PS Seismic Risk of the Meers Fault, SW Oklahoma: A Hoary Giant or Great Imposter?*

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Abstract

The Wichita-Amarillo fault system defines the southern edge of the Anadarko basin and records Pennsylvanian inversion of a Cambrian continental rift. The basement-involved fault system is comprised of multiple segments and the subject of vigorous debate over the amounts of low angle thrust faulting vs. high angle left-lateral wrench faulting. This paper presents a crustal scale cross section that integrates outcrop work on Ft. Sill, Wichita Wildlife Refuge, and Slick Hills with subsurface data to consider the nature, deformation history, and seismic hazard of the Meers Fault. A recent 14,200ft well (Kimbell Ranch 32-1) drilled in the Slick Hills two miles north of the Meers Fault crossed a repeated Arbuckle-Timbered Hills-Basement (Rhyolite-Granite) section before drilling into granite wash beneath what is probably the Mountain View Fault. These thrusts are expressed log-based cross sections near NW Fort Sill Field, 15mi SE. Outcrops on Ft. Sill 17 miles south of the Meers Fault show minor folding and thrusting in the Timbered Hills and Arbuckle. These outcrops also indicate the same Timbered Hills-Rhyolite nonconformity that crops out north of the Meers Fault, at approximately the same topographic elevation of both sides of the Meers Fault. Thus, the Meers Fault did not have appreciable vertical movement during the Pennsylvanian. The data indicate that the Meers Fault is cutoff by the Mountain View Fault, which leads to the intriguing question as to the causes of the Meers Fault

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Seismic Risk of the Meers Fault, SW Oklahoma: A Hoary Giant or Great Imposter?

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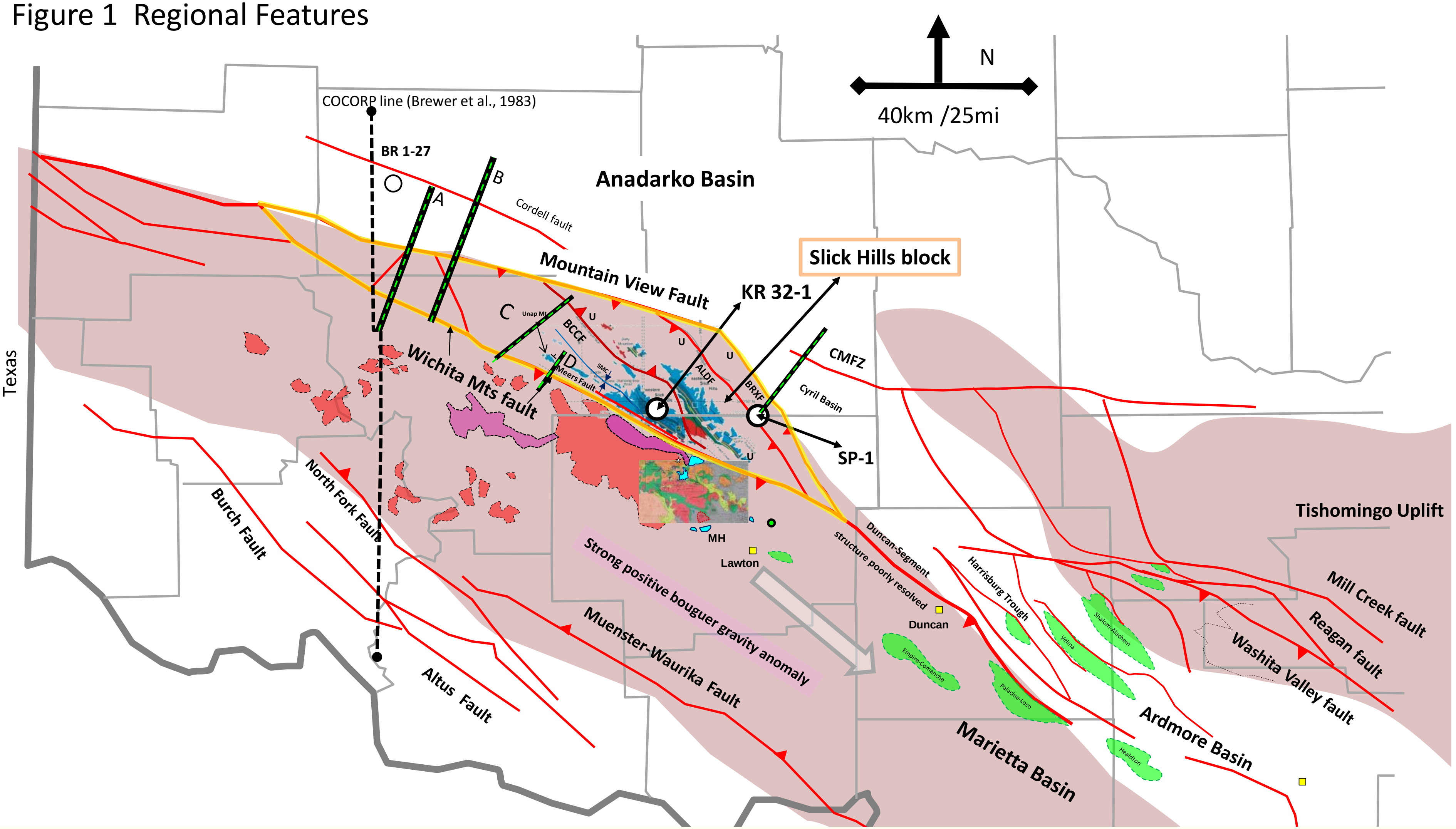
STATEMENT of the PROBLEM: The southern edge of the Anadarko basin in SW Oklahoma is defined by a regional fault system that records Pennsylvanian-aged inversion of a failed Cambrian intra-continental rift; an aulacogen formed during the break-up of Rodinia (Hoffman, 1974; Wickham, 1978; Keller & Baldridge, 2002). This thick-skinned, basement-involved system is the subject of a long and on-going debate over the relative partitioning of low-angle shortening vs. high-angle strike slip faulting (see Gay, 2014). The Meers fault, originally mapped as the Thomas fault (Harlton, 1951) was renamed for the town of Meers (Miser, 1954); it is regarded as one the region's prominent tectonic elements (Harlton, 1964; Hamm et al., 1964). A prominent fault scarp exposed at the surface on the south side of the Slick Hills can be traced for over 24km (Figures 2 and 3). It is the only Holocene fault scarp in the Midcontinent. The fault's last movement as an oblique reverse fault displaced Quaternary alluvium (Gilbert 1983; Crone & Luza, 1986), possibly producing an earthquake between Mw 6.8 to 7.1 (Ramelli & Slemmons, 1986; Luza et al., 1987; Baker & Austin, 2015). Cetin (2003) suggests that the rupture extended an additional 16km to the NW suggestive of an even larger earthquake. The Meers fault strikes N60^{o}W and is optimally orientated within the modern regional stress field for reactivation (Darold & Holland, 2015). Thus, the Meers fault is of great interest from both a regional geotectonic perspective and as a modern seismic hazard There are conflicting interpretations of the nature of the Meers fault. All studies of the fault -trenching (Crone & Luza, 1986), shallow seismic (Miller et al., 1982), magnetic profiles (Cecil-Jones, 1990) and coring (Collins, 1992)- indicate the fault is a reverse fault that dips steeply north into the Anadarko basin. As it is unlikely the fault turns back over itself, its northerly dip is at odds with interpretations treating the fault as a major SW dipping thrust / reverse fault that placed the Wichita Mountains over the Slick Hills block (Brewer et al. 1982; McConnell, 1989; Soreghan et al., 2012). The Slick Hills block, which is bounded on the north by the Mountain View fault system, is an intermediate fault block between the Wichita Mountains and the deep Anadarko Basin The following slides and text attempt to resolve the question of the nature of the faults that bound the Slick Hills block (Figure 2) and whether or not the Meers fault is a significant tectonic basement fault.

