAM surveys in hydrocarbon exploration have significantly increased recently, due to the development of magnetometers that are more accurate, improved aircraft positioning due to availability of high precision global positioning systems (GPS), and advancements in data processing (Glenn and Badgery 1998; Peirce et al., 1998; Spaid-Reitz and Eick, 1998). Such improvements can be seen in its application to basement structure mapping (Gibson and Millegan, 1998) and intra-sedimentary structure mapping (Grauch et al., 2001; Berger et al., 2008).

Algorithmic advances in extracting detailed information from magnetic data have also gained wide acceptance in recent years (e.g., Grauch and Cordell, 1987; Verduzco et al., 2004; Nabighian, et al., 2005; Salem et al., 2007). Modern processing techniques for aeromagnetic data produce a variety of derivative maps (e.g., tilt-derivative, gradients, and Euler deconvolution depth estimation) that extract important details from the data. Since interpretation of magnetic data is non-unique, interpreting HRAM data calls for an integrated interpretation approach that requires calibration with drilling, gravity, and/or seismic data.

Such integrated approaches have been used in the FWB to establish a link between Precambrian basement structures and sedimentary basin structures and features (Elebiju et al., 2008). Other areas where such links have been established include the Jonah field in the Green River basin, the Doig Sand play in the Horn River basin, and the Bakken play from Williston basin in Canada Stone (2008). HRAM surveys are gradually becoming a tool of choice for imaging subtle, deep Precambrian and shallow sedimentary structures. In these aforementioned basins, the HRAM data and its derivatives were used to image shallow structures and trends not detectable by the seismic data. This methodology has also been used to extend interpretations beyond the limits of existing seismic data coverage. The authors believe that this approach can positively impact how basin scale unconventional plays are mapped and exploited.

GENERAL TECTONIC SETTING OF STUDY AREA

The Fort Worth basin (FWB) is one of the major late Paleozoic foreland basins associated with the Ouachita Orogenic belt located along the southern margin of North

America. It is an asymmetric basin whose structural axis is aligned parallel to the east-bounding and advancing Ouachita structural front. The FWB is bounded on the west by the Bend Arch, to the south by the Llano Uplift, and to the north and northwest by basement uplifts of the Muenster and Red River Arches, which were created by the reactivation of Southern Oklahoma aulacogen basement faults during the Ouachita orogeny (Figure 1) (Walper, 1982; Keller et al., 1989). This classic failed rift intersects the early Paleozoic passive continental margin that was stable until Mississippian time when the Ouachita orogeny began (e.g., Thomas, 1989).

Prior to the late Paleozoic orogeny that affected the FWB, the Grenville Orogeny and Cambrian rifting affected the basement upon which the basin is deposited (Mosher, 1998). However, the Ouachita orogeny controlled the sedimentary history and structural setting of the FWB. The subsidence and sedimentation from the uplifted Ouachita thrust belt resulted in a westward migration of the depocenter with time and the development of the northeast-trending faulted anticlinal flexure across the Llano uplift (Walper, 1982). These northeast trending features disappear to the northeast, where the FWB intersects the Muenster Arch. Deepening northward, the deepest part of the basin is located at its northeast corner adjacent to the Muenster arch, where the sediment thickness reaches about 3700 m (Montgomery et al., 2005).

In the FWB region, late Paleozoic–Mississippian movements periodically reactivated a northeast-southwest trending Precambrian structure that was mapped across the Newark East field. This structure, termed the Mineral Wells fault, is important to exploration within the FWB because it controls sediment deposition, as well as oil and gas distribution. Specifically, it prohibits gas accumulation in the Barnett Shale within the Newark East field, where it intercepts closed fractures (Figure 1). Other minor structures sub-parallel to the Mineral Wells fault and the Ouachita thrust front have been identified by Montgomery et al. (2005).

METHODOLOGY

The integrated geophysical and geological methodology employed in this study consists of 3D seismic data analysis that supplemented by HRAM data analysis. Figures 1 and 2 show the location of the HRAM and 3D seismic data used for the study. Within the FWB, we hypothesize that calibrating HRAM derivative images and HRAM Euler deconvolution results with scattered 3D seismic surveys can provide a means to accurately map and study the relationships between the basement structures and the overlying sedimentary structures in areas where seismic data are unavailable.

HRAM and seismic data

Devon Energy, as part of their Barnett Shale exploitation program, acquired the seismic data used for this study. Pearson, deRidder and Johnson, Inc. on behalf of Mitchell Energy (Devon's Predecessor) acquired the HRAM data during January and February of 2000. The HRAM survey was flown at 152 m ground clearance, with an east-west profile separation of 402 m tied by north-south lines spaced at 805 m. Corrections applied to the HRAM data by Pearson, deRidder and Johnson, Inc. included removing the International Geomagnetic Reference Field (IGRF), leveling, and diurnal correction. Cultural noise was also removed.

Seismic data

Conventional workflows for most seismic interpreters involve the integration of lower vertical resolution but denser areal coverage seismic data with higher vertical resolution, but aerially sparse production, well log, and geologic outcrop data. By design, structural and stratigraphic features in the sedimentary column can be accurately mapped using seismic reflection data and seismic attributes. However, mapping Precambrian features using seismic reflection data can often be a difficult task because reflections from the Precambrian basement are laterally discontinuous due to heterogeneities within the basement and poor signal strength. Wells that penetrate the Precambrian are also very limited. Therefore, potential field data can be used effectively to delineate Precambrian structures.

