Source Mechanism Analysis to Determine Optimal Wellbore Orientation in the Eagle Ford Play*

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Introduction

Advancements in drilling technology in recent years have opened new opportunities in upstream oil and gas production (Figure 1). With new opportunities in shale plays throughout the continent, energy companies are looking for information that will optimize their reservoir production. Drilling the wellbore orthogonal to the anticipated fracture direction opens maximum drainage area while minimizing stage requirements.

Interest in the Eagle Ford Shale has seen tremendous growth since 2010 (Figure 2). According to the Railroad Commission of Texas, there were 1262 producing oil leases in 2012; compared to the 40 producing oil leases in 2009. Some analysts are suggesting that, by 2015, investments in the Eagle Ford will surpass one of the world's most expensive stand-alone ventures, the Kashagan project in Kazakhstan. As demand increases, large parcels of land in the Eagle Ford are becoming scarcer, resulting in high demand for new insights and methods to maximize production.

Background

The Eagle Ford was deposited in the Late Cretaceous approximately 96-89 Ma. Sea levels were at a highstand due to the high average global temperatures of the epoch. Much of the area now represented by the State of Texas was inundated due to the expansion of the Western Interior seaway and the Gulf of Mexico. The Eagle Ford unconformably overlies the Buda Limestone; it is the major to main source rock for production from the Cretaceous section in Texas.

The Eagle Ford consists of three members. The lower, middle, and upper beds of the Middle member of the Eagle Ford Shale (Figure 4) are commonly referred to as the "productive zone." They are mainly composed of calcareous shales with lower levels of clay than the Lower Member of the Eagle Ford. The brittle nature of the productive zone tends to make this formation very fracable.

The Eagle Ford Shale in the play area lies in the extensional Western Gulf Basin. Growth faults extend roughly parallel to the Gulf Coast: so most faults within the Eagle Ford play (Figures 5 and 6) are oriented approximately NE-SW.

Methods

In the Eagle Ford, surface-based and shallow-buried geophone arrays have been used to monitor microseismic events during hydraulic fracture stimulation treatments. This study includes data from well treatments in 14 counties within the Eagle Ford play (Figure 7). Surface-based microseismic data collected with a wide azimuth, high fold, large aperture arrays can deduce focal mechanisms that reveal rock fracture orientation. Microseismic datasets collected from 87 well treatments were evaluated. Eighty four of the 87 event sets contain data of sufficient quality to pick focal mechanisms with high confidence.

The full waveform approach to surface-based microseismic monitoring allows the analyst to pick first breaks for multiple events during a treatment. The polarity and amplitude of the arrival wave are plotted on a map of the array (Figure 8). A waveform nodal plane, where destructive interference is complete, delineates a small set of possible seismic energy radiation patterns that expose potential rock failure orientations of the event. Final selection of a focal plane solution is based on logic, geology, and tectonic setting.

Focal mechanisms can reveal, through inference, optimal horizontal wellbore azimuth (Figure 9). In this study, detailed analysis of the microseismic focal mechanisms was performed to determine the direction of rock fracture for each well treatment.

Mechanism orientations within each county (or general region) were combined into a set of 12 local rose diagrams. The 12 diagrams were combined to show a general orientation of rock failure throughout the Eagle Ford Shale (Figure 10).

With the exception of results in Walker County (in the NE section of the dataset), Zavala and Frio Counties (in the SW section of the dataset), 94% of the data analyzed showed a strong preference for NE-SW-oriented rock failure between 30^{o} and 70^{o} azimuth. Results from Walker, Zavala ,and Frio Counties were reviewed after completing this analysis. These three counties represent the lowest signal quality of all data in the study.

Discussion

The World Stress Map (WSM) in the Eagle Ford shows one high quality break-out measurement (Figure 11) oriented at 29^{o}. The orientation of this single WSM point represents the northernmost extreme of the orientation analysis of the studied dataset. Figure 12 shows the range of rock fracture orientations from three different locations around the Eagle Ford in green. The blue rose diagram on the map shows the orientation range prescribed by the WSM. The rose diagram to the right shows that the WSM orientation (in blue), representing the extreme of the northerly range of rock fracture orientations from the combined dataset.

Conclusion

Fracture orientations extracted from 84 of 87 surface microseismic datasets were collected from 12 sections of the Eagle Ford. Fracture orientations from 9 of the sections show a range from 30° to 70° azimuth. One major and two minor outliers occurred among the dataset. Outliers represent data that had the lowest signal quality. Outliers also appear toward the edge of the Eagle Ford formation and may represent areas of transitional subsurface geology. Based on the dataset presented, optimum wellbore orientations for the locations studied in the Eagle Ford are 120°-160° (Figure 13), with some local variations. The WSM is generally rotated 5^{o} to 40^{o} counterclockwise from our measured principle stress orientation.