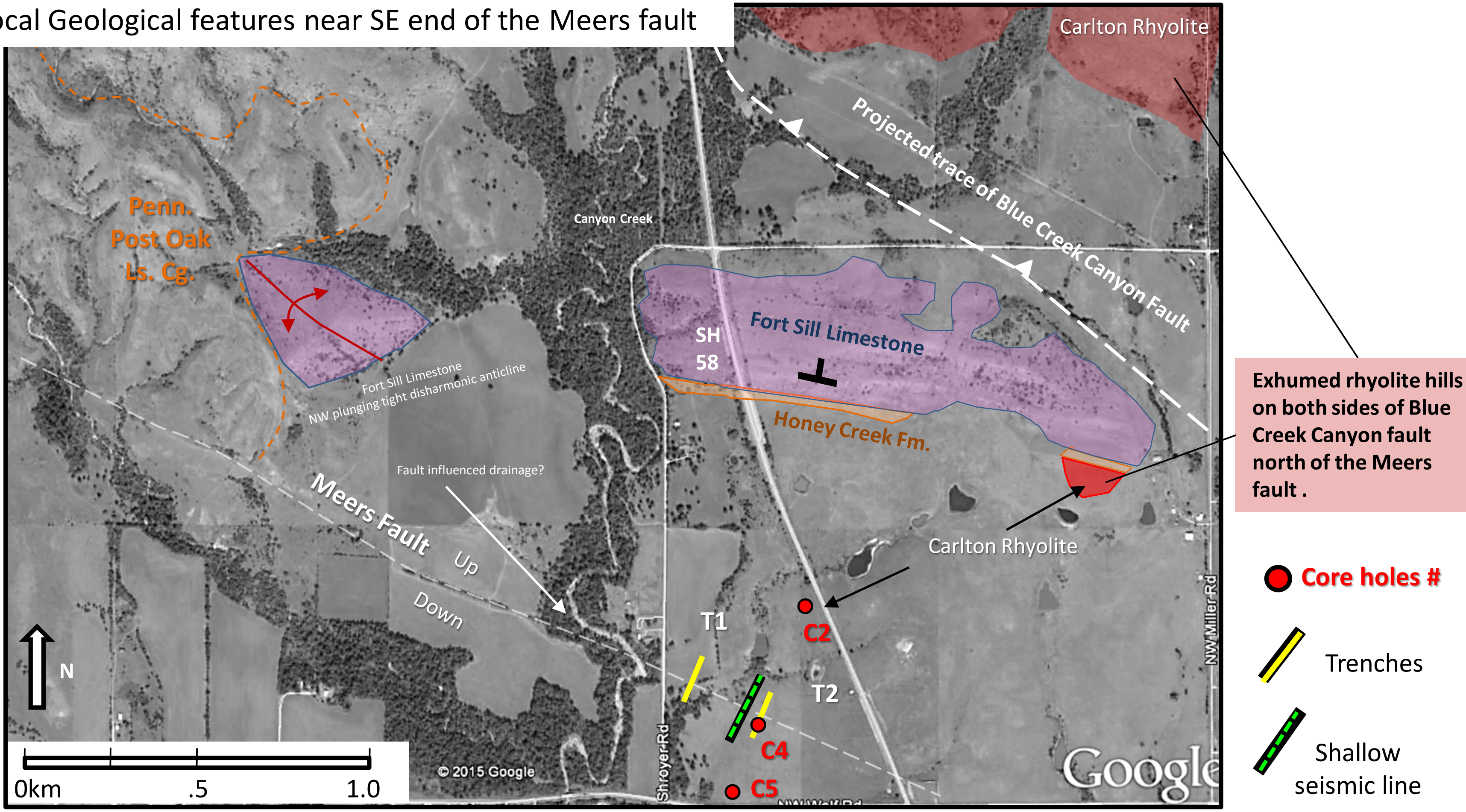
SUMMARY: A true scale crustal cross section (Fig.13) is presented that integrates outcrop work on Ft. Sill & the Slick Hills with bore hole, gravity, and seismic data. A key constraint is the Kimbell Ranch 32-1 (TD 15,280) that drilled through the Slick Hills block 2mi north of the Meers fault. The KR32-1 crossed a repeated Arbuckle-Timbered Hills-basement section beneath the NE dipping Meers Fault and then cut a much deeper second thrust before terminating in granite wash in the footwall of the Mountain View fault (Figures 4 and 5). The Mountain View fault, the major basin-bounding fault, dips 20-30^{o} SW beneath the Slick Hills and Wichita Mountains. It cuts off the Meers fault. Regional subsurface mapping, seismic data, and outcrop observations indicate that the Wichita Mountains have been thrust over the Slick Hills by a fault named here as the Wichita Mountains fault (Figure 5-9) . Outcrops on Ft. Sill document minor folding & low angle thrusting in the Timbered Hills & Arbuckle section that overlie the same Cambrian nonconformity that occurs in the Slick Hills (Figures 10 and11). Considering that current levels of erosion exhume a Permian landscape, the fact that the same Cambrian nonconformity crops out at similar topographic elevations of both sides of the Meers fault strongly suggests that the fault does not have significant throw (<10,000ft). The Meers fault is interpreted here as a back thrust of similar the Blue Creek Canyon fault. If the Meers fault does not extend into the basement, then we are led to the intriguing question as to the cause of its Holocene rupture and possibly examining whether assumptions its estimating paleo-magnitude are correct - delicately balanced granite boulders in the Wichita Mountains appear inconsistent with the estimates of Mw 6-7 for its last rupture ca. 1000 years ago. Rather than a major tectonic feature the Meers fault may be a relatively small back thrust (inverted Cambrian rift fault?) confined to the Slick Hills block rather than a hoary giant; the ultimate seismic hazard lurking elsewhere in the basement. Certainly, more work & further study is warranted.

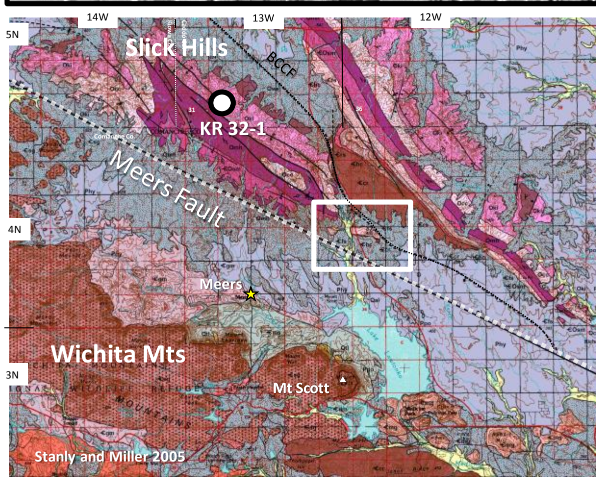
Figure 1 Regional Features



- White circles are key wells.
- Major Faults in red lines (various sources including Oklahoma fault map.
- 2D seismic lines in dashed green-black lines
- Green polygons are oil fields in thrust-related anticlines (thin-skinned / Ardmore Basin)
- Light gray arrow denotes SE plunging Wichita-Criner Hills upper plate anticlinorium (Marietta Basin is a piggy back basin in the hanging wall of a on basement involved thrust sheet.
- Mauve shading is indicates strong positive Bouguer gravity – mafic and ultra mafic igneous rocks of Cambrian aulaogen.
- Surface geology modified from Stanley and Miller (2005)

Figure 2 Local Geological features near SE end of the Meers fault





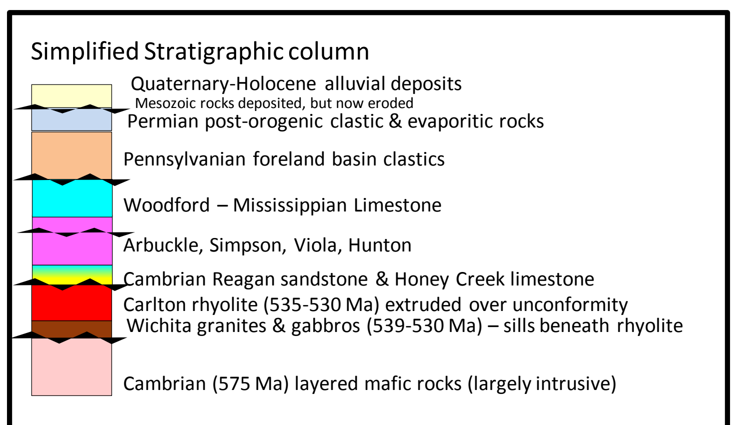
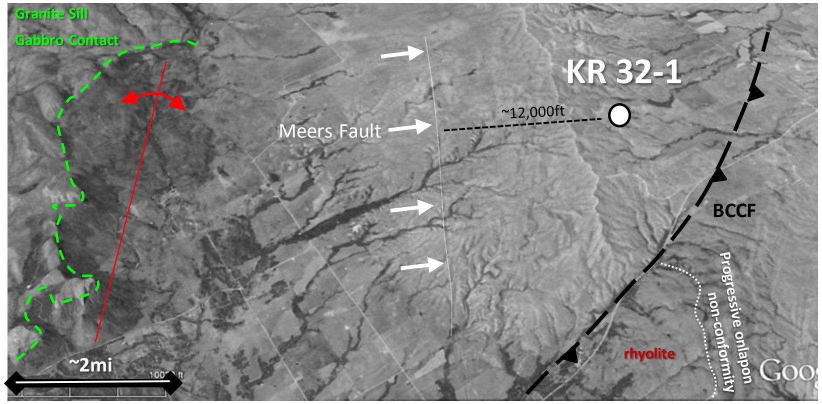
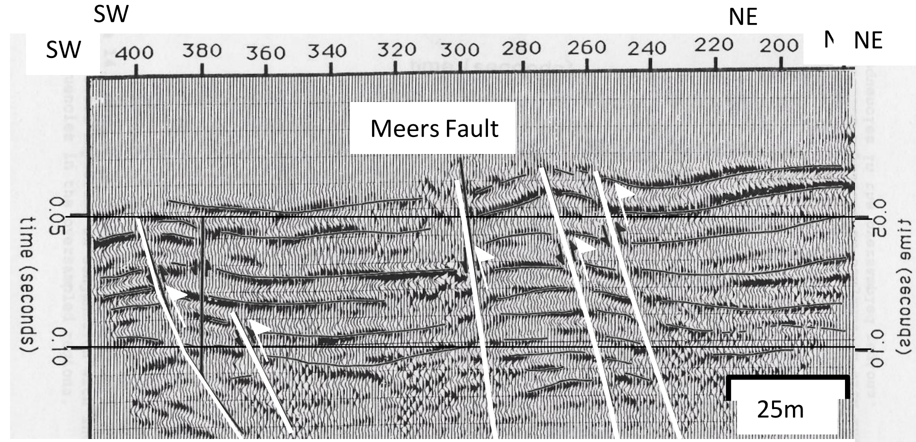


Figure 3 Meers fault prior fault studies documenting NE dip 60° to 85°.

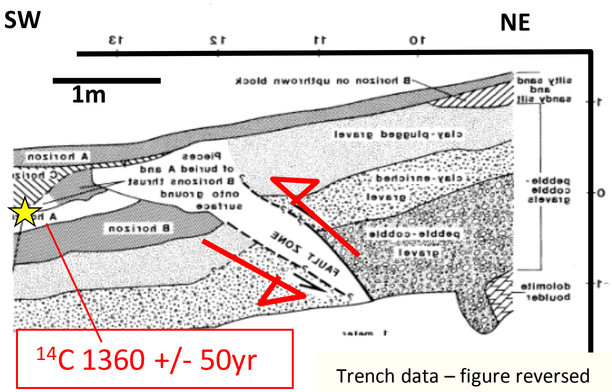


Comment: Linear fault scarp suggest high dip at surface.



Miller et al., 1982

Comment: Note other additional faults with steep NE dip; good reflectivity in alluvium.