We adopted a conventional seismic interpretation workflow to interpret sedimentary structures using seismic data and seismic attributes. The seismic attributes were generated in-house, and we extracted the desired attributes along the Ellenburger horizons and the top of basement. We found the coherence and the most-negative curvature attributes to be very useful. Hakami et al. (2004), Sullivan et al. (2006), and Aktepe et al. (2008) have effectively utilized these kinds of attributes to study the various sedimentary features within the FWB. The physical and geometrical features in these attributes use models of dip and azimuth, amplitude, frequency content, and waveform similarity from adjacent seismic samples (Chopra and Marfurt, 2007).

Coherence is a measure of seismic waveform or trace similarity. This attribute is sensitive to lateral changes in the physical models mentioned above, and their lateral sensitivity makes them suitable to map features like faults (Lawrence, 1998) and fractures (Neves et al., 2004) effectively.

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Curvature is a measure of the deviation from a planar geometry based on a calculated quadratic surface derived in three dimensions (Chopra and Marfurt, 2007). Most-negative curvature measures synclinal reflector shapes and this attribute is effective in mapping subtle lineaments (e.g., fractures and faults) within fault blocks (Blumentritt et al., 2006), as well as karst features that appear as bowls or synclines on a carbonate surface, such as the Ellenburger Formation (Akpete et al., 2008).

HRAM data and derivative maps

We resample the HRAM grid to 400 m grid spacing using a minimum curvature algorithm available in a commercial gravity and magnetic processing and interpretation software package. This grid spacing is appropriate for selecting a window size for our Euler deconvolution depth estimation. For example, an anomaly with a wavelength of 10000 m on data that has a grid spacing of 400 m will require a window size of 25. However, if a larger anomaly is the target, then the grid spacing can be increased (Phillips, 2007).

Before any interpretation is done on the HRAM data, the data need to be reduced-to-the pole (RTP) in order to remove magnetic anomaly distortion caused by varying magnetization inclination and azimuth (Kis, 1990). To highlight local anomalies, we generate a residual total magnetic intensity (TMI) map (Figure 2a) by subtracting grid values calculated by upward continuing the original RTP HRAM data to 5 km, to represent regional anomalies (Figure 2b), from the original grid. Maps for several upward continuation heights (i.e., 1 km, 10 km, etc.) were generated and evaluated before we choose the height that we felt best represented the regional anomaly.

To highlight lateral or abrupt changes in magnetization that can suggest faults or source contacts, we compute the horizontal gradient magnitude (HGM) and horizontal derivative of the tilt derivative from the HRAM data. These derivatives (Figure 3) are edge-detecting derivatives that enhance lateral discontinuities in a TMI grid (e.g., Grauch and Cordell, 1987; Roest et al., 1992; Blakely, 1996; Verduzco et al., 2004). The interpreter still has the responsibility of providing geological meaningful interpretation of what is seen on these maps.

We also attempt to estimate the depth to the top of the Precambrian basement from the HRAM data. Depth estimates from the Euler deconvolution can be employed in areas where seismic data are unavailable or limited to provide an indirect knowledge of overlying sediment thickness (Li, 2003). We attempt to use the results of Euler deconvolution to delineate magnetic anomaly source type and fault trends (Reid et al., 1990). The Euler deconvolution method is an automated depth estimation method (Thompson, 1982) that can help determine the location or depth to the shallowest or deepest reasonable magnetic source or edges for various geological sources such as, dikes, faults, magnetic contacts, and extrusives (Phillips, 2007). It utilizes the structural index N, which is used to describe the geometry of the desired geologic structure, as a geological constraint (Reid et al., 1990; Barbosa et al., 1999). Three-dimensional Euler depth estimation on a magnetic grid data requires selecting a desired range of structural indices (i.e. N = 0.0, 0.5, and 1.0) and the size of a square window for analysis within the grids. Window size should be determined based on the grid size and anomaly length (Phillips, 2007). The window should be large enough to contain the curvature of the anomaly of interest without compromising lateral resolution, yet small enough to reduce interference from an adjacent anomaly without yielding poor results (Reid et al., 1990).

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INTEGRATED ANALYSIS AND INTEGRATED INTERPRETATION

Area of Seismic Survey A

Our integrated analysis and interpretation is based on areas where seismic and HRAM data are both available (Figure 2 and 3). In Seismic Survey A, 3D visualization views of the coherence horizon slice extracted along the Ellenburger Formation and a north-south seismic section view shows two major faults systems (orange and blue arrows) (Figure 4a). Faults that trend east-west and northeast-southwest agree with previous interpretations by Sullivan et al. (2006), as a wrench (regional strike-slip) fault (blue arrows) and antithetic strike-slip faults (orange arrows) that penetrate the Precambrian basement. Circular collapse features (indicated by yellow arrows) seen on the coherence horizon slice are aligned along northeast and northwest orientation (red-dashed lines in Figure 4a) and correlate to intersection of the valley-shaped lineaments seen on the most-negative curvature slices. The circular collapse features that are often associated with cockpit karst and karst collapse features are clear on the most-negative curvature attribute. The most-negative curvature attribute enhances features with a bowl or valley shape usually exhibited by the collapse features. Faults interpreted on the coherence horizon slice (Figure 4a) are also seen on the most-negative curvature horizon slice, when the two attributes are co-rendered into a composite display (Figure 4b).

In order to compare structures seen within the sedimentary section via seismic attributes with Precambrian basement structures, we generate a series of derivative magnetic maps. Within the area occupied by Seismic Survey A, the horizontal gradient magnitude and the horizontal derivative of the tilt derivative anomaly map generated from the HRAM data (Verduzco et al., 2004) show a lineament trend that is parallel to the wrench fault interpreted from the seismic data. However, the east-west strike-slip fault interpreted on the seismic data could not be indentified on the derivative anomaly maps (Figure 3). This inability to image the strike-slip fault on the derivative maps could suggest the strike-slip fault may not penetrate into the basement or does not have a significant displacement to cause a magnetic susceptibility contrast.

