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Subsurface Geologic Characterization of Johnson County, Texas, in Support of Induced Seismicity Modeling*

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Abstract

The Fort Worth Basin (FWB) in north-central Texas has seen a surge in shale-gas drilling and associated hydraulic fracturing in the Barnett Shale. The FWB is a structural basin bounded by the Ouachita Thrust Zone to the east and the Muenster Arch to the north. Disposal of most of the hydraulic fracturing fluids and subsequent produced water from the wells is into a deep carbonate formation, the Ellenburger Dolomite, which underlies the Barnett Shale. This disposal appears to be associated with seismic activity. An attempt is being made to model the disposal of these fluids into the Ellenburger and develop methods to predict the most likely places of seismic activity. A working model could assist in mitigating the strength of seismic activity through providing optimum disposal rates, optimum disposal well siting, and prediction of potentially imminent seismicity.

To develop models to simulate the disposal of hydraulic fracturing fluids, a geologic framework of the area is required. This framework includes the distribution, thickness, and depth of major geologic units, and the distribution of existing fractures and faults in the area. To develop this geologic framework, data from over 350 wells within and adjacent to Johnson County were reviewed along with nearly 300 geophysical logs obtained from the Texas Railroad Commission and IHS, a well information service.

These data show that the depth and thickness of major units generally increases eastward toward the Ouachita Thrust Zone on the east side of Johnson County. The principal unit of interest, the Ellenburger, ranges from 5,600 to 10,000 feet in depth and its thickness increases from about 2,400 feet to the northwest to 3,400 feet near the Ouachita Thrust Zone. These increases are in agreement with the geologic literature.

Structure contour maps in conjunction with the cross sections indicate potential fault zones that trend north-northeast near the Ouachita Thrust and east-northeast in the western part of the county. The faults near the thrust correspond with faults in Ewing (1990) and Elebiju (2010). Potential faults to the west more closely follow faulting presented in Turner (1957), which are slightly different from those presented by Ewing.

The data compiled gives a starting point for modeling the injection of hydraulic fracturing fluids and the potential effects of this on nearby faults and fractures. These data can be used to create seismic models to assist regulators in mitigating seismic activity due to hydraulic fracturing fluid disposal.

Introduction

The Fort Worth Basin (FWB) in north-central Texas has seen a surge in shale-gas drilling and associated hydraulic fracturing in the Barnett Shale. This basin is a structural basin bounded by the Ouachita Front to the east and the Muenster Arch to the north (Figure 1). The hydraulic fracturing fluids and subsequent produced water from the Barnett wells must be disposed of, and most of this disposal is into a deep carbonate unit, the Ellenburger Group dolomite, which directly underlies the Barnett Shale over most of Johnson County.

Johnson County is an area of general geologic stability with very few earthquakes prior to shale-gas development, but since shale gas development, the number of earthquakes has mushroomed. Most of these earthquakes cannot be felt by residents in the area, but a few have caused damage. These earthquakes have been shown to be associated with the disposal of produced water in injection wells (Frohlich et al., 2015). For background, when produced water is injected into the Ellenburger unit, stress builds up within this aquifer until that stress is relieved by an earthquake (Figure 2). Stress relief can also occur if the injected water moves up into another formation, such as the Barnett, where stress is much lower due to the removal of water from that unit.

Most of the documented earthquake epicenters occur within Johnson County and an area near the Dallas-Fort Worth airport in Tarrant County (Figure 3), and these epicenters ranged from about 1.6 km to nearly 5 km depth (Justinic et al., 2013), often within the basement rocks below the Paleozoic carbonates. Yet injection wells are scattered throughout the Fort Worth Basin. An obvious question is, why earthquakes are generally limited to Johnson County and an area to the northeast, near the Dallas-Fort Worth Airport, and not in other areas with injection wells?

An attempt is being made to model the disposal of these fluids into the Ellenburger and develop methods to answer this question and to predict the most likely places of seismic activity. A working model could assist in mitigating the intensity and frequency of seismic activity through providing optimum disposal rates, optimum disposal well siting, and prediction of potentially imminent seismic activity (Eastman and Murin, 2016).

To develop models to simulate the disposal of hydraulic fracturing fluids, a geologic framework of the area is required. This framework includes the distribution, thickness, and depth of major geologic units, and the distribution of existing fractures and faults in the area. This geologic framework is the basis of this study.

Geology of Johnson County, Texas

To develop this geologic framework, well data reports from over 350 wells and nearly 300 geophysical logs within and adjacent to Johnson County were obtained from the Texas Railroad Commission (RRC, 2015), the Texas Bureau of Economic Geology (2014), and IHS (2015), a well information service (Figure 4). The geophysical logs were evaluated for depth to the various geologic units, in conjunction with the associated well data report. These data were then compiled and Surfer® and Strater® were used to provide cross sections across the county and structure contour maps of specific units of interest to the seismic modelers. Geologic units were identified primarily based on the well data reports and the geologic literature (e.g. Montgomery et al., 2005; Turner, 1957). These geologic units determined by this study are presented in Table 1 and graphically in Figure 5.

Some authors place the Marble Falls unit entirely within the Pennsylvanian (e.g. Pollastro et al., 2007). The Marble Falls unit grades from dominantly limestone to the west to dominantly shale to the east. The Viola, a carbonate with sand units, overlies a portion of the Ellenburger in the northeastern part of the study area (Turner, 1957).

The data compiled for this report show that the depth of major units generally increases eastward toward the Ouachita Front, a major structure on the east side of Johnson County. This trend is shown in the cross sections given in Figure 6 and is in agreement with all reports on the FWB geology (e.g. Montgomery et al., 2005; Turner, 1957). The principal unit for produced water injection, the Ordovician Ellenburger Group, underlies the Barnett Shale with a depth of about 5,000 to 10,000 feet deep, increasing eastward. Its thickness ranges from about 2,400 feet to the northwest to 3,400 feet near the Ouachita Front. This eastward thickening is, again, in agreement with the geologic literature.