Luza et al., 1987

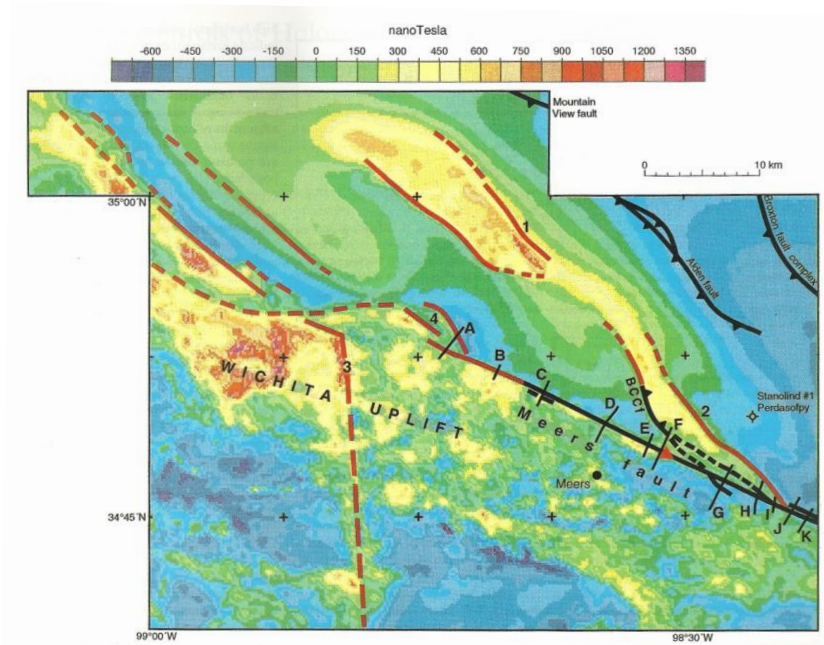
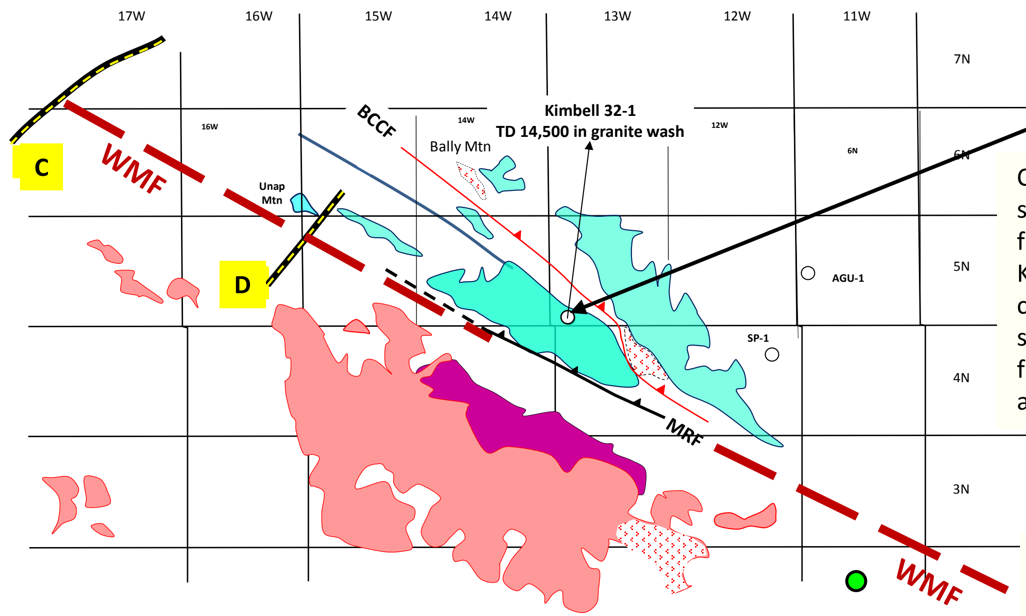


Figure 2. Northern part of reduced-to-north pole total-field aeromagnetic map, after Jones-Cecil (1995) (1954 site inclination of 64° and declination of 10°). BCCf, Blue Creek Canyon fault. Wide solid and dashed black lines indicate locations of selected major faults from geologic information from Harlton (1951, 1963, 1972), Ham et al. (1964), McConnell (1983), Ramelli and Slemmons (1986), and Ramelli et al. (1987) (on Meers fault this corresponds to late Quaternary scarp). Solid and dashed red lines indicate alignments of horizontal gradient maxima and/or inferred faults from aeromagnetic data. Narrow black lines and letters identify ground-magnetic profile locations crossing the Meers fault. Not shown, profile L is 3.8 km southeast of K and extends 2.5 km northeast of the Meers fault and 1.3 km southwest. Orange triangle shows location of Oklahoma Geological Survey drill holes.

Jones-Cecil, 1990

Comment: Jones-Cecil interpreted the the pronounced magnetic anomaly associated with the Meers fault to reflect Paleozoic dike-like structure in the magnetic basement intruded along the Meers fault. As there is no record of Pennsylvanian magmatic activity, a more plausible interpretation is the anomaly represents a Cambrian igneous event

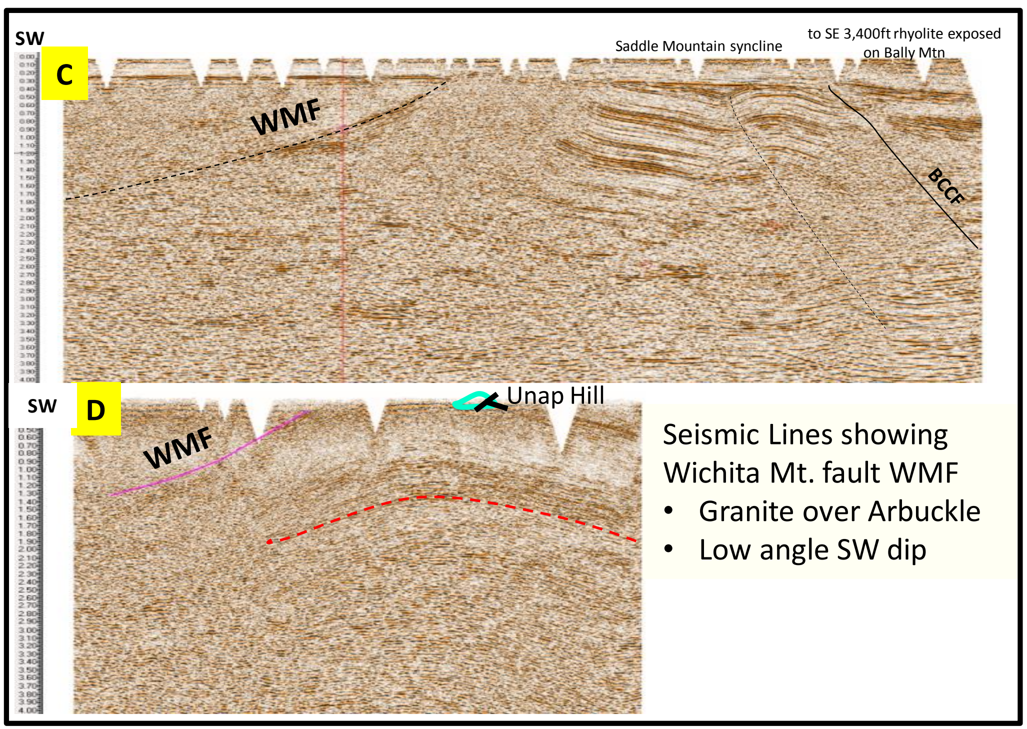
Figure 4 Kimbell Ranch well – Mt. View, Meers, and Wichita Mt. faults on key seismic lines.



Comment: Donovan (1986) shows about 5,000ft the section for the Timbered Hills through Kinblade section, which is consistent (considering some structural complexity dip & small folds) with drilled thickness above basement in the KR 32-1

BCCC fault dips the wrong way to cut well. Data best fit Meers fault with 40° dip.