Euler deconvolution computations using values of N=1 (Figure 5a) and N=0 (Figure 5b) are designed to delineate low-displacement and large-displacement faults respectively (Reid et al., 1990). Within the area of Seismic Survey A, we notice linear clustering of depth solutions (N=1.0) that trend northeast and northwest (Figure 6b). Northeast trending lineaments indicated by the blue arrow are consistent with the northeast lineament and northeast strike-slip fault identified on the derivative maps and seismic attribute data respectively (Figure 3 and 4).

The strike-slip fault located at the southeast corner of Seismic Survey A also correlates with a derivative anomaly that is also parallel to the northeast trending anomalies (white arrows) located about 25 km east of Seismic Survey A (Figure 3). Based on our workflow, we predict that a northeast trending fault will be present within the sedimentary section above these anomalies. Although, the seismic data for that location was not available for this study, a northeast trending basement penetrating sedimentary fault termed the "Mineral Wells fault" (Montgomery et al., 2005) has been interpreted on seismic data at this location (Perez et al., 2009). Thus, this interpretation suggests that HRAM data can also be used to predict sedimentary features where seismic data is unavailable or limited.

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Area of Seismic Survey B

Seismic Survey B (Figure 7) shows more diverse lineaments orientations than survey A. We identified three lineaments on the coherence and most-negative curvature horizon slices at the Ellenburger Formation. Two orthogonal lineaments trend northeast (blue arrows) and northwest (black arrows) in addition to an east-west (orange arrow) lineament (Figure 7). We interpret three lineaments as faults that penetrate the Precambrian basement based on the intrabasement horizon shown in Figure 8.

To generate the rose diagram we picked the trends of anomalies on the horizontal gradient magnitude map. Trend on faults interpreted on seismic data parallel anomaly trend on the horizontal gradient magnitude map as indicated by the rose diagram plot shown in Figures 3, 7, and 9. Similarly, the linear clustering of Euler depth solutions are parallel to faults interpreted on the seismic data (Figure 9b). These similarities in orientations between sedimentary and Precambrian basement structures are common to both survey areas (Figures 6b and 9b).

Based on the analysis of all the available datasets, we indentify three trends of lineaments within the study area. The lineaments within the sedimentary section strike northeast, northwest and east-west. Such lineaments are correlated to healed fractures (Rich, 2008). Simon (2005) shows measured borehole breakout using image logs to be northeast. In those wells, the maximum horizontal stress estimated by velocity anisotropy is dominantly northeast, the hydrofractures measured using microseismic propagate predominantly northeast. In other more "isotropic" areas, the hydrofractures form a relatively uniform northeast-northwest grid. Precambrian basement lineaments predominantly trend northeast and northwest.

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The northwest-directed Ouachita orogenic compression controlled the depositional history and the types of structures found within the FWB. For example, northeast trending normal faults and anticlinal flexures of Atokan age that offset the basement developed across the exposed Llano uplift, which is located south of the FWB. According to Ewing (1991), these northeast-trending features disappear to the northeast toward the Muenster Arch.

In contrast, the natural fractures have orientations parallel to the northwest trending lineaments that are parallel to the Muenster Arch fault, which is a reactivated basement fault. Another lineament study conducted east of the FWB near the Ouachita thrust front subcrop, indicates that faults and surface lineaments trends are sub-parallel to the Ouachita basement structural fabric (Caran et al., 1981). Pre-existing basement faults associated with formation of the Cambrian-rifted southern edge of the North American craton may be related to both the Muenster Arch and the Ouachita thrust (Hale-Erlich and Coleman, 1993). Thus, the lineaments within the study area appear to be following the zones of weakness within the basement that may have been reactivated and propagated through the sedimentary section. On a regional scale, strains generally are related to deep crustal movements during reactivation and may be directly expressed as faults and shear zones in the overlying sedimentary cover (Jacques, 2003).

In summary, we interpret the structures identified within the sedimentary section in this study to be related to the basement structures because lineaments indentified with the aid of a seismic attributes are aligned parallel to basement features indentified with the aid of HRAM data.

CONCLUSIONS

The orientation of faults and collapse features mapped using seismic attributes are parallel to trends mapped using the high-resolution aeromagnetic (HRAM) data in the Fort Worth basin (FWB). The northeast-southwest and northwest-southeast orientation of these features are consistently parallel with Precambrian structural fabric that form large scale structures such as the northeast trending Ouachita orogenic belt and the northwest trending Muenster Arch, which is a reactivated Precambrian fault. We interpret the propagation of the Precambrian structural fabric through the sedimentary section along zones of weakness is responsible for creating the linear faults and joints in the Paleozoic section.

Based on the analysis of the HRAM data we predict the occurrence of the northeast fault systems beneath the Mineral Wells fault where seismic data are absent, and confirm this prediction with an independent seismic study (Perez et al., 2009).

Calibrating non-unique, large scale, lower resolution, less expensive HRAM data with moderate scale, higher resolution, more expensive seismic data enhances our prediction where seismic data are unavailable or limited.

While the FWB is now covered by dozens of 3D seismic surveys, basin-scale shale reservoirs are currently being developed throughout North America, as well as in Eastern Europe and southern Africa. We believe our methodology will be useful in mapping basement structures, that coupled with an appropriate geologic model, can help choose location for more expensive 3D seismic surveys. In frontiers areas where seismic data is limited, HRAM data can be cheaply used to determine the lateral extent of structures interpreted on seismic data. Acquisition of HRAM data is also faster to acquire than seismic data, thus exploration cycle-time can be significantly reduced.