Acknowledgements

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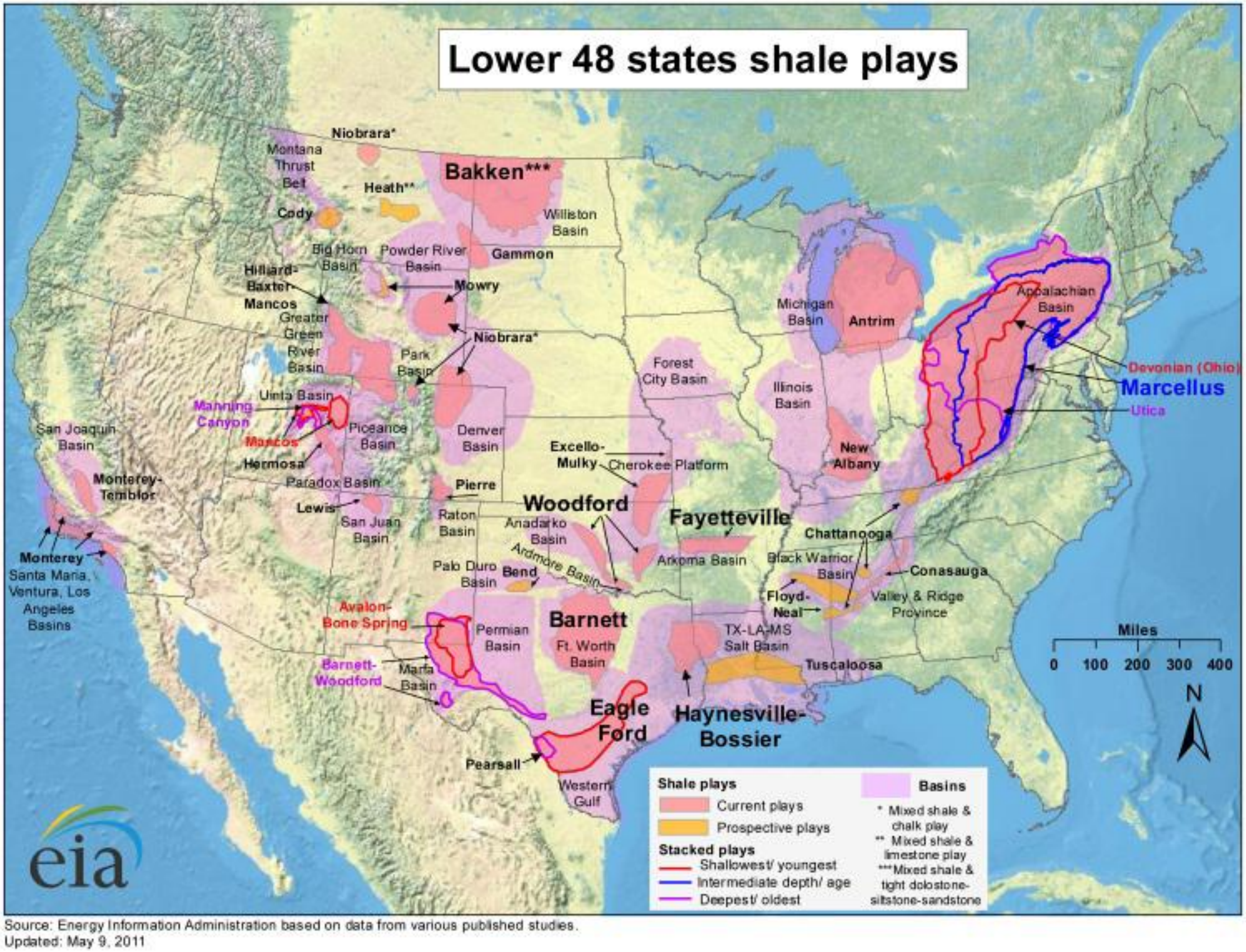

Figure 1. A map of oil and gas producing shale plays in the lower 48 states. (U.S Energy Information Administration, May 2011)