12000
40 °
9720ft



Seismic Lines showing Wichita Mt. fault WMF

- Granite over Arbuckle
- Low angle SW dip

Mt. View fault
20° to 30° dip

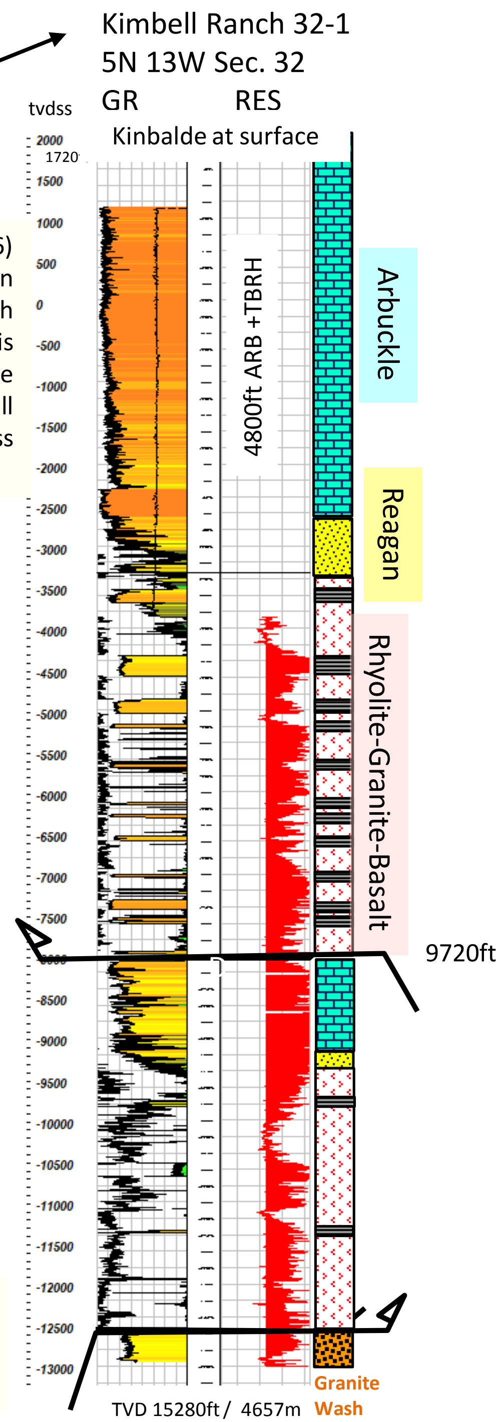
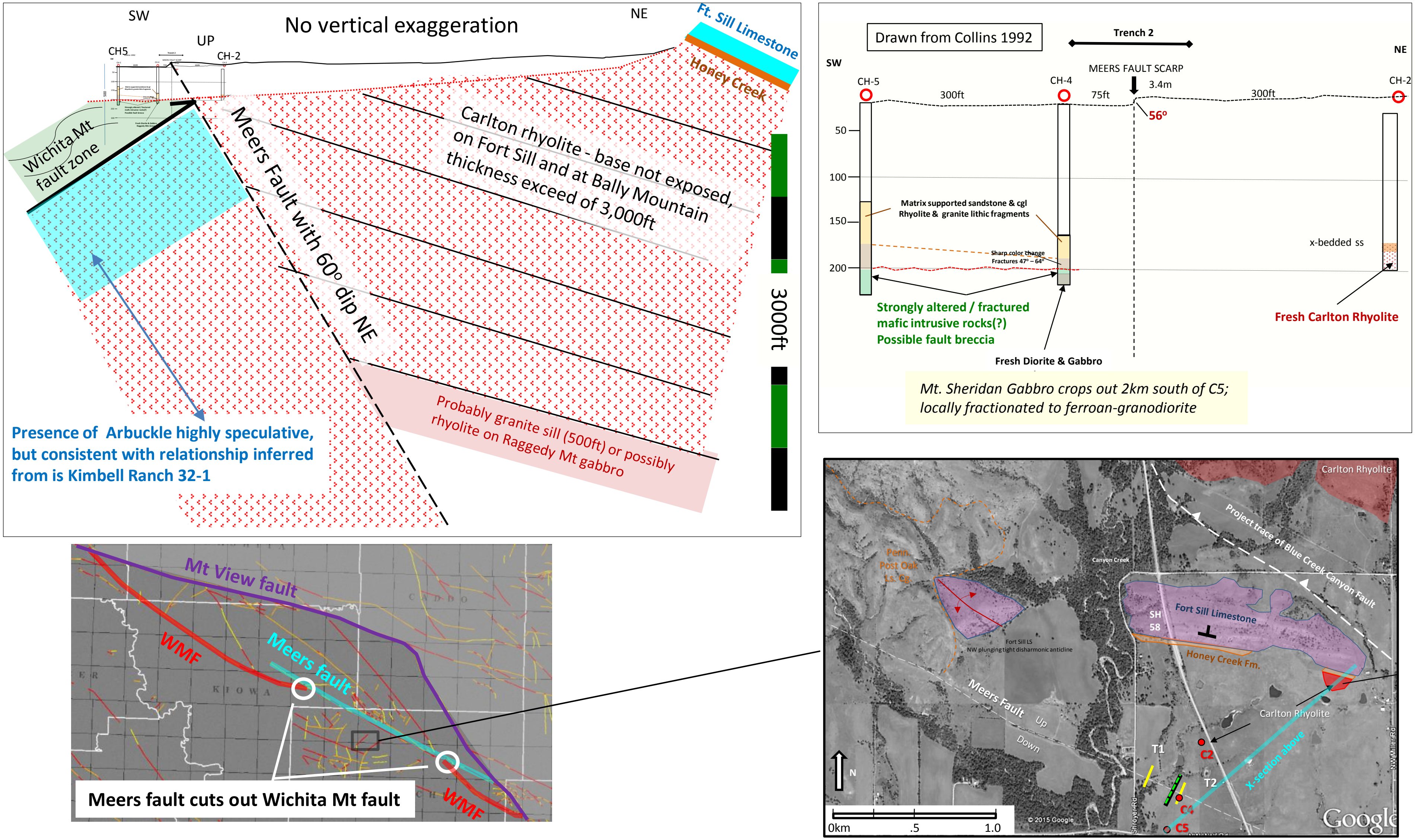


Figure 5 Structural Interpretation of core data along the Meers fault reported by (Collins1992). These data indicate that the Meers fault has locally cut off the Wichita Mountains thrust.



This interpretation honors the available data and offers a resolution to the question of how the Meers fault can interpreted to be both a north-dipping and south-dipping reverse fault. There are 2 separate faults; the Meers fault locally cutsoff the Wichita Mountains fault.

Figure 6 Seismic lines across Mt. View and Wichita Mt. (from Keller 2014), but re-displayed below at true scale

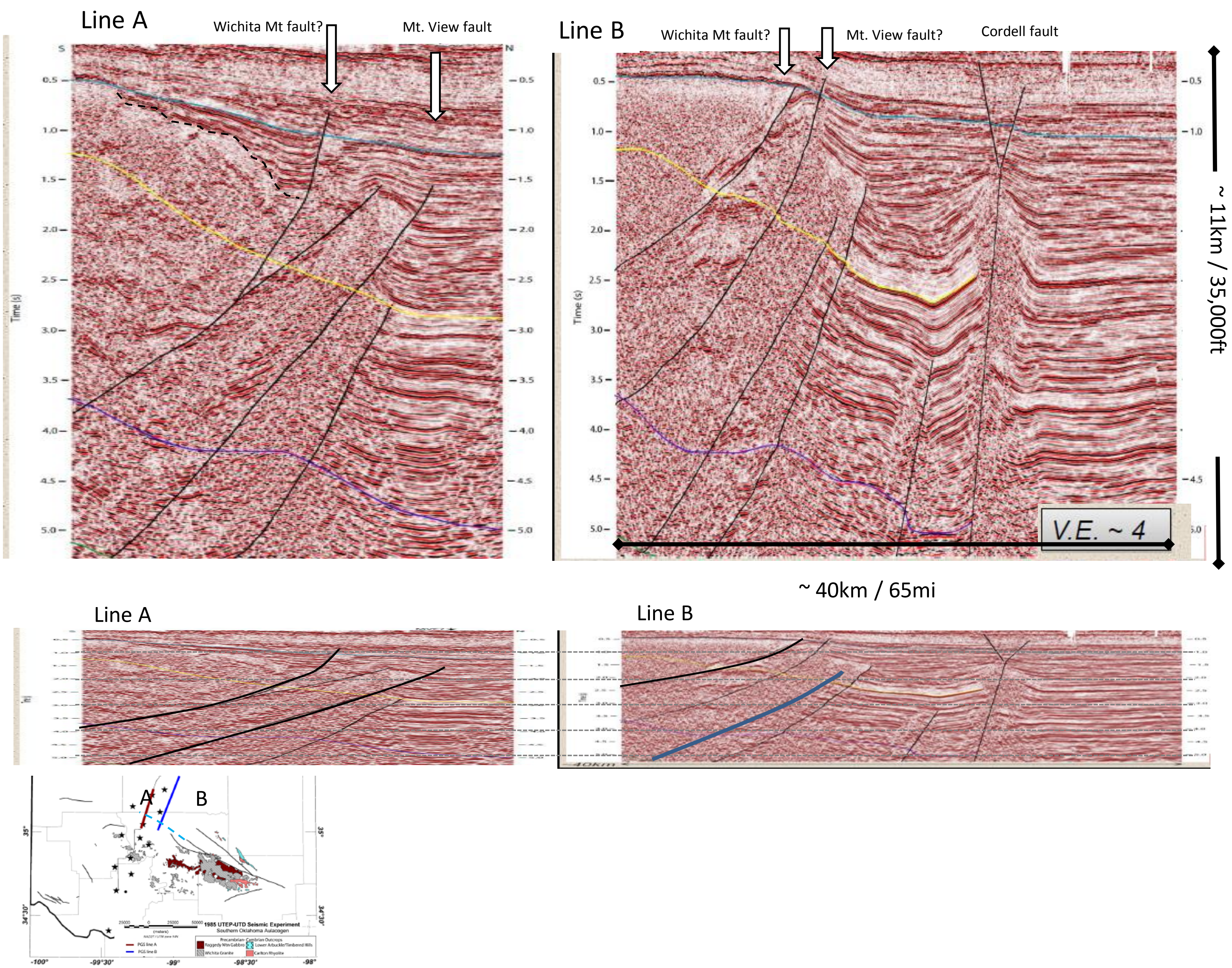
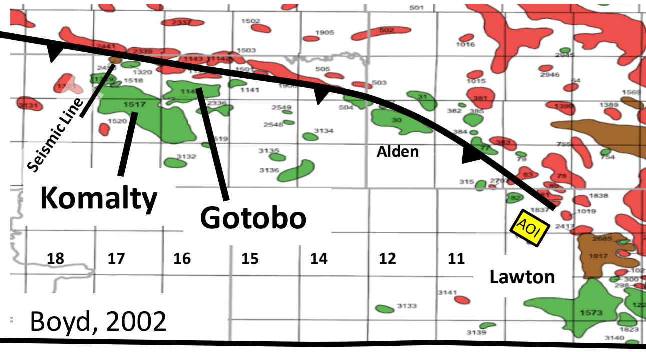
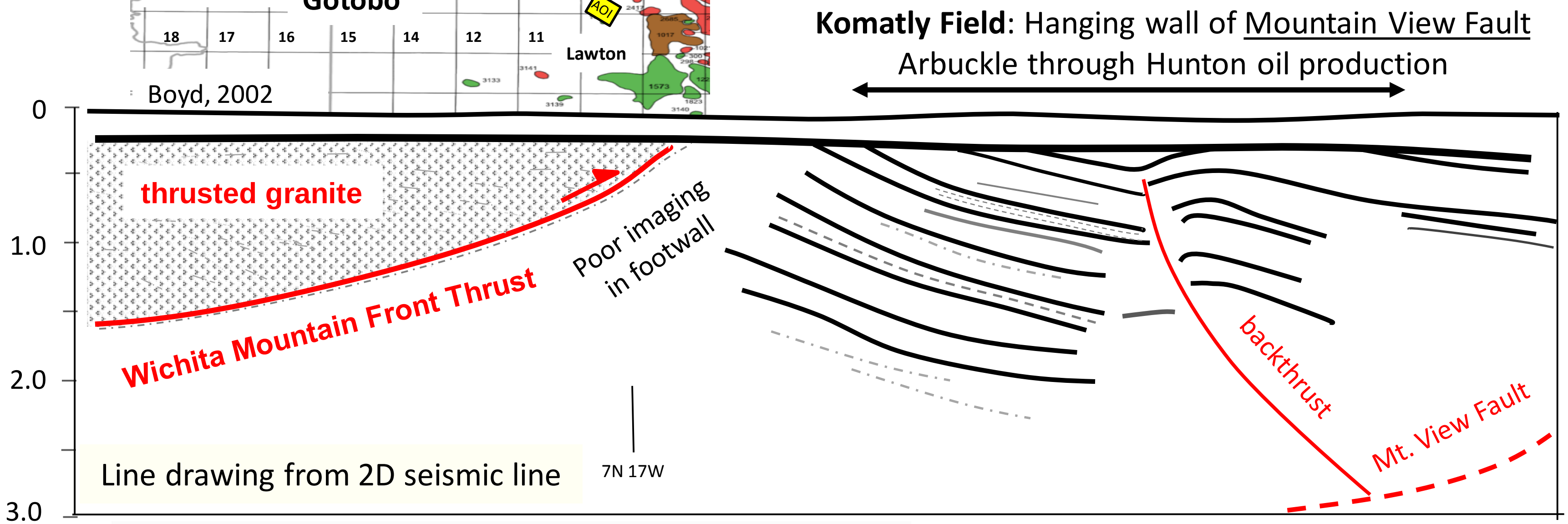
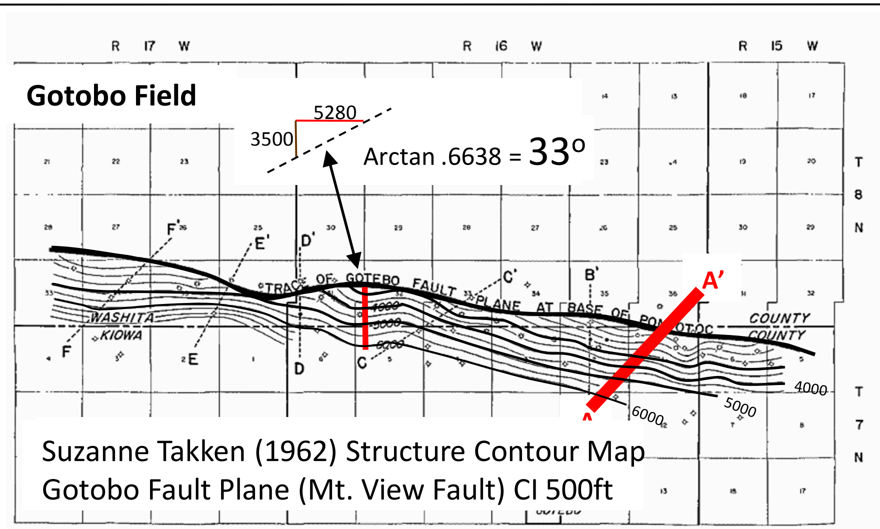