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Our results have shown that the integration of derivative images from high resolution aeromagnetic data with scattered 3D seismic surveys can provide a means of effectively mapping basement features and establishing a links between the basement and sedimentary structures within the north central part of the FWB. The knowledge gained here will positively impact oil and gas exploration and development within the study area because the orientation of the natural can be predicted even if seismic data is limited or unavailable. Mapping such features can aid in the design of the hydrofracture program and provide help in predicting which area of the basin may be more structurally deformed.

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References

Aktepe, S., K. J. Marfurt, and R. Perez, 2008, Attribute expression of basement faulting - Time versus depth migration: The Leading Edge, **27**, 360-367.

Barbosa, V. C. F., J. B. C. Silva, and W. E. Medeiros, 1999, Stability analysis and improvement of structural index estimation in Euler deconvolution: Geophysics, **64**, 48-60.

Barosh, P. J., 1995, A brief history of basement tectonics and the international basement tectonics conferences, *in* R. W. Ojakangas, A. B. Dickas, and J. C. Green, ed., Basement Tectonic **10**: Kluwer Academic Publisher, xvii-xxi.

Berger, Z., M. Boast, and M. Mushayandebvu, 2008, The contribution of integrated HRAM studies to exploration and exploitation of unconventional plays in North America: Reservoir, **35**, 42-48.

Blakely, R. J., 1996, Potential theory in gravity and magnetic applications: Cambridge University Press.

Blumentritt, C. H., K. J. Marfurt, and E. C. Sullivan, 2006, Volume-based curvature computations illuminate fracture orientations - Early to mid-Paleozoic, Central Basin Platform, west Texas: Geophysics, **71**, B159-B166.

Caran, S. C., C. M. Woodruff, and E. J. Thompson, 1981, Lineament analysis and inference of geologic structure - Examples from the Balcones/Ouachita trend of Texas: Transactions - Gulf Coast Association of Geological Societies, **XXXI**, 59-69.

Chopra, S., and K. J. Marfurt, 2007, Seismic Attributes for Prospect Identification and Reservoir Characterization, *in* S. J. Hills, ed., Society of Exploration Geophysicists Geophysical Development Series No. **11**.

Elebiju, O. O., G. R. Keller, and K. J. Marfurt, 2008, New Structural mapping of basement features in Fort Worth Basin, Texas, using high-resolution aeromagnetic derivatives and Euler depth estimates: 78th Annual international meeting, SEG, Expanded Abstracts, **27**, 844.

Ewing, T. E., 1991, The tectonic framework of Texas, *in* W.L. Fisher, ed., Text to accompany "The Tectonic Map of Texas": Bureau of Economic Geology - The University of Texas at Austin, scale 1:750,000.

Gerhard, L. C., and S. B. Anderson, 1988, Geology of the Williston Basin (United States portion), *in* L. L. Sloss, ed., Sedimentary cover - North American Craton, U.S.: Boulder, Geological Society of America, The Geology of North America, **D-2**, 221-241.

Gibson, R. I., and P. S. Millegan, 1998, Geologic applications of gravity and magnetics: Case history: Society of Exploration Geophysicists - Geophysical References Series, No. **8**.

Glenn, W. E., and R. A. Badgery, 1998, High resolution aeromagnetic surveys for hydrocarbon exploration: Prospect scale interpretation: Canadian Journal of Exploration Geophysics, **34**, 97-102.

Grauch, V. J. S., and L. Cordell, 1987, Limitation of determining density or magnetic boundaries from the horizontal gradient of gravity or pseudogravity data: Geophysics, **52**, 118-121.

Grauch, V. J. S., M. R. Hudson, and S. A. Minor, 2001, Aeromagnetic expression of faults that offset basin fill, Albuquerque basin, New Mexico: Geophysics, **66**, 707-720.

Hakami, A. M., K. J. Marfurt, and S. Al-Dossary, 2004, Curvature attributes and seismic interpretation: Case study from Fort Worth Basin, Texas, USA: 74th Annual international meeting, SEG, Expanded Abstracts, **23**, 554.

Hale-Erlich, W. S., and J. L. Coleman, 1993, Ouachita-Appalachian juncture: a Paleozoic transpressional zone in the southeastern USA: American Association of Petroleum Geologist Bulletin, **77**, 552-568.

Jacques, J. M., 2003, A tectonostratigraphic synthesis of the Sub-Andean basins: implications for the geotectonic segmentation of the Andean Belt: Journal of the Geological Society of London, **160**, 687-701.

Keller, G. R., J. M. Kruger, K. J. Smith, and W. M. Voight, 1989, The Ouachita system: A geophysical overview, *in* R. D. Hatcher, W. A. Thomas, and G. W. Viele, ed., The Appalachian-Ouachita Orogeny in the United States: Boulder, Colorado, Geological Society of America, The Geology of North America: Geological Society of America, **F-2**, 689-694.

Kis, K. I., 1990, Transfer properties of the reduction of magnetic anomalies to the pole and to the equator: Geophysics, **55**, 1141-1147.

Lawrence, P., 1998, Seismic attributes in the characterization of small-scale reservoir faults in Abqaid field: The Leading Edge, **17**, 521-525.

Li, X., 2003, On the use of different methods for estimating magnetic depth: The Leading Edge, **22**, 1090-1099.

Montgomery, S. L., D. M. Jarvie, K. A. Bowker, and R. M. Pollastro, 2005, Mississippian Barnett Shale, Fort Worth basin, north-central Texas: Gas shale play with multi-trillion cubic foot potential: American Association of Petroleum Geologist Bulletin, **89**, 155-175.