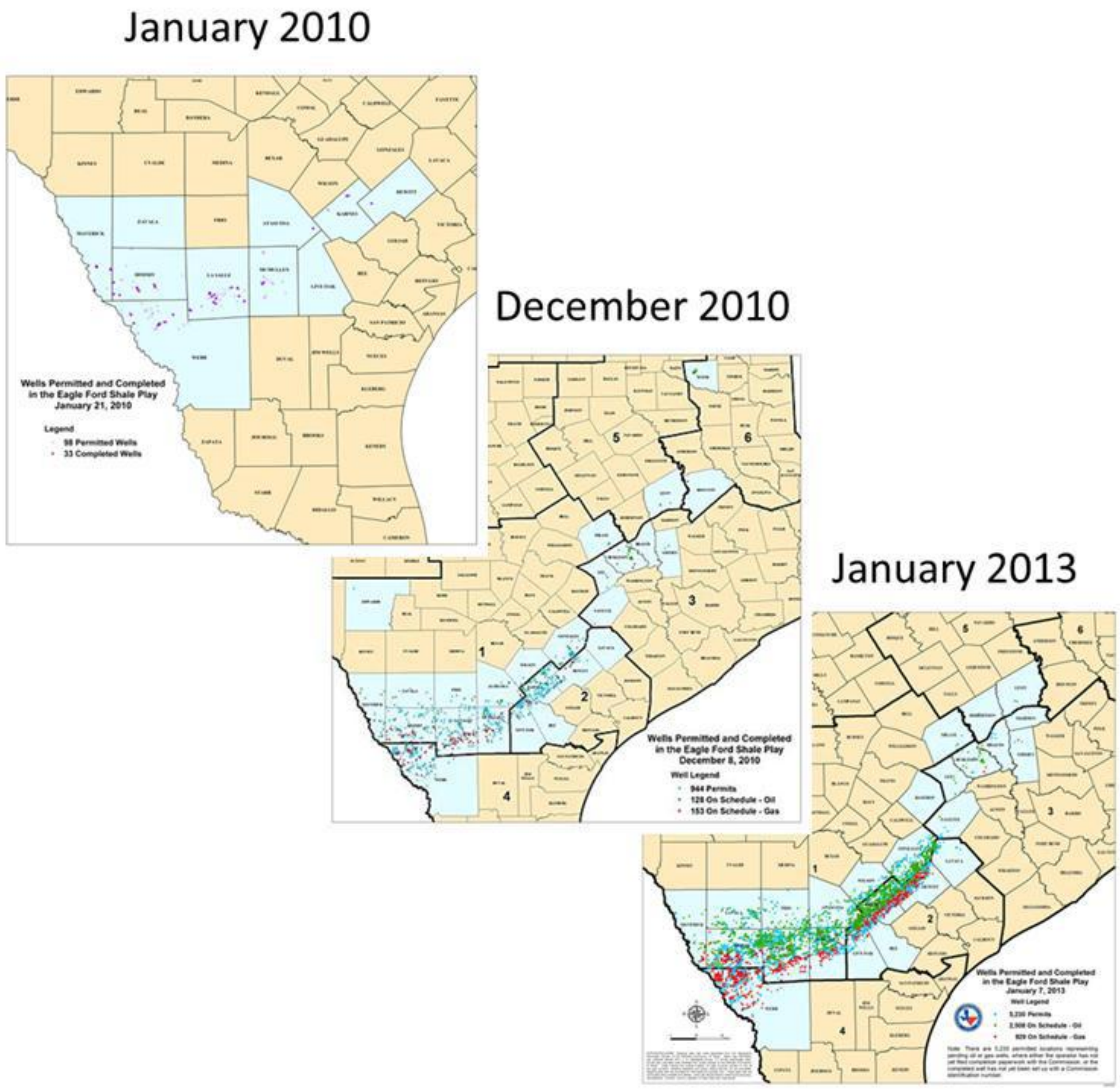

Figure 2. Oil and gas interests in the Eagle Ford Shale play have seen exponential growth in the last 36 months. (Railroad Commission of Texas, January 2013)