Geophysical logs to the basement rocks show that the Cambrian unit appears to be about 850 to 1,000 feet thick. The depth to the Cambrian varies from about 8,500 to 13,500 feet, increasing eastward. The thickness and depth correlate with other geologic and geophysical studies of the FWB (e.g. Elebiju et al., 2010).

Structure contour maps, in conjunction with the cross sections, were used to evaluate potential faulting and fracturing and relate this to published faulting in the literature (Figure 7). Potential fault zones appear to trend north-northeast near the Ouachita Front and east-northeast in the western and central parts of the county. Some probable cross faults were noted, approximately east-west near the thrust, and northwest-southeast farther west. The faults near the thrust correspond with faults in Frohlich et al. (2015), Ewing (1990), and Elebiju (2010). The potential faults to the west more closely follow faulting presented in Turner (1957) (Figure 8), which are slightly different from those presented by Frohlich et al. (2015) (Figure 3).

The data compiled give a starting point for modeling the injection of hydraulic fracturing fluids and the potential effects of this on nearby faults and fractures. These data can be used to assist regulators in mitigating the effects of fluid disposal on seismic activity. In addition, these data may be useful to other researchers studying the geology in the Fort Worth Basin. A more complete report on this study is presented in Eastman and Murin (2016). For this presentation, geophysical logs and well data reports for about 60 additional wells were examined.

Oklahoma-Kansas Study

Due to the abundance of induced seismic events in Oklahoma, a study was also begun in north-central Oklahoma and adjacent Kansas. The geologic data was compiled using well logs obtained from the Oklahoma Corporation Commission (2016), the Kansas Corporation Commission (2016), and the IHS well log database (2015). This study was not completed prior to Dr. Eastman's retirement from AECOM. It is hoped that this study would be continued at NETL, as the data compiled for this study could also be used for induced seismicity modeling in that area of Oklahoma and Kansas. A preliminary structure contour map of the top of the Mississippian Lime is presented in Figure 9, and other contour maps have been produced for the top of the Arbuckle Group, essentially equivalent to the Ellenburger Dolomite, and the basement rocks.

Acknowledgements

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References Cited

Eastman, H.S., and T. Murin, 2016, Geologic characterization of Johnson County, Texas, NETL-TRS-17- 2016: NETL Technical Report Series, U.S. Department of Energy, National Energy Technology Laboratory, Morgantown, WV.

Elebiju, O.O., G.R. Keller, and K.J. Marfurt, 2010, Investigation of links between Precambrian basement structure and Paleozoic strata in the Fort Worth basin, Texas, U.S.A., using high-resolution aeromagnetic (HRAM) data and seismic attributes: Geophysics, v. 75/4, p. B157-B168.

Ewing, T., 1990, Tectonic Map of Texas: Univ. Texas Bureau of Economic Geology, Austin, TX.

Frohlich, C., J. Gale, and P. Eichhubl, 2015, Relationships between induced seismicity and fluid injection: Development of strategies to manage fluid disposal in shale hydrocarbon plays – Draft Final Report: RPSEA Project No. 11122-27.

IHS Enerdeq® Browser, IHS Energy, 2015, Website accessed June 16, 2017. https://my.ihsenergy.com/

Justinic, A.H., B. Stump, C. Hayward, and C. Frohlich, 2013, Analysis of the Cleburne, Texas, earthquake sequence from June 2009 to June 2010: Bull. Seismological Soc. of America, v. 103, p. 3083-3093.

Kansas Corporation Commission, 2015, Oil and Gas well log database, Website accessed June 16, 2017. http://www.kgs.ku.edu/Magellan/Logs/index.html

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

NETL, 2015, Mid-continent fault database, MidCont_BasementFaults shape files.

Oklahoma Corporation Commission, 2015, Oil and Gas well records. Websites accessed June 16, 2017. http://www.occeweb.com/og/oghome.htm and http://occpermit.com/wellbrowse/

Oklahoma Geological Survey, 2015, Oklahoma fault database. Website accessed June 16, 2017. http://www.ou.edu/content/ogs/data/fault.html

Pollastro, R.M., D.M. Jarview, R.J. Hill, and C.W. Adams, 2007, Geologic framework of the Mississippian Barnett shale, Barnett-Paleozoic total petroleum system, Bend arch-Fort Worth Basin, Texas: American Association Petroleum Geologists Bulletin, v. 91, p. 405-436.

Texas Bureau of Economic Geology, 2014, Gage well log, Johnson County, Texas: University of Texas at Austin.

Texas Railroad Commission (RRC), 2015, RRC Oil and Gas Well Records. Websites accessed June 16, 2017. http://www.rrc.state.tx.us/about-us/resource-center/research/ and Public GIS Viewer http://wwwgisp.rrc.state.tx.us/GISViewer2/

Turner, G.I., 1957, Paleozoic stratigraphy of the Fort Worth Basin, *in* W.C. Bell, ed., Abilene and Fort Worth Geological Societies Joint Field Trip Guidebook, p. 57-77.

Table 1. Major geologic units and unit thicknesses. Unit names based on geologic descriptions in Turner, 1957, and in geologic depths given in well data reports (RRC, 2015)

	Thickness (ft)			
Geologic Unit	**From**	**To**	**Average**	**Note**
Cretaceous	**600**	**2400**	**NR**	**Unconformity at base**
Upper Strawn-Atoka sand and shale	0	2500	700	**Pennsylvanian**
Upper Atoka Shale	1440	3930	2870	
Atoka and Grant Sandstones, Bend Conglomerate	40	1620	440	
Smithwick shale	50	3200	1050	
Big Saline Limestone-Clastics and Hood Sandstone	20	600	140	
Lower Smithwick Shale	20	950	150	
Total Pennsylvanian units	**2068**	**5790**	**4150**	
Marble Falls Limestone-Shale	90	760	360	**Penn.-Mississippian**
Barnett Shale	**120**	**700**	**360**	**Unconformity at base**
Ellenburger Group	**2400**	**3400**	**3030**	**Ordovician**
Cambrian	**870**	**1035**	**940**	**estimate**
PreCambrian				**ND**

NR - Not relevant, ND - Not determinable

Marble Falls is at least in part, Pennsylvanian.