Mosher, S., 1998, Tectonic evolution of the southern Laurentian Grenville orogenic belt: Geological Society of America Bulletin, **110**, 1357-1375.

Nabighian, M. N., V. J. S. Grauch, R. O. Hansen, T. R. LaFehr, Y. Li, J. W. Peirce, J. D. Phillips, and M. E. Ruder, 2005, The historical development of the magnetic methods in exploration: Geophysics, **70**, 33ND-61ND.

Neves, F., M. S. Zahrani, and S. W. Bremkamp, 2004, Detection of potential fractures and small faults using seismic attributes: The Leading Edge, **23**, 903-908.

Peirce, J. W., W. E. Glenn, and K. C. Brown, 1998, High resolution aeromagnetic for hydrocarbon exploration - Special Issue: Presented at the Canadian Society of Exploration Geophysicists (CSEG) Forum.

Phillips, J. D., 2007, Geosoft executables (GX's) developed by the U.S. Geological Survey, version 2.0 with notes on GX development from Fortran code: U.S. Department of Interior, U.S. Geological Survey.

Perez, R., O. O. Elebiju, and E. Baruch, 2009, Geophysical evidence of basement controlled faulting in the Ellenburger Group and Viola Limestone, Fort Worth Basin, Texas: paper accepted for presentation at the 79th annual Society of Exploration Geophysicists (SEG) meeting in Houston, Texas.

Plotnikova, I. N., 2006, Nonconventional hydrocarbon targets in the crystalline basement, and the problem of recent replenishment of hydrocarbon reserves: Journal of Geochemical Exploration, **89**, 335-338.

Reid, A. B., J. M. Allsop, H. Granser, A. J. Millett, and I. W. Somerton, 1990, Magnetic interpretation in three dimensions using Euler deconvolution: Geophysics, **55**, 80-91.

Rich, J., 2008, Expanding the applicability of curvature attributes thorgh clarification of ambiguities in derivation and terminology: 78th Annual international meeting, SEG, Expanded Abstracts, **27**, 884.

Roest, W. R., J. Verhoef, and M. Pilkington, 1992, Magnetic interpretation using 3-D analytical signal: Geophysics, **57**, 116-125.

Salem, A., S. William, J. D. Fairhead, D. Ravat, and R. Smith, 2007, The meter reader - Tilt-depth method: A simple depth estimation method using first-order derivatives: The Leading Edge, **26**, 1502-1505.

Simon, Y. S., 2005, Stress and fracture characterization in a shale reservoir, North Texas, using correlation between new seismic attributes and well data: Master of Science, University of Houston.

Spaid-Reitz, M. K., and P. M. Eick, 1998, HRAM as a tool for petroleum system analysis and trend exploration: A case study of the Mississippi Delta survey, southeast Louisiana: Canadian Journal of Exploration Geophysics, **34**, 83-96.

Stone, C., 2008, Technology sweeps data from basement: HRAM "flies low" over subtleties: American Association of Petroleum Geologist Explorer, **29**, 22.

Sullivan, E. C., K. J. Marfurt, A. Lacazette, and M. Ammerman, 2006, Application of new seismic attributes to collapse chimneys in the Fort Worth basin: Geophysics, **71**, B111-B119.

Thomas, W. A., 1989, The Appalachian-Ouachita orogen beneath the Gulf Coastal Plain between the outcrops in the Appalachian and Ouachita Mountains, *in* R. D. Hatcher, W. A. Thomas, and G. W. Viele, ed., The Appalachian-Ouachita Orogen in the United States: Boulder, Colorado, Geological Society of America, The Geology of North America: Geological Society of America, **F-2**, 537-553.

Thomas, W. A., and D. L. Baars, 1992, A North American continental-scale fracture zone (Abstract): Presented at the Structural styles in the Southern Midcontinent - a workshop; Abstract and Program, Oklahoma Geological Survey.

Thompson, D. T., 1982, EULDPH: A new technique for making computer-assisted depth estimates from magnetic data: Geophysics, **47**, 31-37.

Verduzco, B., D. J. Fairhead., C. M. Green, and C. MacKenzie, 2004, The meter reader - New insight into magnetic derivatives for structural mapping: The Leading Edge, **23**, 116-119.

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

Wilson, F. W., and P. Berendsen, 1998, The role of recurrent tectonics in the formation of the Nemaha Uplift and Cherokee-Forest City Basins and adjacent structural features in eastern Kansas and Contiguous State, USA (abstact), *in* J. P. Hogan, and M.C. Gilbert, ed., Basement Tectonics 12 Central North America and other regions: Kluwer Academic Publishers, **12**, 301-303.

FIGURE CAPTIONS

Figure 1. Map showing the Fort Worth Basin province and its major surrounding structural features (e.g., Mineral Wells fault, Bend Arch, Muenster Arch, etc). The shaded rectangle shows the location of the seismic and high-resolution aeromagnetic (HRAM) data used in this study. (Adapted after Pollastro et al., 2007).

Figure 2. (a) Reduced-to-pole (RTP) residual total magnetic intensity map (TMI) generated by subtracting the 5 km upward continuation grid from the TMI grid. Square cyan boxes shows the location of the seismic data used in this study. (b) Map showing the 5 km upward continuation grid that was subtracted from the original TMI map to produce the RTP map shown in Figure 2a. Broad anomalies are related to deep regional features that masked the more local crustal features that are enhanced on the residual RTP map.