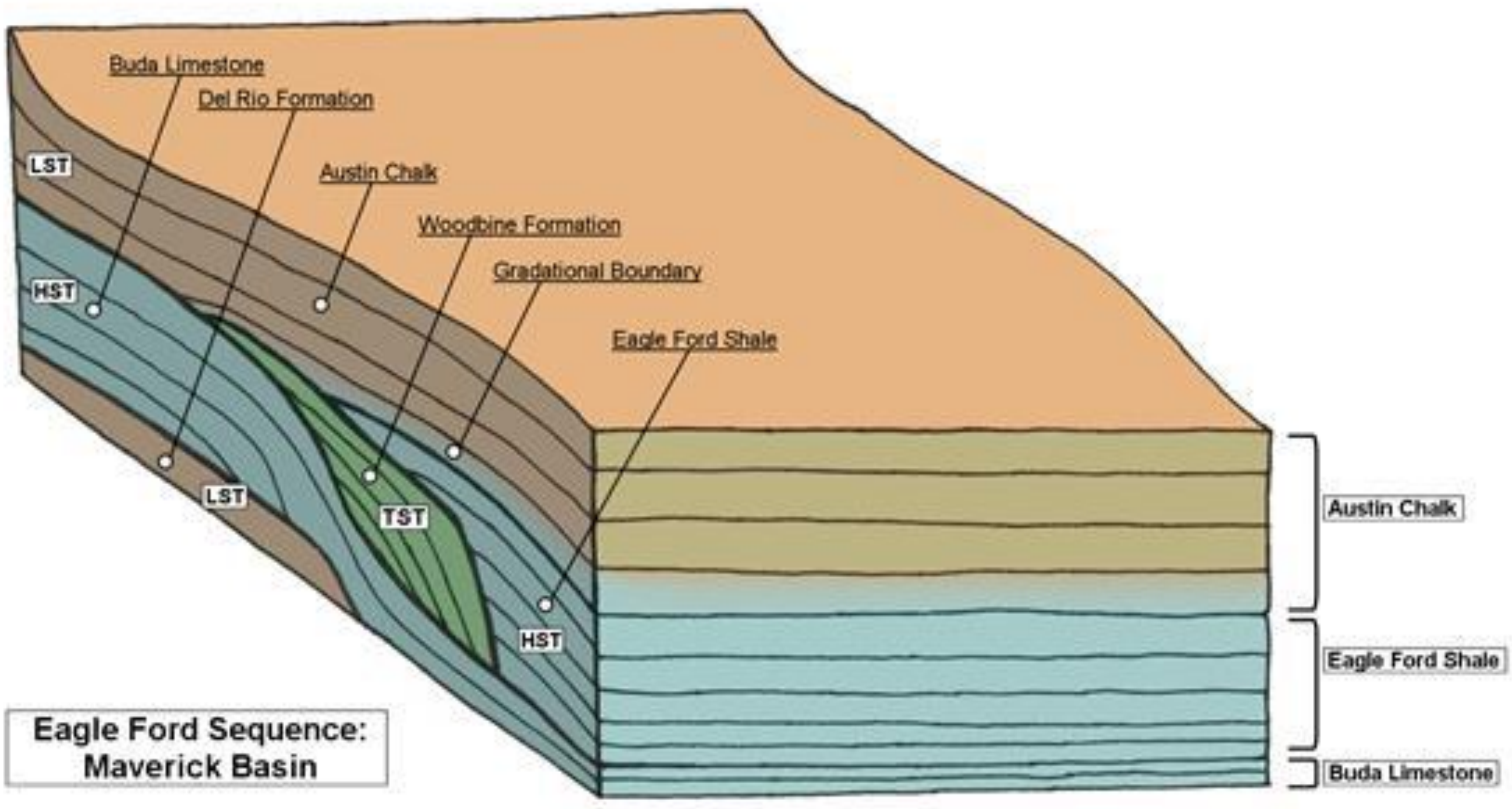

Figure 3. Cross-sectional diagram of Eagle Ford sequence in the Maverick Basin. The Eagle Ford lies between the Buda Limestone and the Austin Chalk.

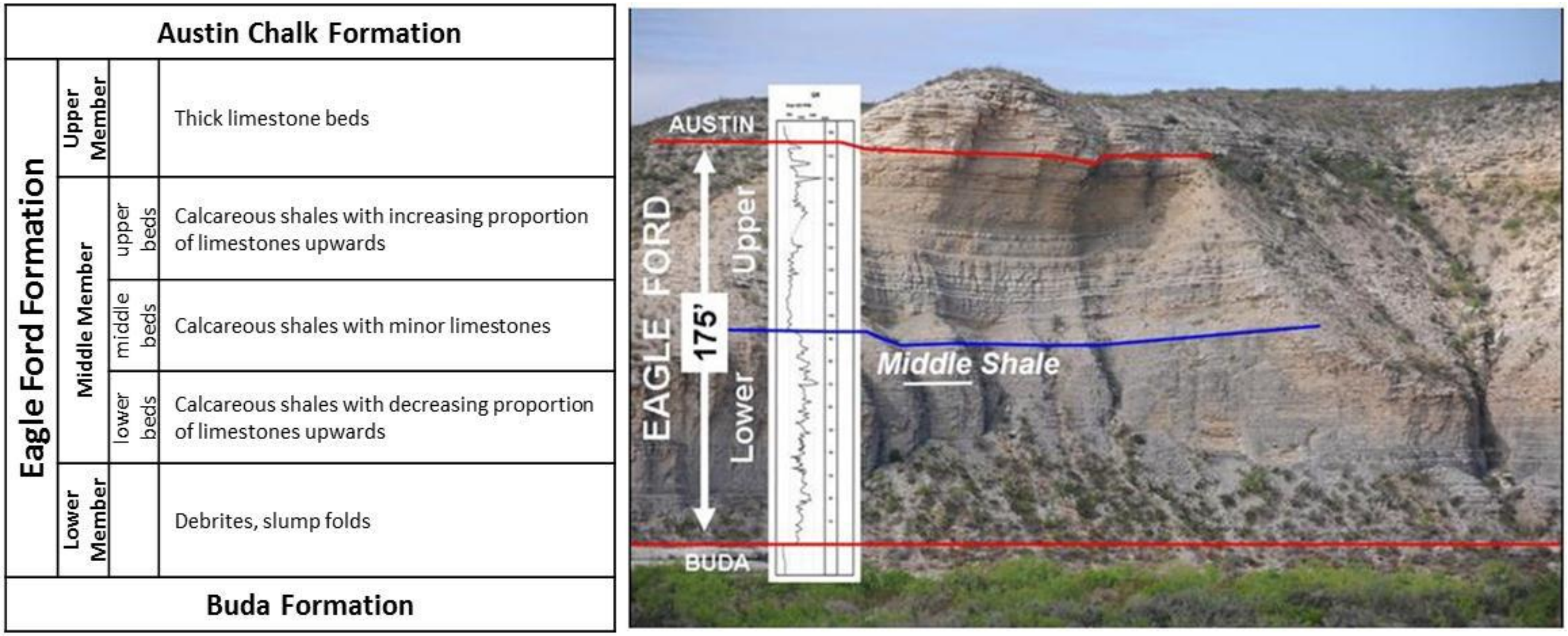

Figure 4. The Eagle Ford is approximately 175 feet thick in this figure. In the "productive zone" it pinches out to a minimum of 40 feet and can be found as thick as 450 feet. (adapted from Peebles, 2012; Lock, 2010.)