Figure 7 Mt. View fault to west of Slick Hills area of interest; two low angle thrusts

- Komalty Field – footwall of low angle basement involved NE vergent
  - Gotobo – Mt. View Fault has 30° to 40° dip SW







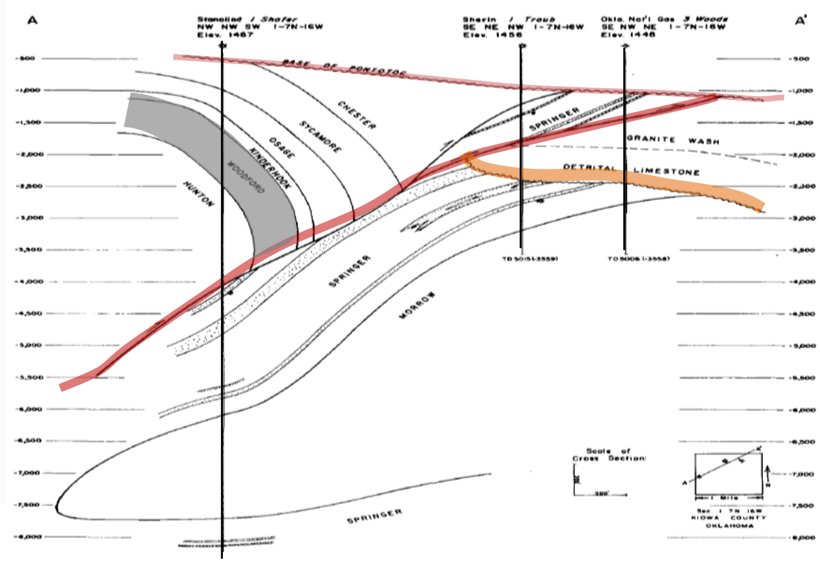
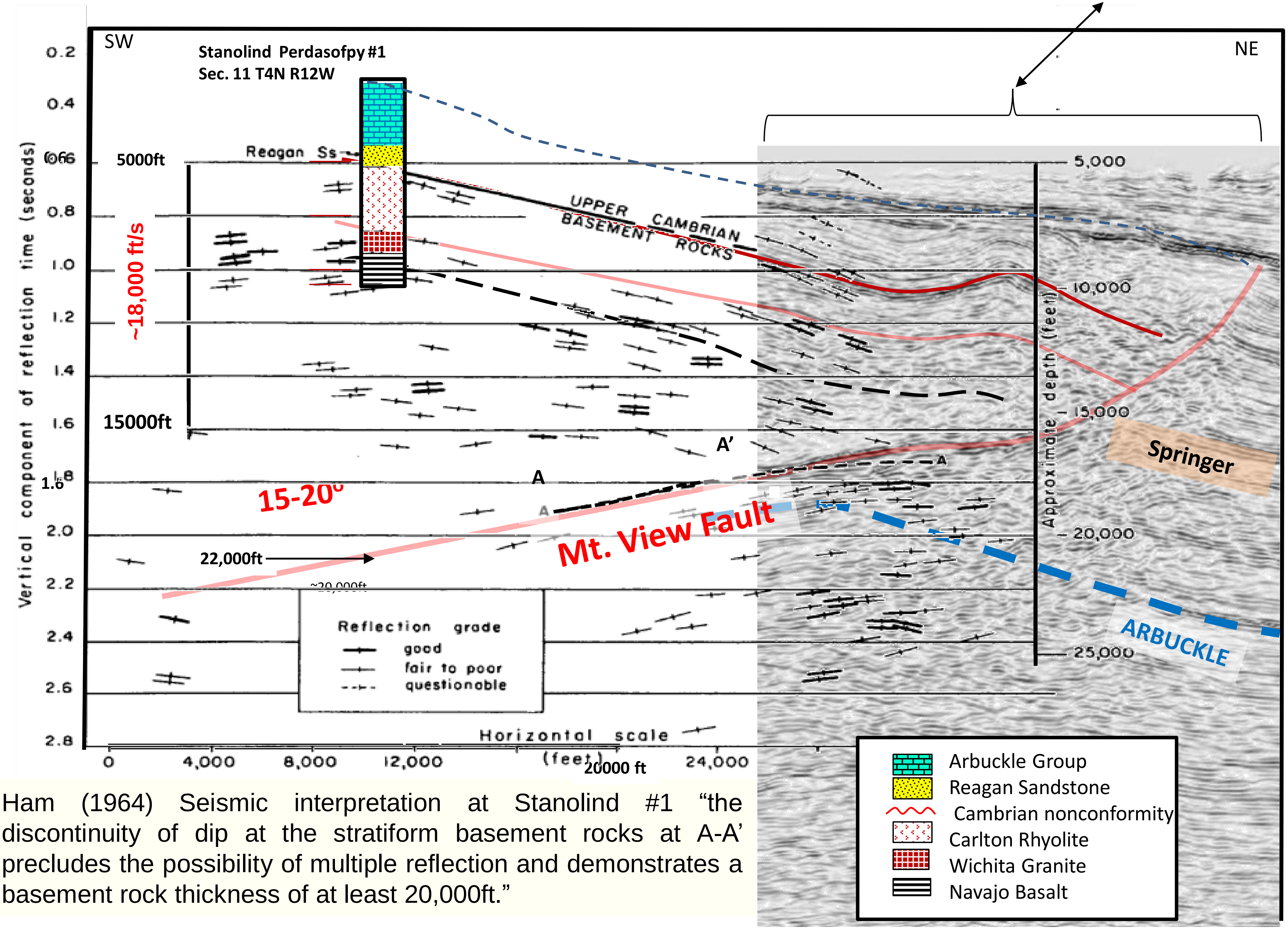
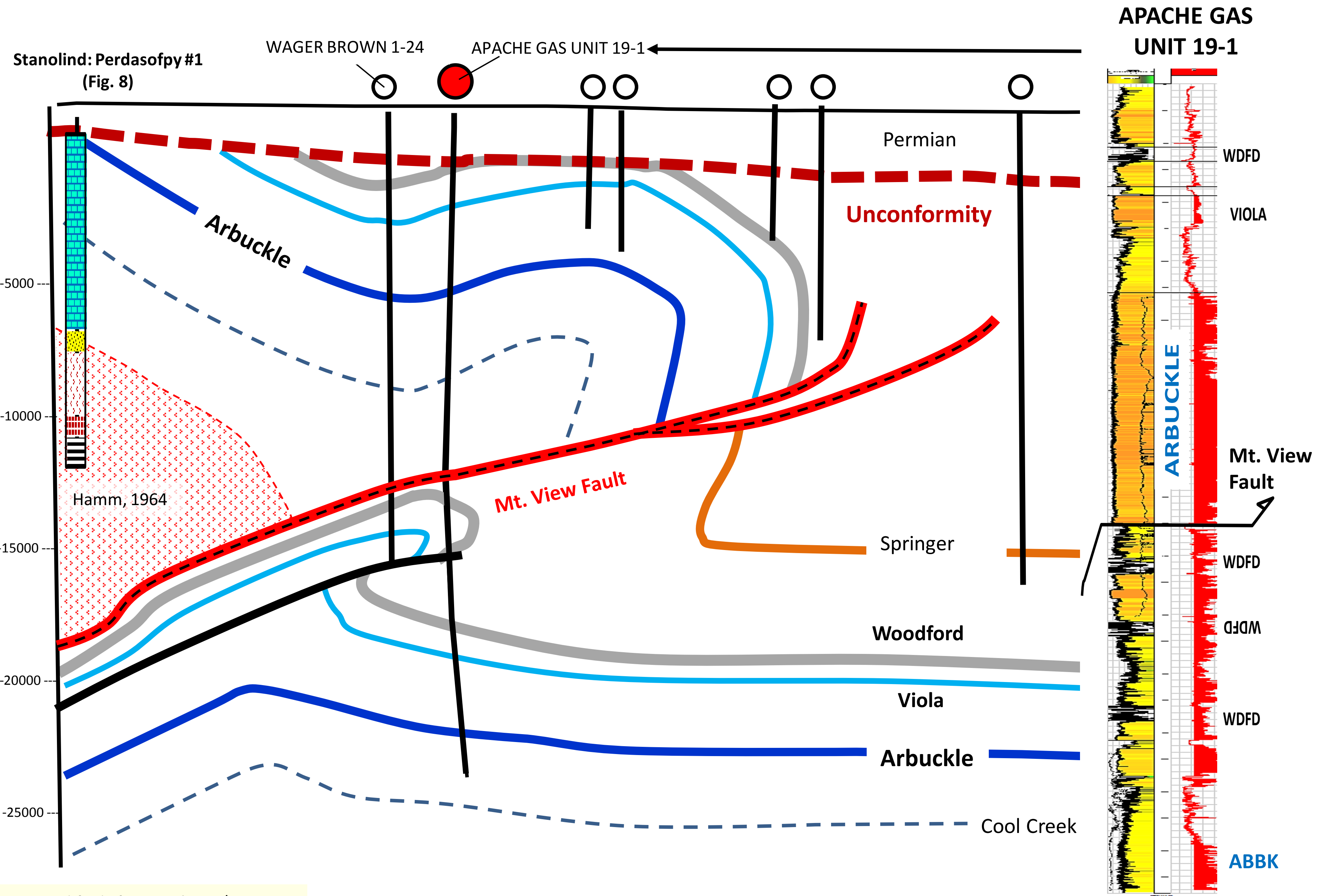