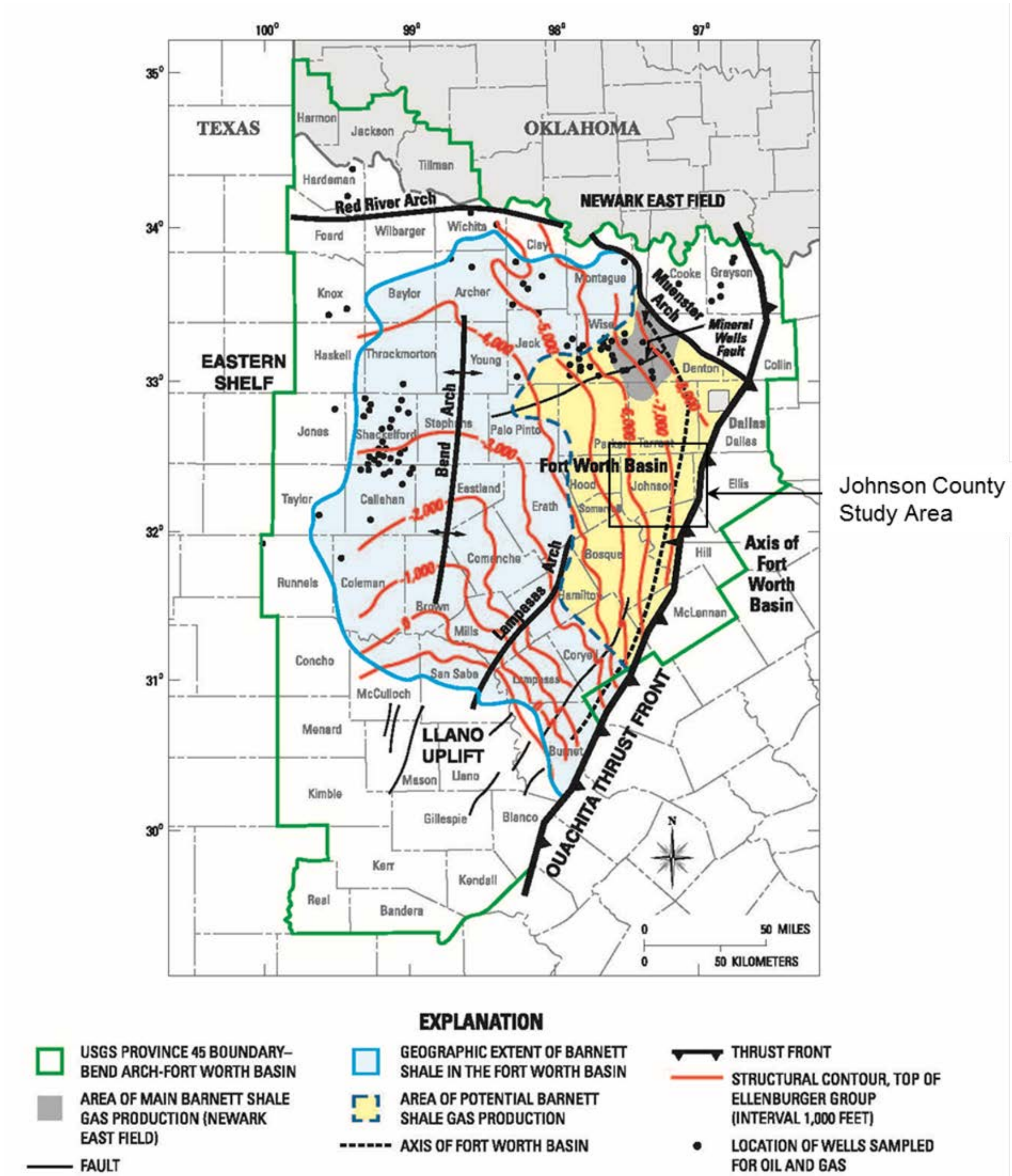

Figure 1. Structure map of the Fort Worth Basin. Area of the Barnett Shale is outlined in blue. Area of primary shale-gas production is in yellow. Elevation contours are of the top of the Ellenburger Group. Modified from Montgomery et al., 2005.