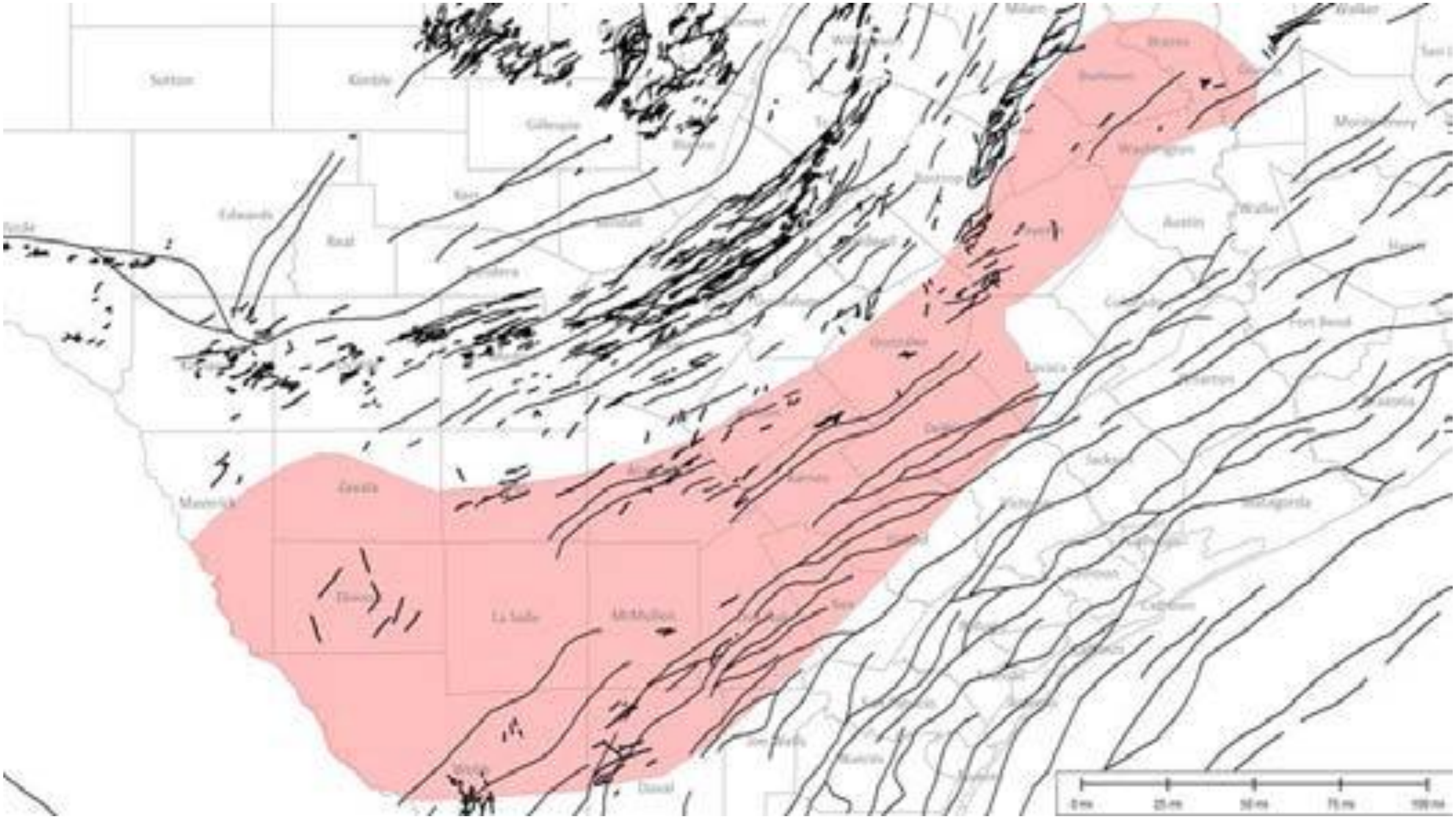

Figure 5. Map of known faults in the area of Eagle Ford Shale play and environs.