Figure 8 Mt. View thrust along the Slick Hills was identified, but not named by Hamm (1964); imaged with 3D seismic data.



Ham (1964) Seismic interpretation at Stanolind #1 "the discontinuity of dip at the stratiform basement rocks at A-A' precludes the possibility of multiple reflection and demonstrates a basement rock thickness of at least 20,000ft."

Figure 9 Mt. View thrust fault with well control.



Modified after Stephens / Davis
Geronimo Prospect ca. 2003

Figure 10 COCORP lines showing Meers and Mt. View thrust faults (after Brewer et al., 1982)

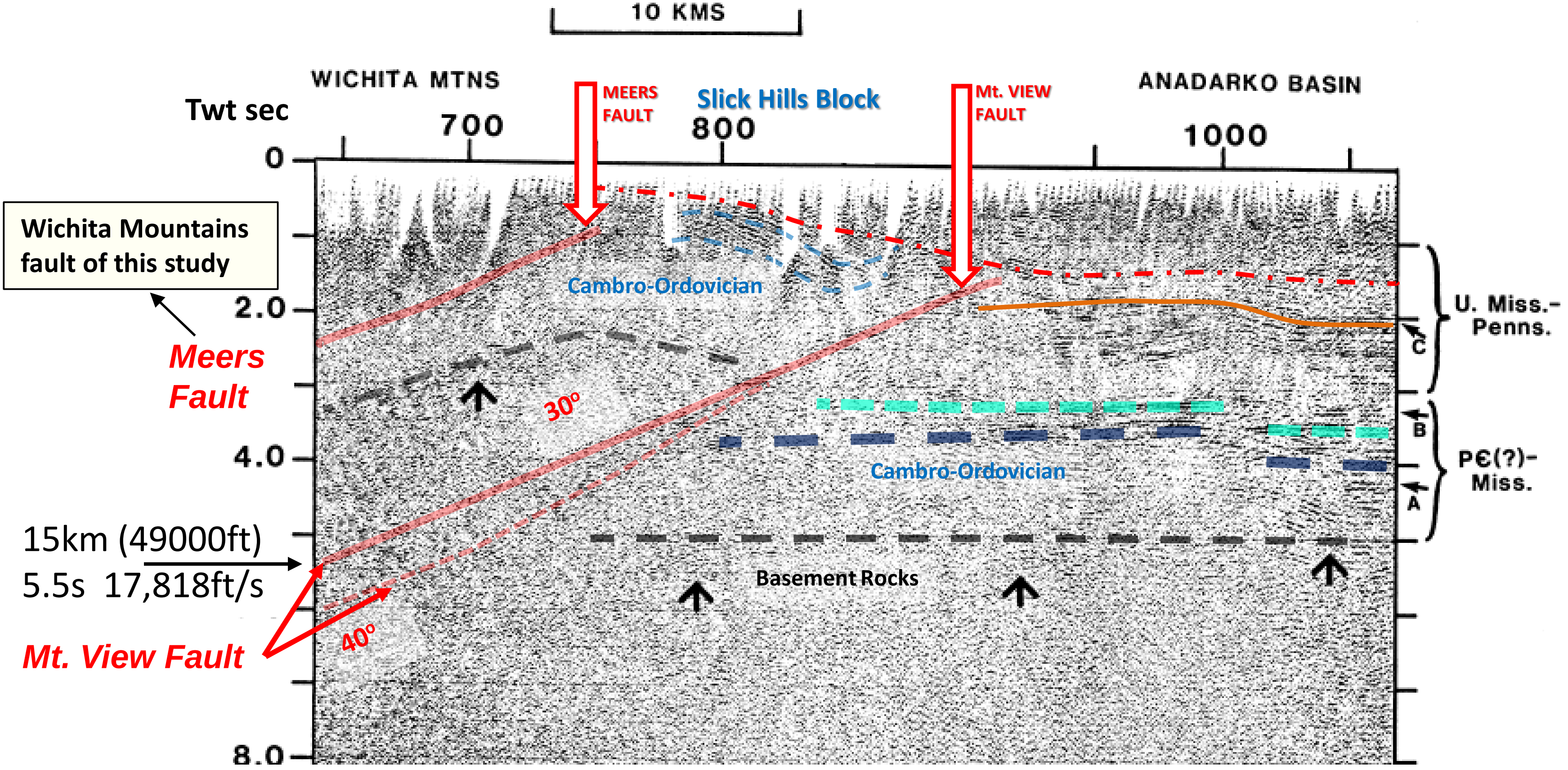
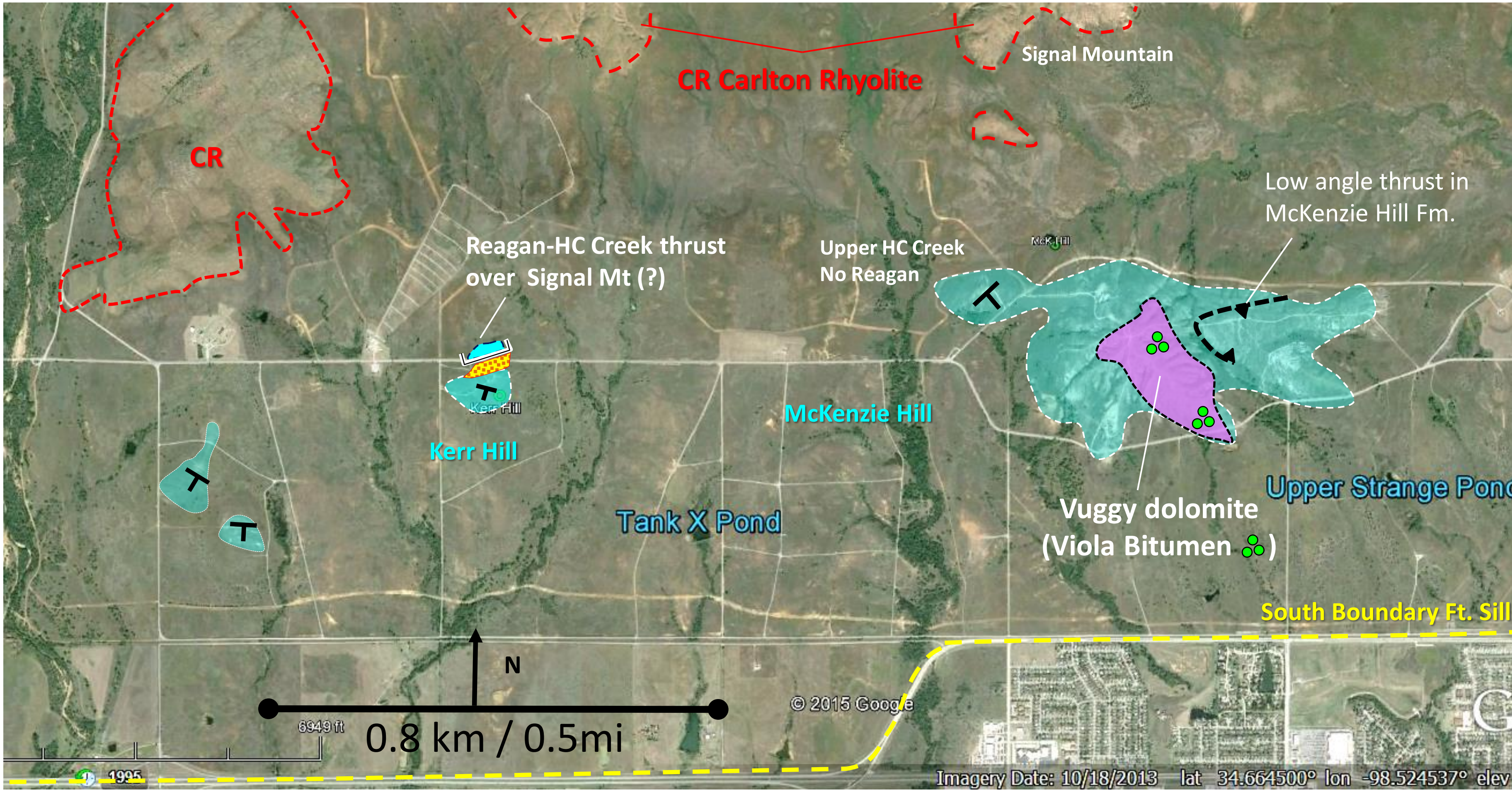


Figure 11 Upper plate geology & deformation at McKenzie Hill and Kerr Hill on Fort Sill.