Figure 3. (a) Horizontal gradient magnitude (HGM) computed from the TMI anomaly map displayed in Figure 2a. Maxima are located at magnetic source edges. Black arrows indicate maxima with northwest trend direction. (b) Total horizontal derivative of the tilt derivative. Lineament orientations discussed in the text. White arrows indicate the location of northeast trending maxima where we predicted a northeast trending fault will be present within the sedimentary section. Mineral Wells fault has been interpreted on seismic at this location (Perez et al., 2009).

Figure 4. Ellenburger horizon slices through (a) coherence and (b) co-rendered most-

negative curvature horizon volumes with coherence volume, computed from Seismic Survey A. Orange arrows indicate a major east-west fault with a strike-slip displacement. Blue arrows indicate northeast lineaments that are consistent with the interpretation of Hakami et al. (2004) and Sullivan et al. (2006). Yellow arrows and red-dashed lines indicate collapse features that follow the northeast and northwest structural lineaments. Inset rose diagram shows the trend of major lineaments mapped manually on the Ellenburger Formation surface.

Figure 5. Euler deconvolution cluster plots computed using structural indices of (a) N=1.0, appropriate for delineating low-displacement faults and (b) N=0.0 appropriate for delineating large displacement faults.

Figure 6. Zoomed-in section of (a) the horizontal gradient magnitude and (b) the Euler deconvolution cluster plot with N value of 1.0 for the area of Seismic Survey A. Blue and orange lines are faults interpreted from the seismic data. The northeast faults appear parallel to linear trend (blue arrow) from the Euler deconvolution estimation, which reflect basement structures. Inset rose diagram shows the trend of major lineaments mapped manually on the horizontal gradient magnitude map.

Figure 7. Ellenburger horizon slices through (a) coherence and (b) co-rendered most-negative curvature horizon volumes with coherence volume computed from Seismic Survey B. The orange arrows (east-west lineaments), blue arrows (northeast

lineaments), and black arrows (northwest lineaments), are the major faults interpreted.

Figure 8. Horizon slices along the basement through (a) coherence and (b) co-rendered most-negative curvature horizon volumes with coherence volume, computed from Seismic Survey B. The orange arrows (east-west lineaments), blue arrows (northeast lineaments), and black arrows (northwest lineaments), are the major faults interpreted. Intra-sedimentary structures appear to penetrate the Precambrian basement.

Figure 9. (a) Zoomed-in section of (a) the horizontal gradient magnitude and b) the Euler deconvolution cluster plot with a value of N = 0.0 corresponding to the area of Seismic Survey B. Blue, orange, and black lines are faults interpreted from the seismic data in Figures 7 and 8. The northeast, northwest, and east-west faults appear parallel to linear trends from the Euler deconvolution depth estimation that follow basement structures. Inset rose diagram shows the trend of major lineaments mapped manually on the horizontal gradient magnitude map.

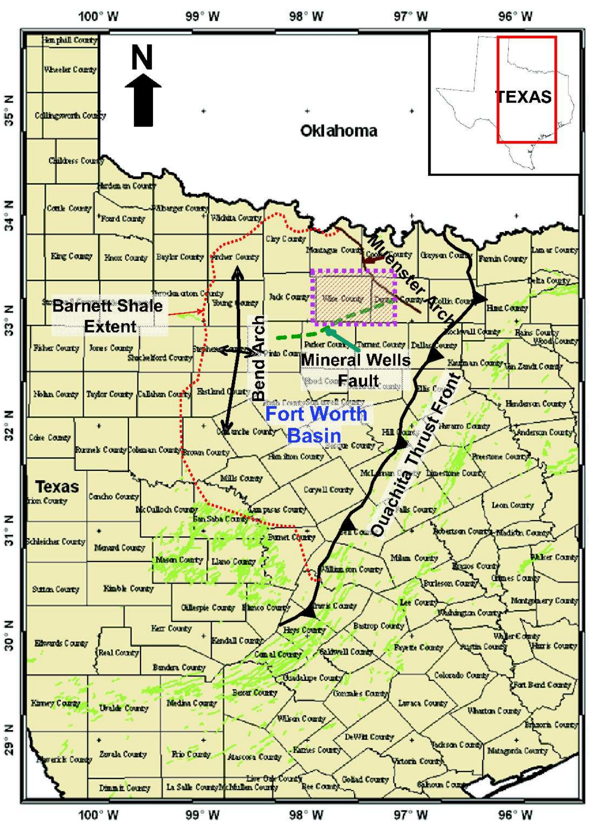

Figure 1.

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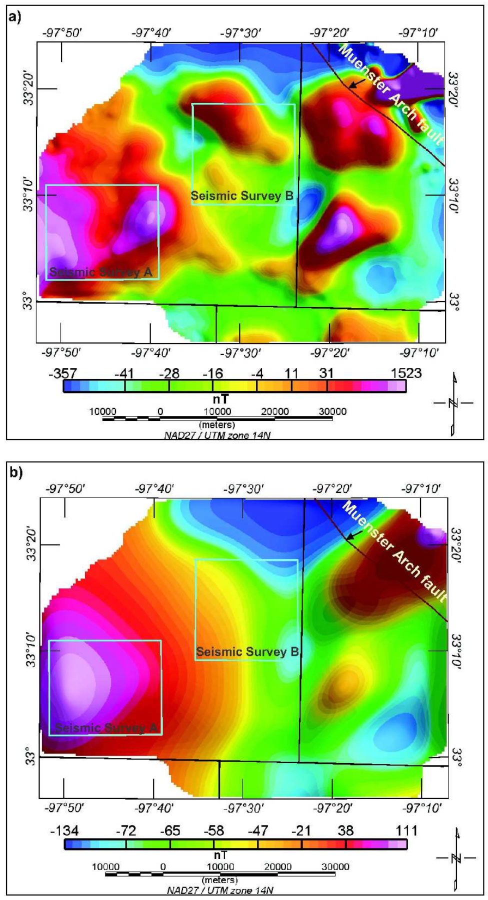