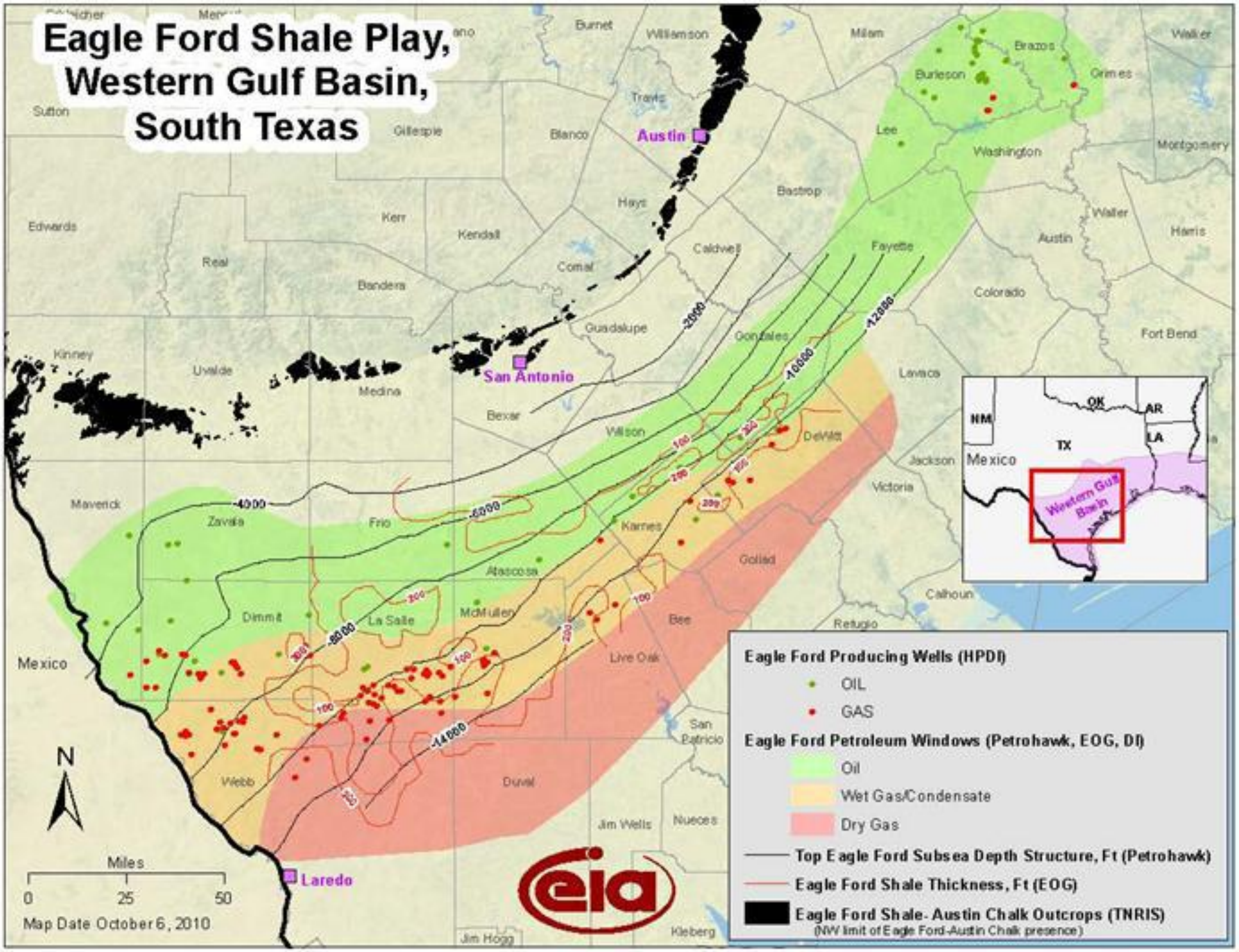

Figure 6. A close-up of the Eagle Ford Shale play in Texas. The formation crops out along the bold black areas near San Antonio and Austin, and dips toward the Gulf Coast. (U.S Energy Information Administration, June 2011)