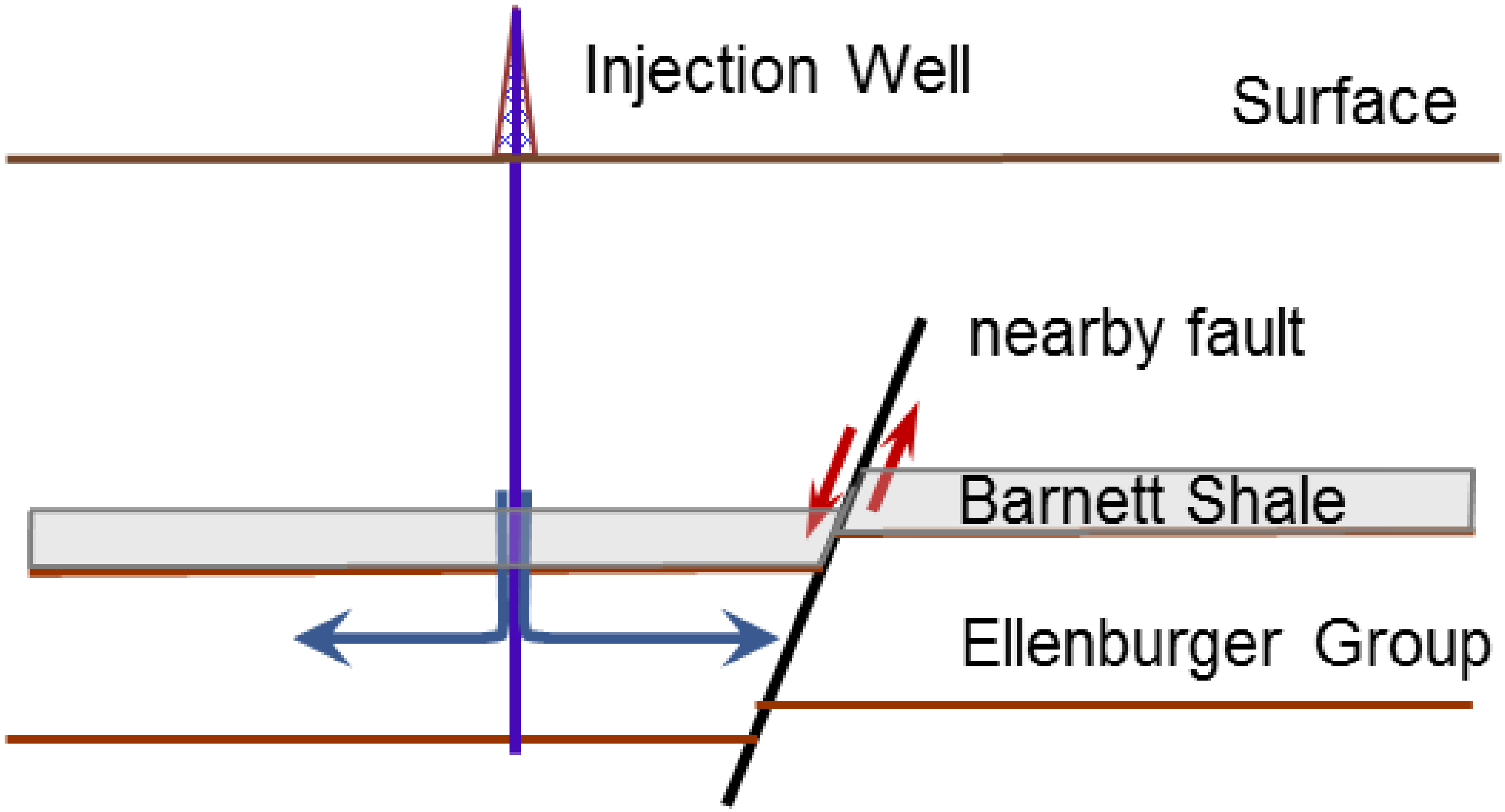

Figure 2. Schematic of injection. Stress builds up along existing faults until it is relieved by an earthquake. This stress is often transferred along faults into the basement rocks.

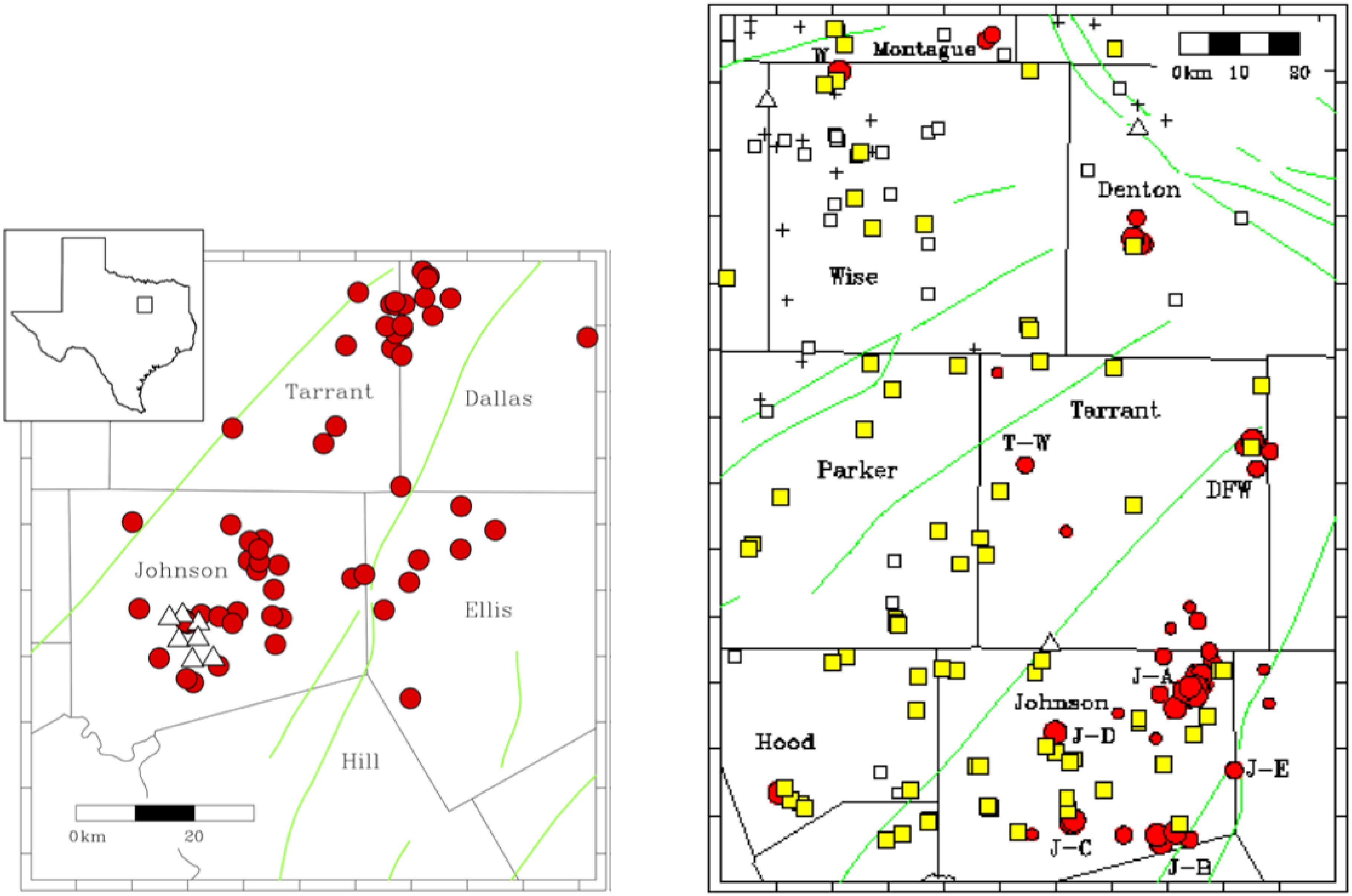

Figure 3. Maps of earthquake epicenters (2009 to 2010) in the Fort Worth Basin.
Red circles – earthquake epicenters; Yellow squares (to right) – Injection wells greater than 150,000 bpm; White triangles (to left) are seismic stations; Green lines – known faults. From Justinic et al. (2013), and Frohlich et al. (2015).