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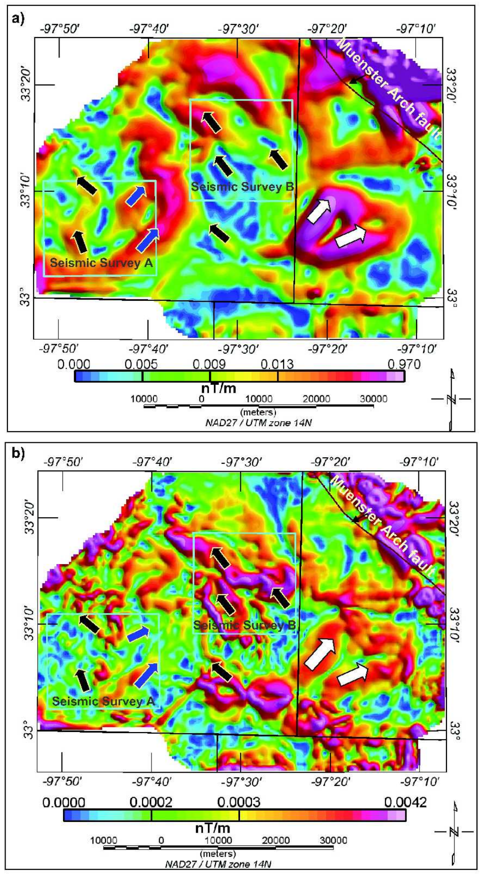

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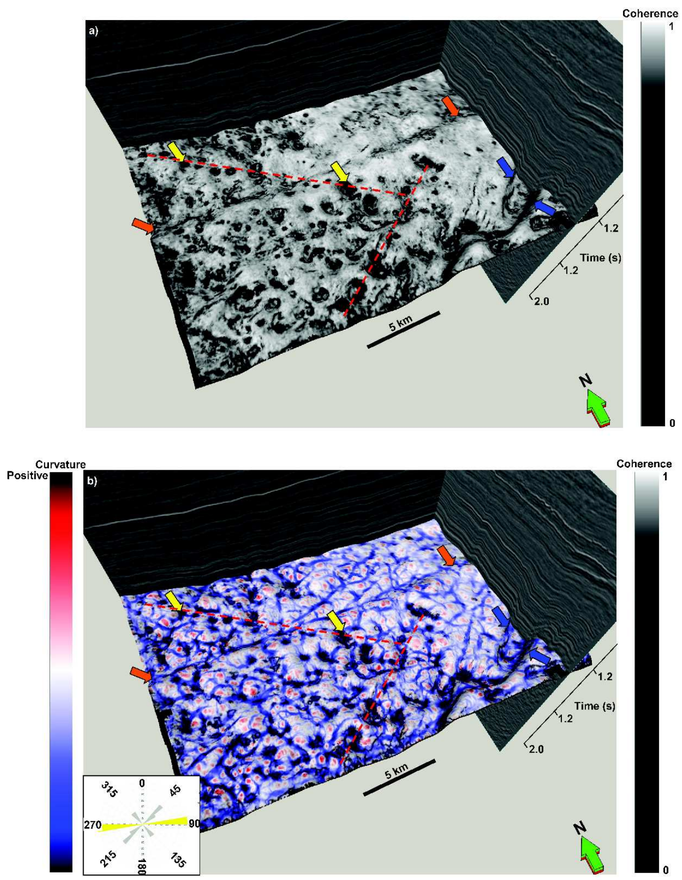

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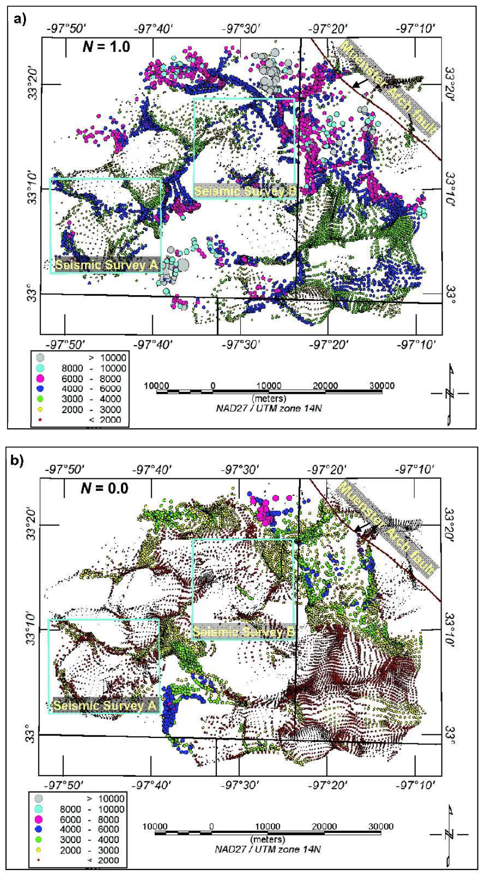