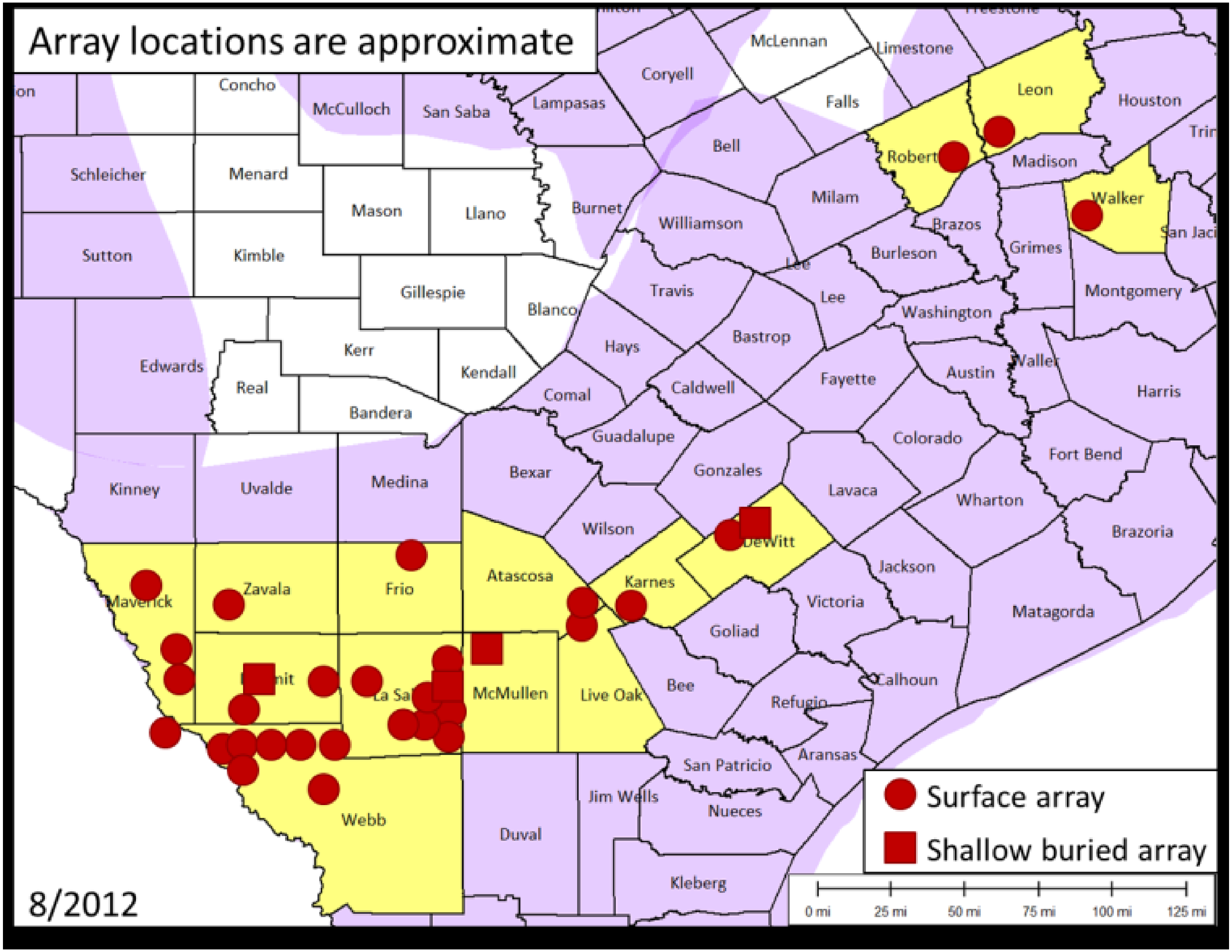

Figure 7. Eighty-four well treatments under 34 arrays from 14 counties (shown in yellow) are included in this study.