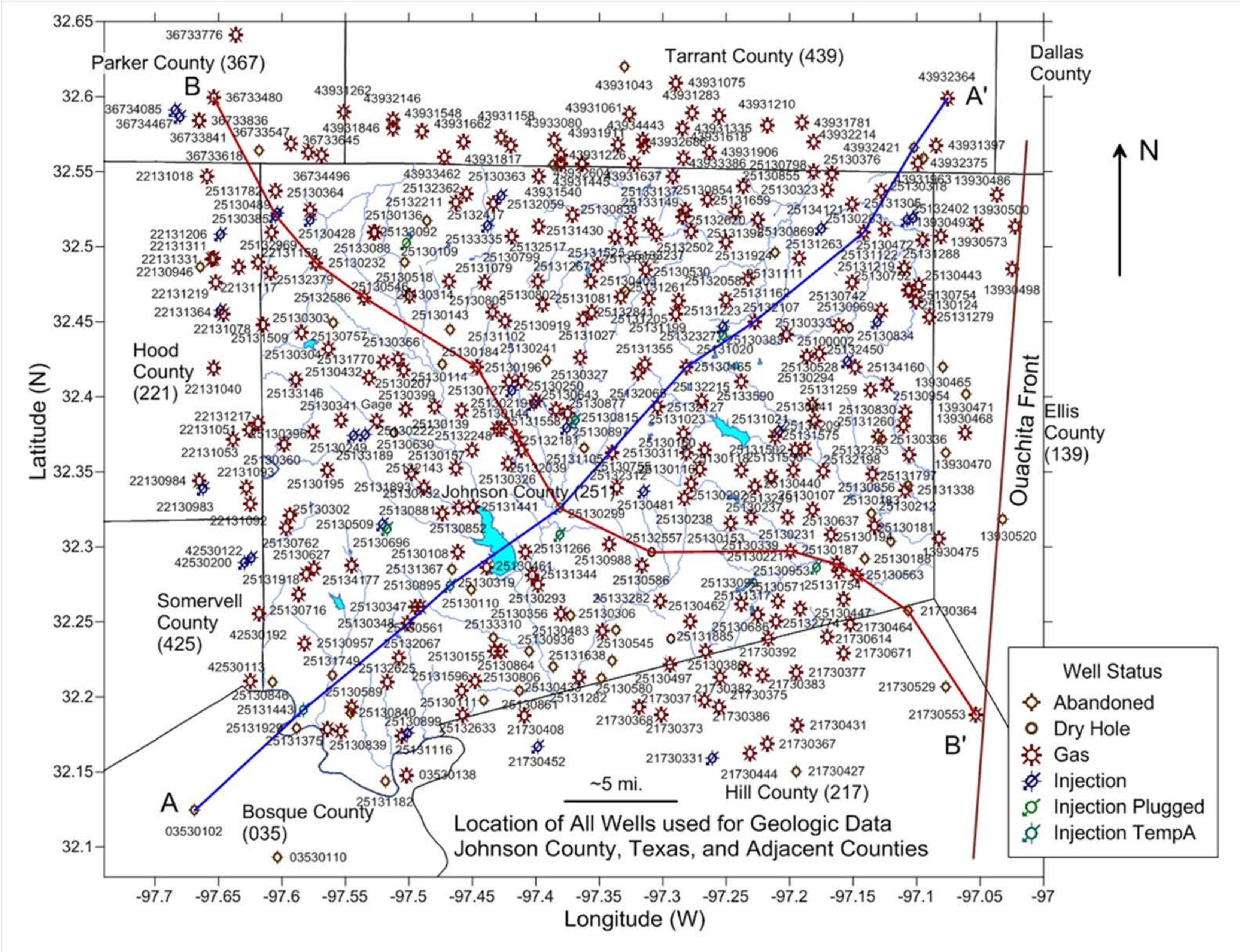

Figure 4. Map of wells used to obtain geologic data for Johnson County and overlapping adjacent areas. Map shows cross sections A-A' and B-B'.