The Timbered Hills-Carlton rhyolite nonconformity although not exposed in outcrop is inferred to be present. This nonconformity also crops out in the Slick Hill north of the Meers fault, 10 miles away(Figure 2). These relationships strongly suggest that the Meers fault did not have significant (>10,000ft) vertical displacement during the Pennsylvanian and is consistent with the interpretation that the Meers fault is a modest back thrust in the Slick Hills block similar to the Blue Creek Canyon fault (BCCF).

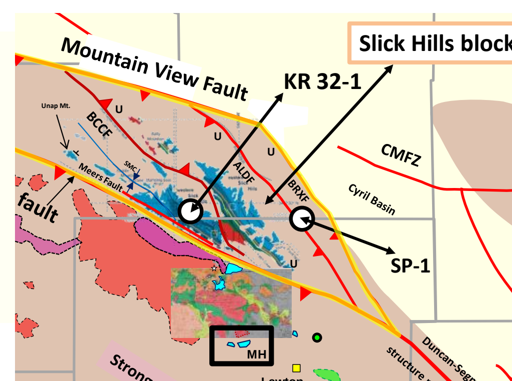
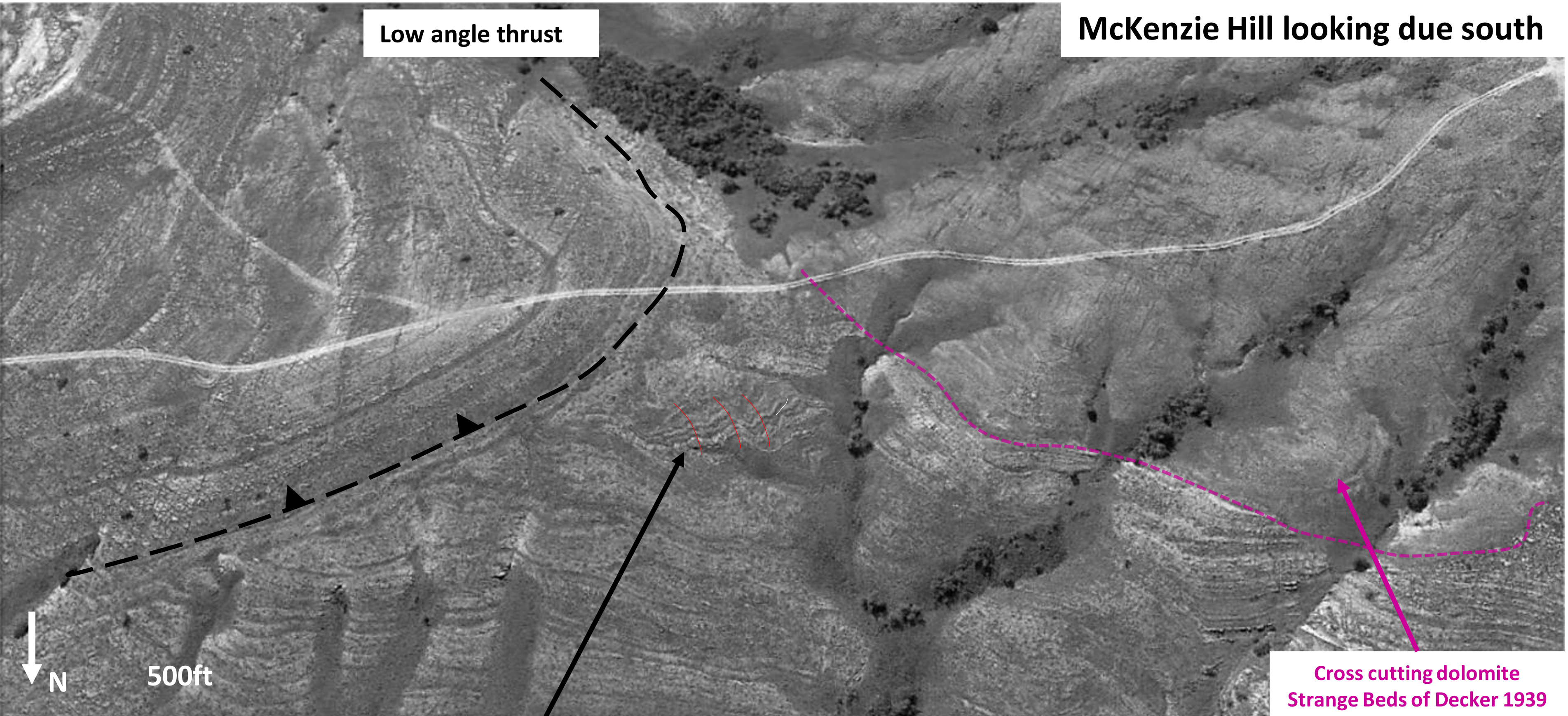
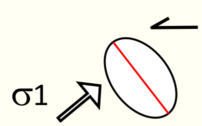


Figure 12 Upper plate low angle thrust at McKenzie Hill, Fort Sill; lower most section an “anticlinorium” that plunges SE into the Marietta Basin



Localized small drag folds in McKenzie Hill footwall trend ~ N30ºW, similar to a small fold in Prisoner quarry (Ft. Sill) and the folds in the Slick Hills. Their is orientation is consistent with left-lateral transpressive stress field (Donovan et al., 1989)



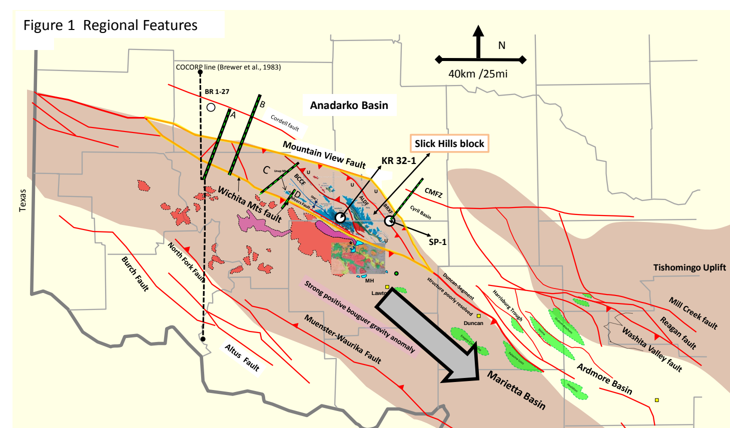
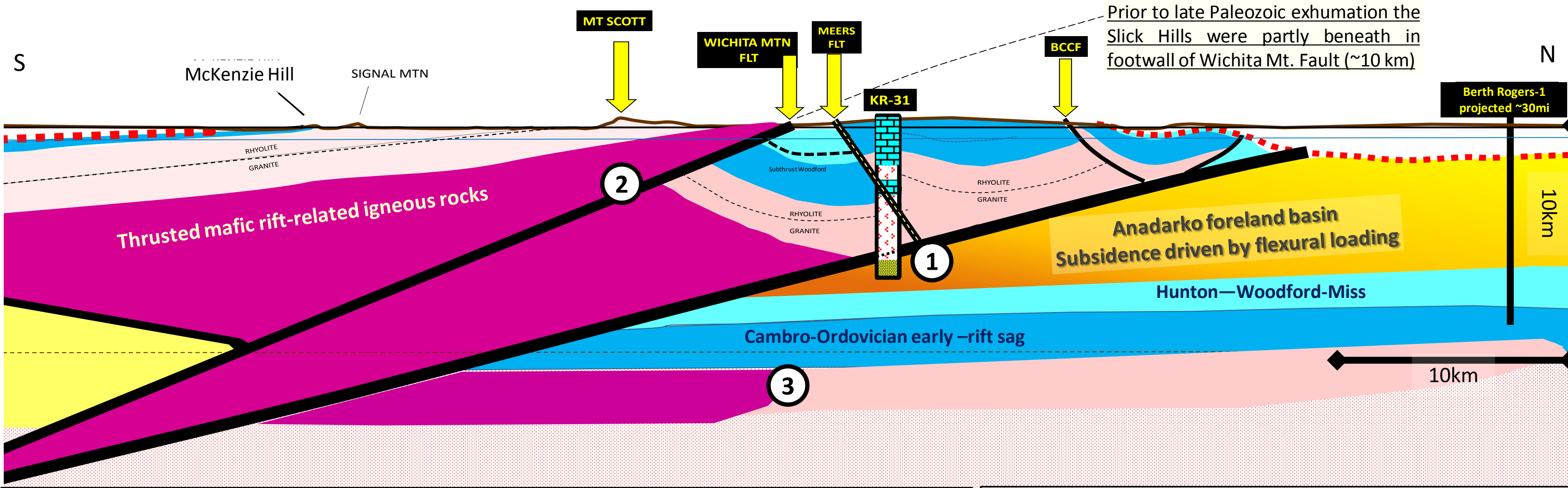


Figure 13 True-scale crustal cross section from Wichita Mountains to the Anadarko Basin (full section lower right).