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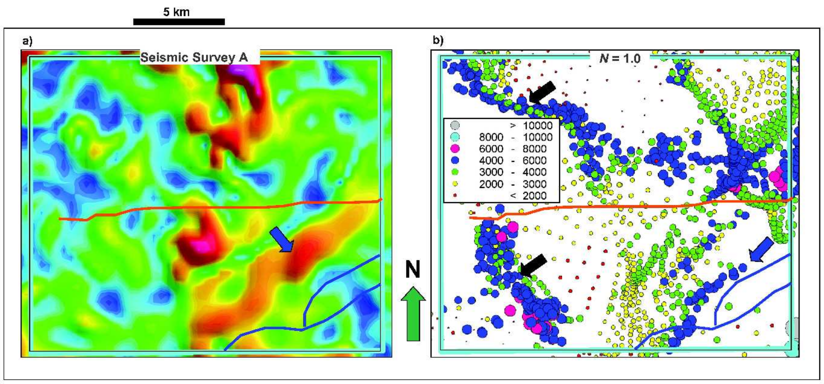

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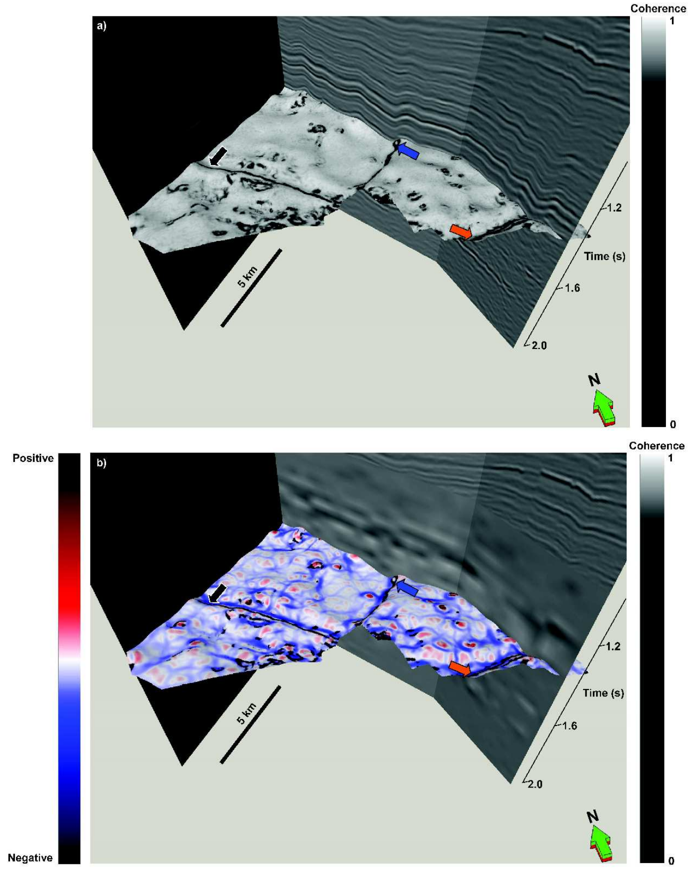

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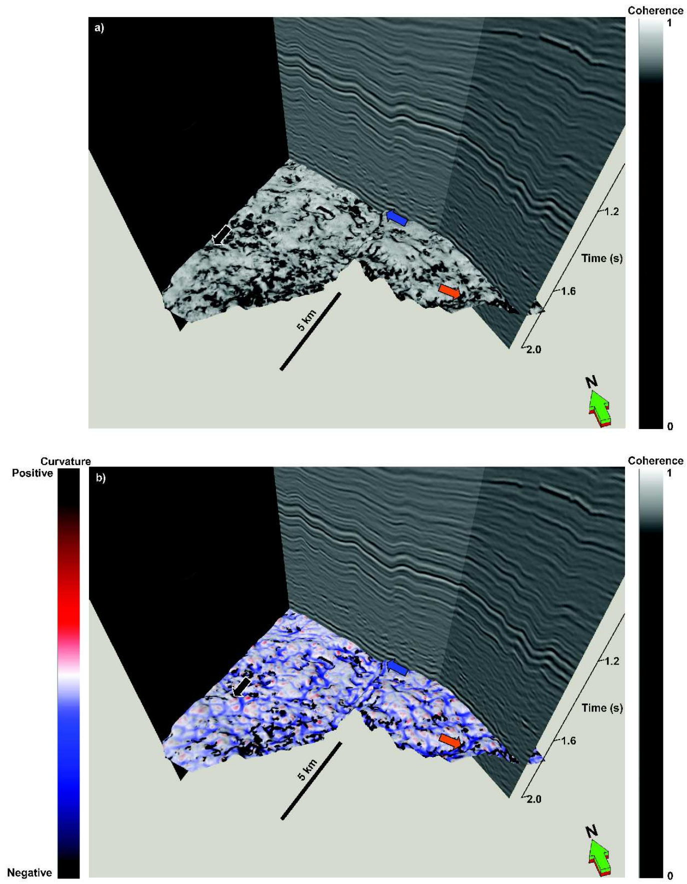

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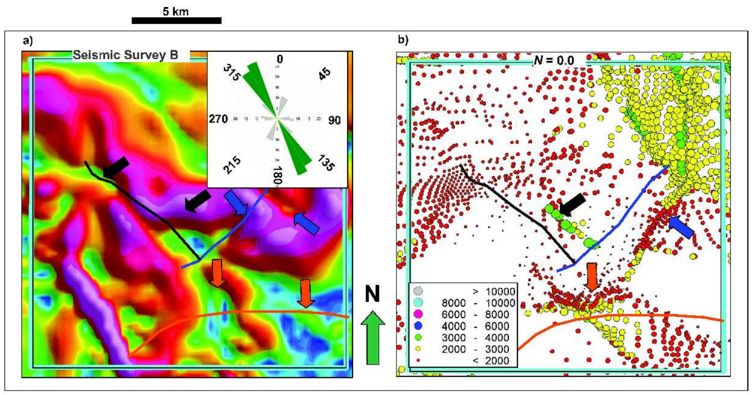

Figure 9.

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