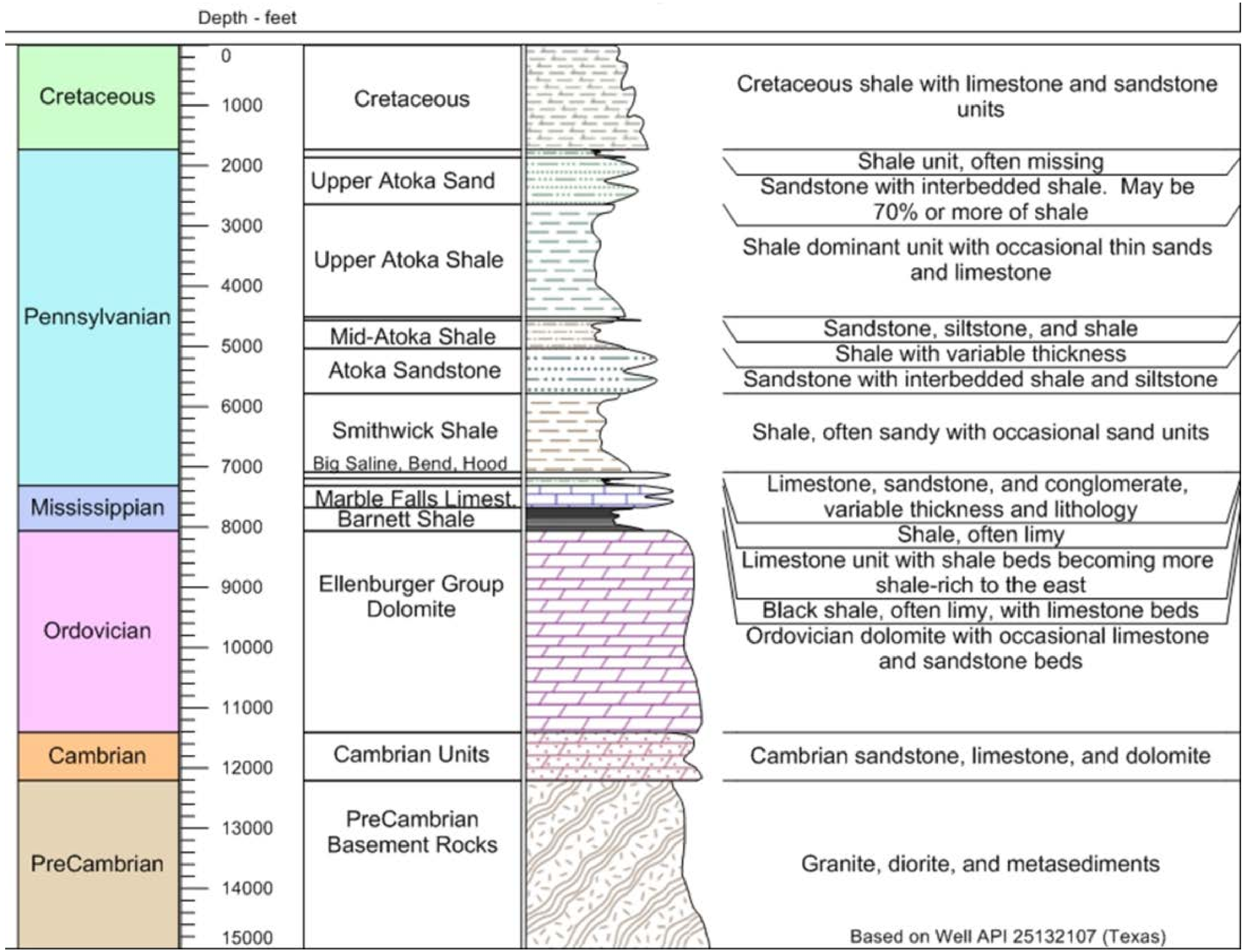

Figure 5. Lithologic section of a typical well in Johnson County, Texas. The Marble Falls unit is at least in part Pennsylvanian (Pollastro et al., 2007).

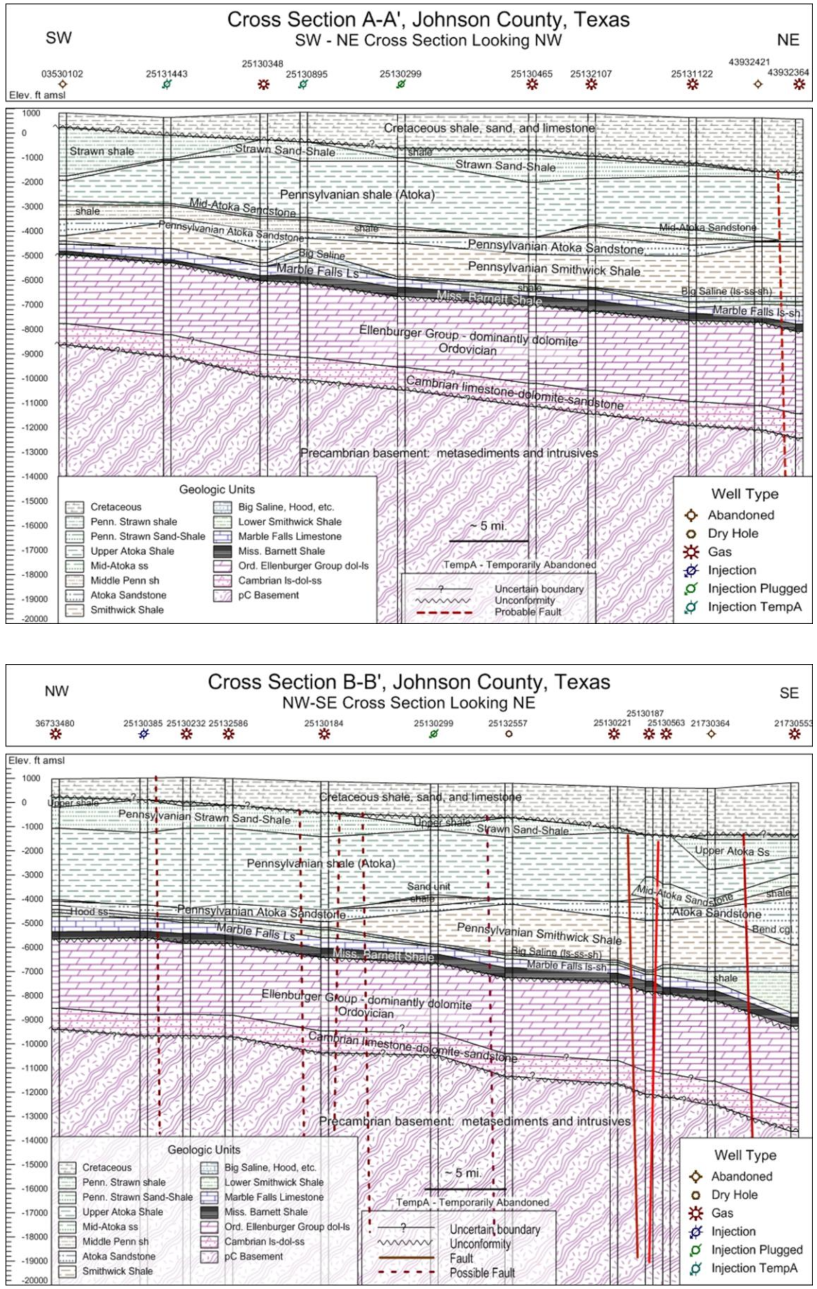

Figure 6. Cross sections A-A' and B-B' to assist with the geologic interpretation of the Johnson County area. Near vertical solid lines appear to be faults, and near vertical dashed lines are probable or potential faults based on interpretation of changes in dip of the units and surface maps.