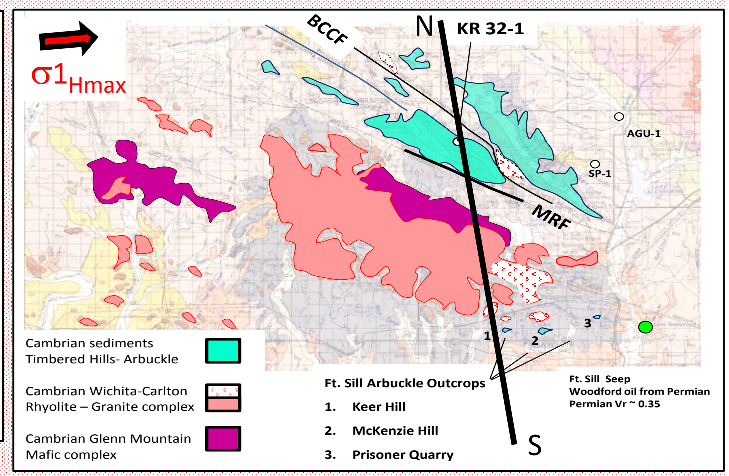


KEY POINTS

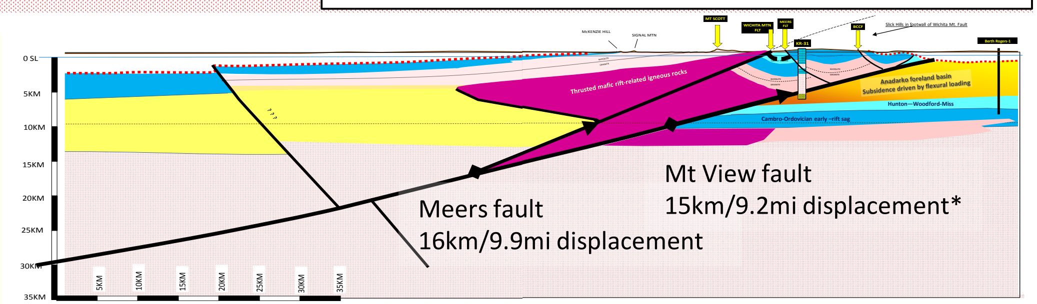
1. The Meers Fault is a high-angle back "thrust" cut-off by the Mt. View Fault. The Meers fault does not extend to the basement; the fault has a favorable orientation for re-activation in the modern stress field (see Darold & Holland, 2014)

2. The shallow dips of the Mt. View and Wichita Mt. faults have unfavorable geometries for re-activation owing to high normal stress across their fault planes.

3. The surface rupture on the Meers Fault may reflect deeper earthquake possibly along much older high-angle normal rift-related. Thus, the Meers Fault may be an imposter for a seismic hazard lurking deeper in the basement.



Deeper basement structure modified from Randy Keller in Hanson et al. (2013) honors 2D gravity and seismic velocities. Deeper geometry is model-driven and drawn to fit rheological concepts of a mid-crust zone of weakness in continental crust (reviewed by Bergman and Dresen, 2008). Whether this is inherited from Cambrian rifting is not resolved; an elevated geothermal gradient associated Cambrian rift magmatism (Hanson et al., 2012) could have resulted in a shallower zone of weakness (Huismans and Beaumont, 2003).



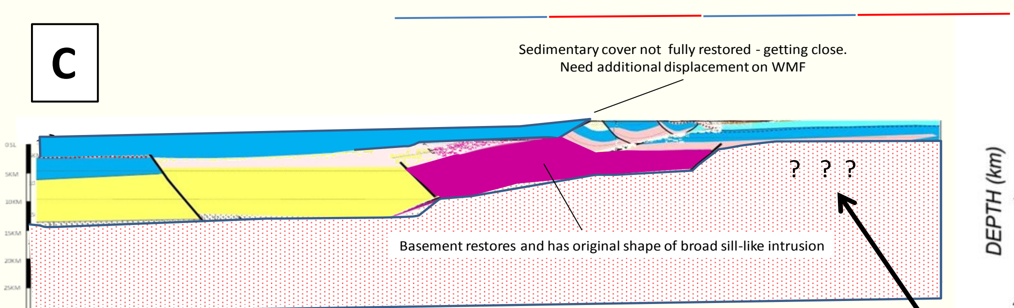
*McConnell (1990) estimated 6.7mi displacement on Mt View fault

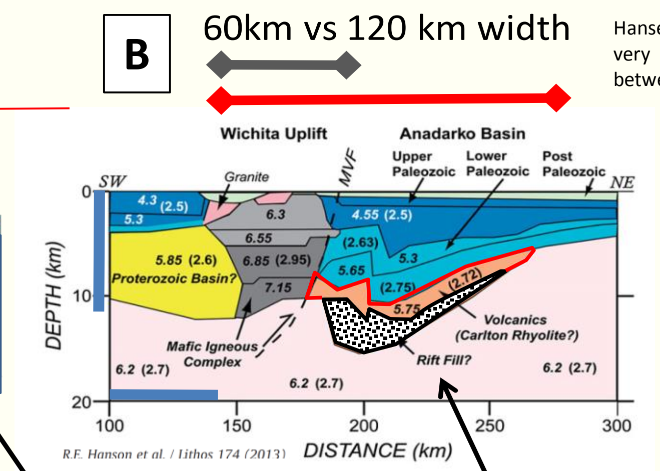
Parting comments & several of many unresolved questions

A) The Cambrian rift (aulacogen) was uplifted and exhumed during Pennsylvanian orogenesis, BUT is it truly inverted in the strict sense that the original master crustal detachments became thrust faults during Pennsylvanian orogenesis?

B) What was the width of the Cambrian rift, 60km or 120km? Note that Hansen et al. (2013) interpret a large volume of volcanic & syn-rift clastic fill east of the Wichita & Mountain View faults. This suggests strongly asymmetric rifting (simple shear) with implications regarding rheology, crustal coupling, strain rate, and cumulative extension (see Huismans & Beaumont 2014).

C) Restoration of the cross-section presented here results in a tabular, lopolithic, geometry for the mafic & ultramafic Cambrian igneous rocks. It is interesting to consider that subsequent thrusting led to thickening this dense root and may be a controlling factor in the anomalous Permian subsidence patterns rather than buoyant isostatic uplift typically observed structurally thickened continental crust (Soreghan et al. 2012).



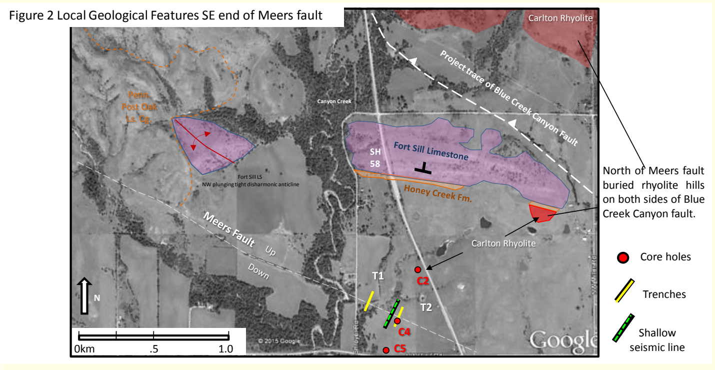


Hansen et al. (2013) indicate a very asymmetric relationship between rift fill and mafic root.

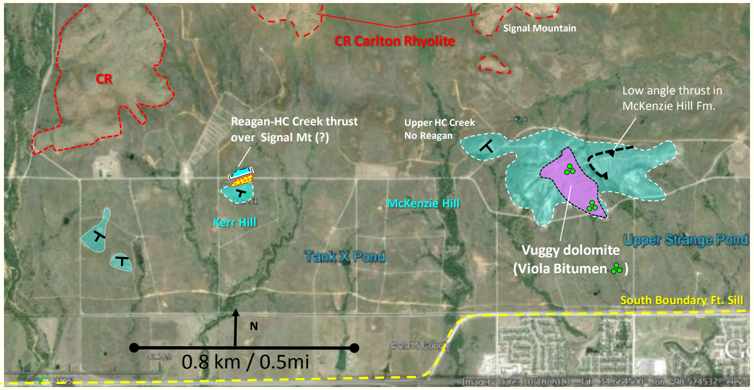
- Rhyolites beyond mafic root.
- Thick rift fill NE of mafic igneous root

Three Suggestions for Additional Study

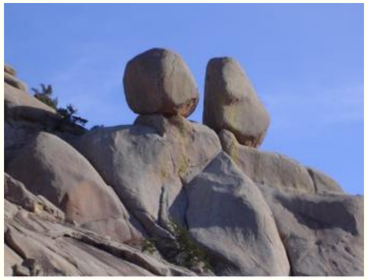
The minimum rupture length (~31km) along the Meers fault is well established, but the maximum length may be as long as 58km (Baker & Holland, 2015). Measurements of displacement (2-3m)are constrained by a what amount to a single transect where the fault has been gouged, shot, shocked and cored. Therefore, estimates of paleo-magnitude based on these two parameters are not well constrained (see Baisi & Weldon 2006). Additional study is needed, e.g., shallow seismic data (ground penetrating radar) to constrain the amount Holocene motion on the Meers fault.

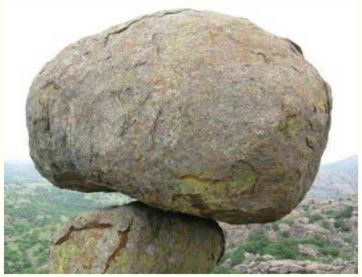


The outcrops of the Timbered Hills-Arbuckle Groups on Fort Sill have been largely neglected since Decker (1939). These outcrops represent key stratigraphic and structural information in the upper plate that can be compared with studies in the Slick Hills, north of the Meers Fault. For example, use trilobite zonations in the two blocks to estimate and compare Cambro-Ordovician subsidence rates in order to build better rifting models for the Southern Oklahoma Aulacogen



Balanced granite tors, Elk Mountain seem inconsistent with a major earthquake on the Meers fault within the last 10,000 years. Cosmogenic isotope studies could determine if these are the remaining remnants of once more widespread balanced rocks.





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