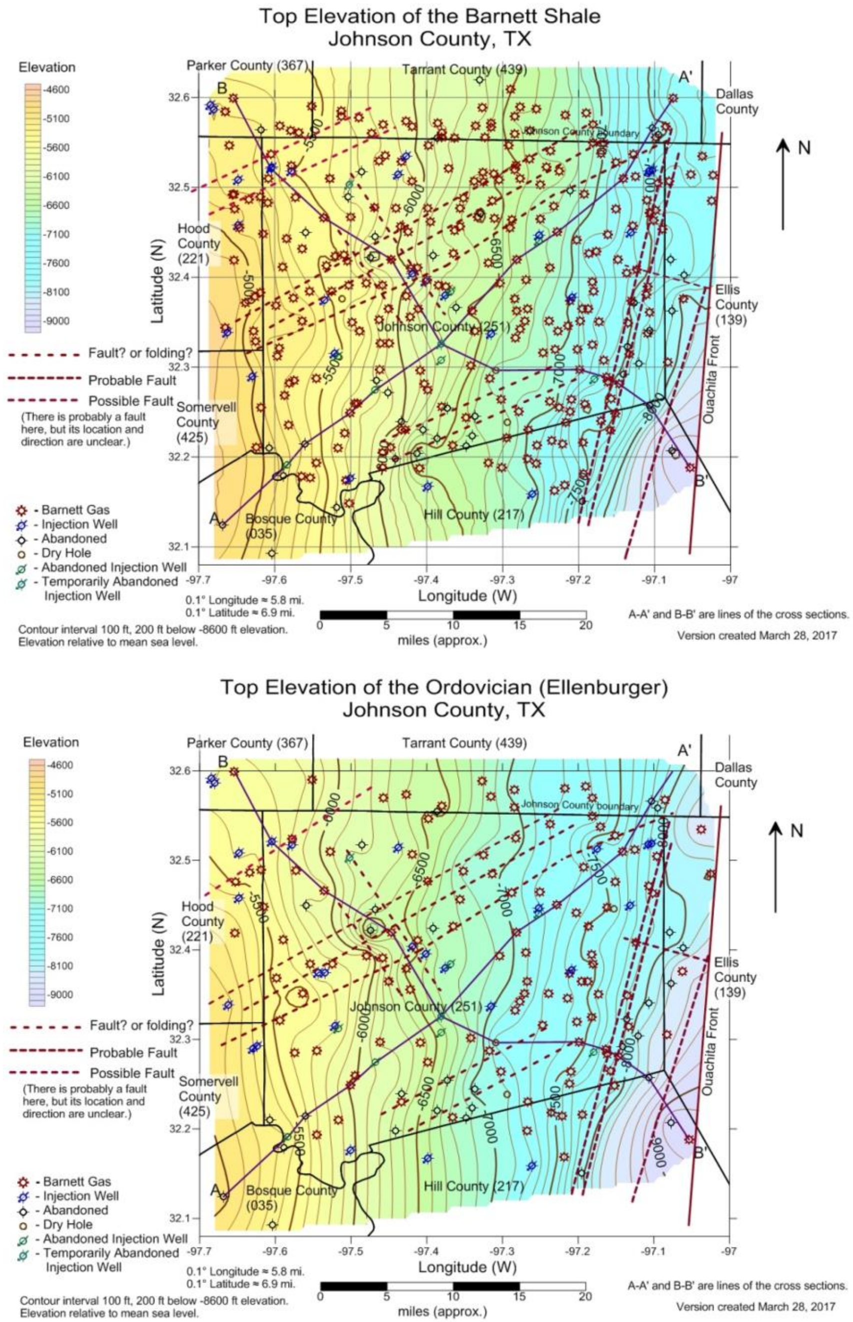

Figure 7. Structure contour maps for the Barnett Shale and the Ordovician carbonates (primarily the Ellenburger).

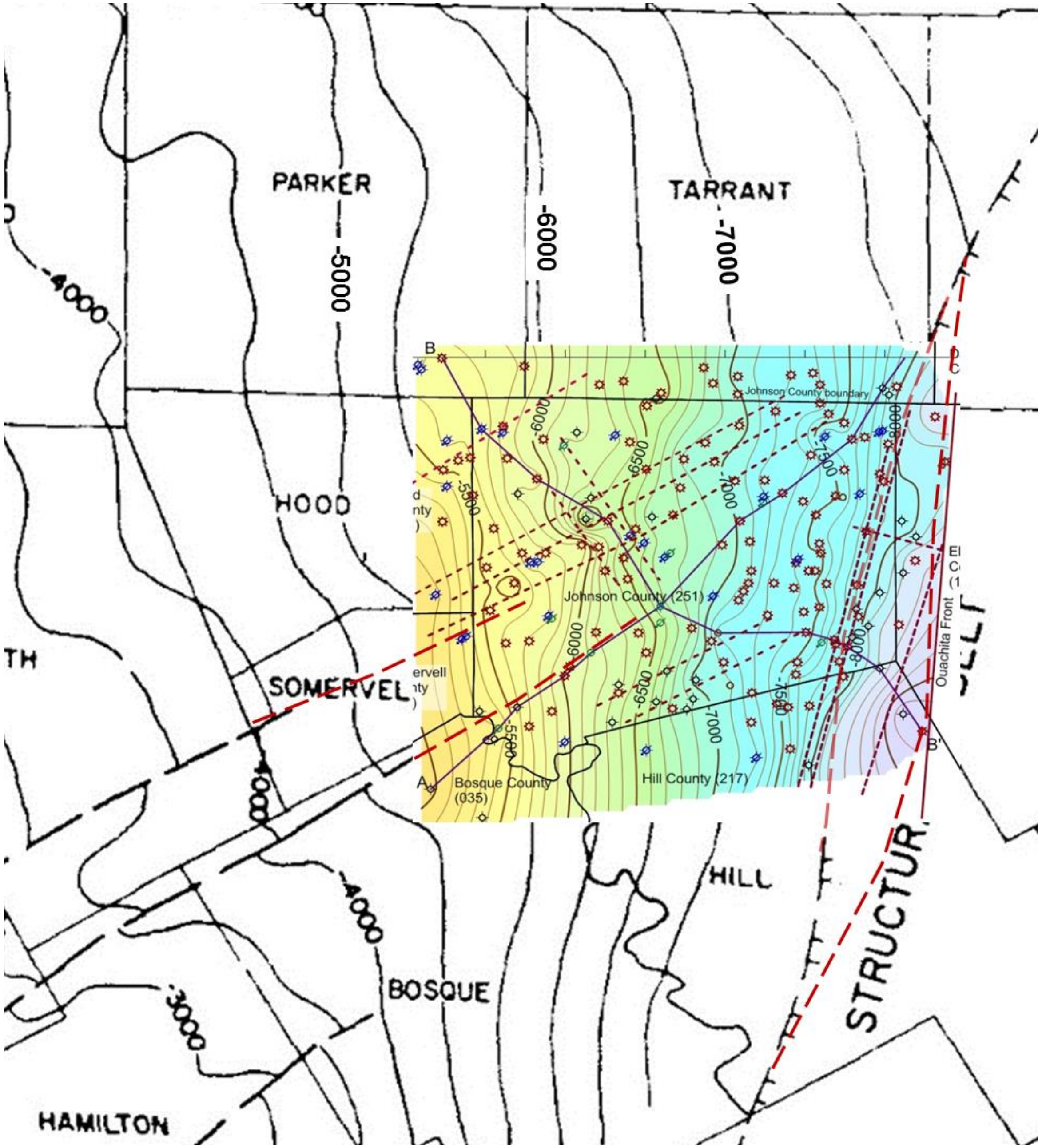

Figure 8. Structure map on the Ellenburger Group with faulting of Turner (1957) and the current fault interpretation superimposed on the map. Note that the current fault interpretation is considered uncertain due to the subtle variation of contours on the Ordovician (Ellenburger) surface.

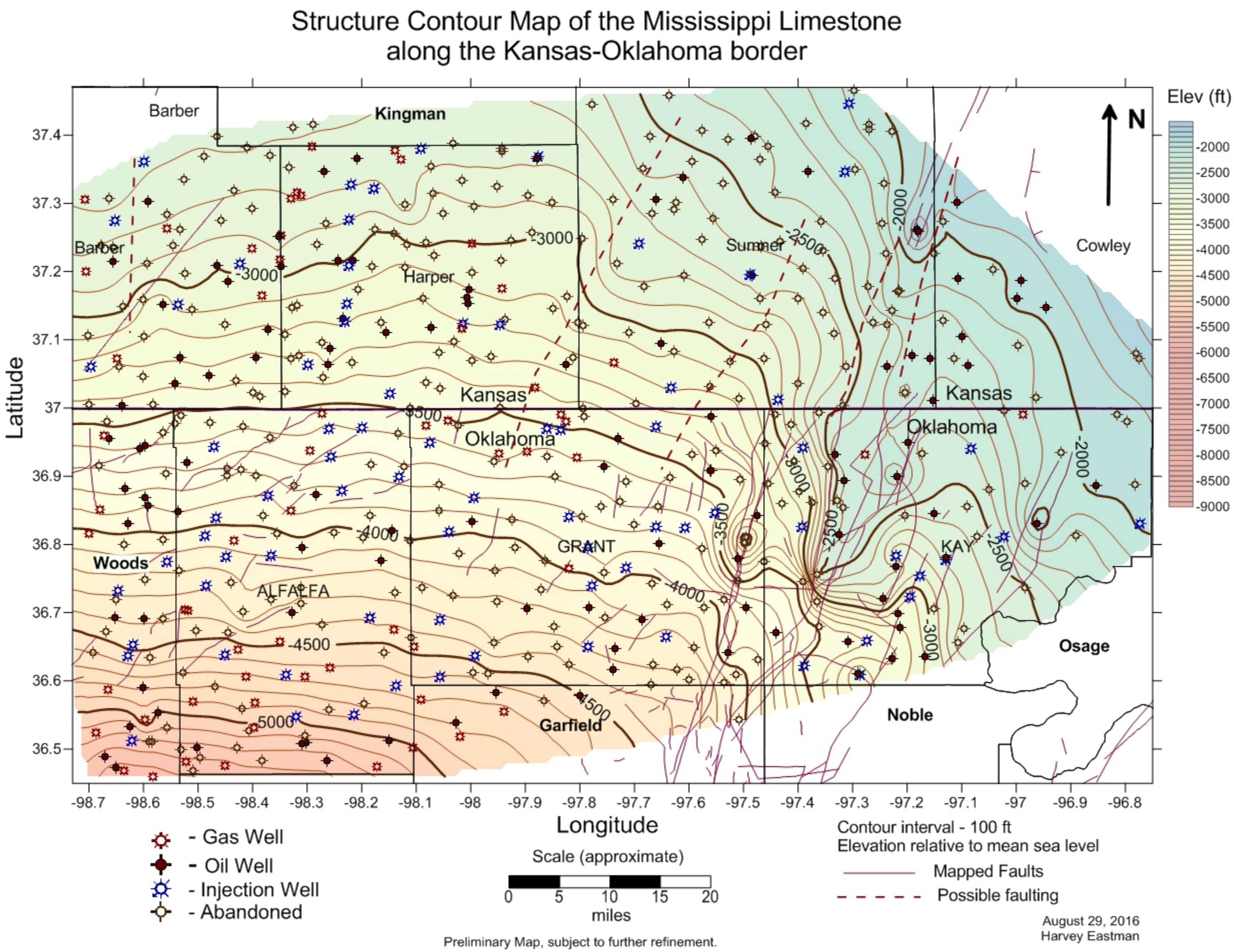

Figure 9. Structure contour map on top the Mississippian Limestone, Kansas-Oklahoma border. Mapped faults from Mid-continent faults database (NETL, 2016) and Oklahoma faults database (Oklahoma Geologic Survey, 2015).