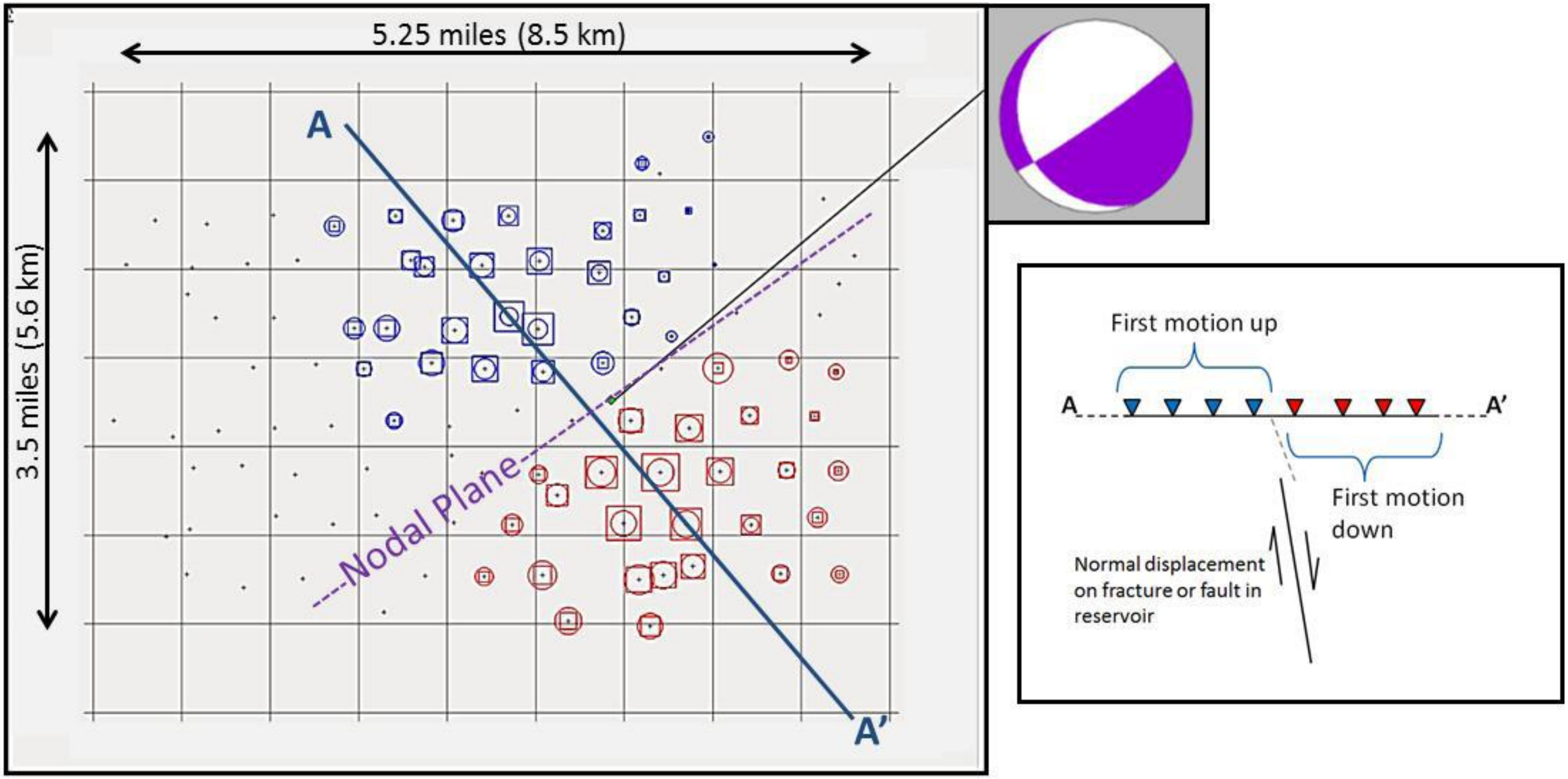

Figure 8. Map view of first motion picking. The focal mechanism shown is inferred from the orientation of the nodal planes.

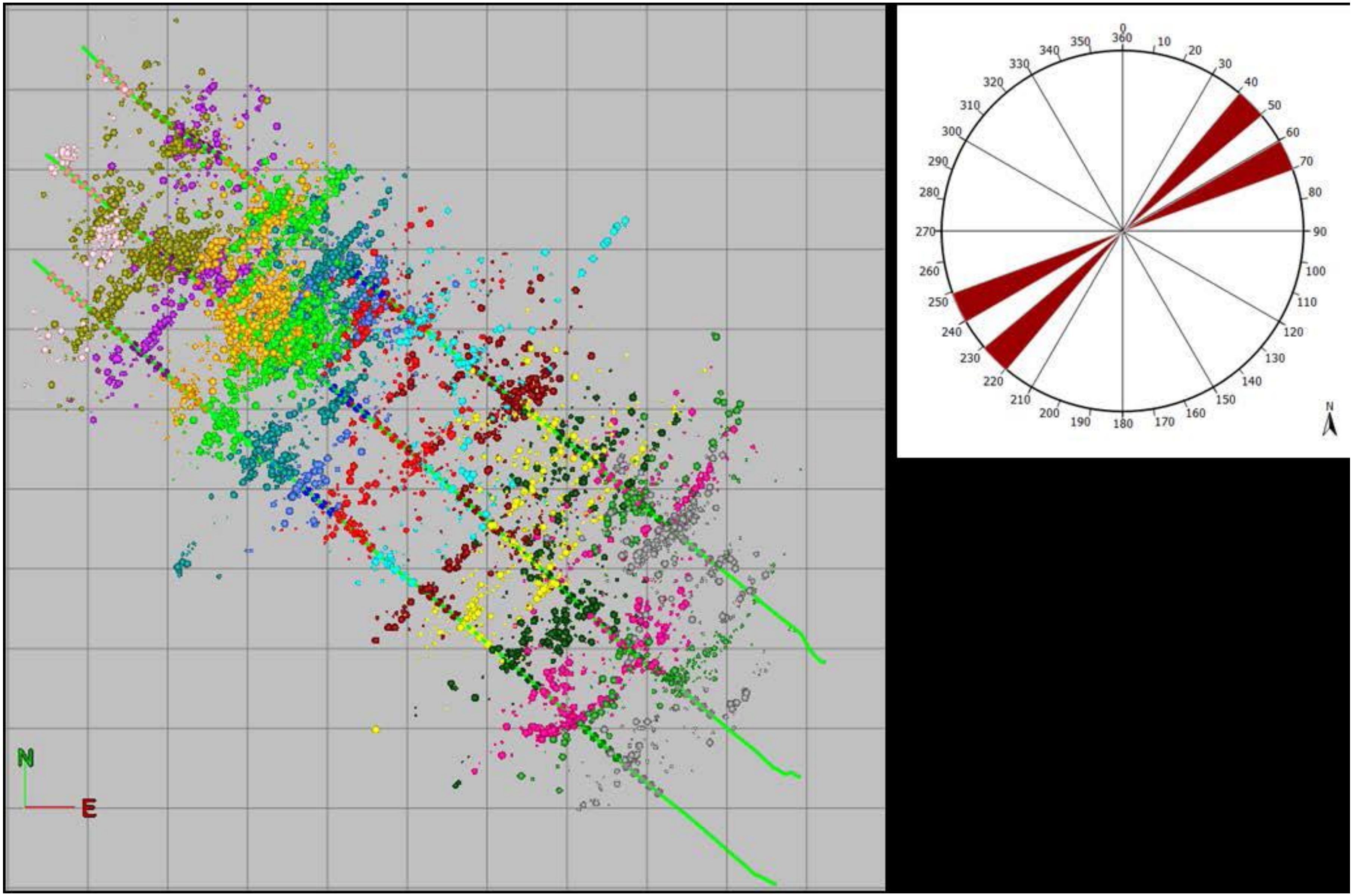

Figure 9. The focal mechanisms inverted from this microseismic dataset indicate a principal stress orientation orthogonal to the wellbore direction (Detring, 2012).

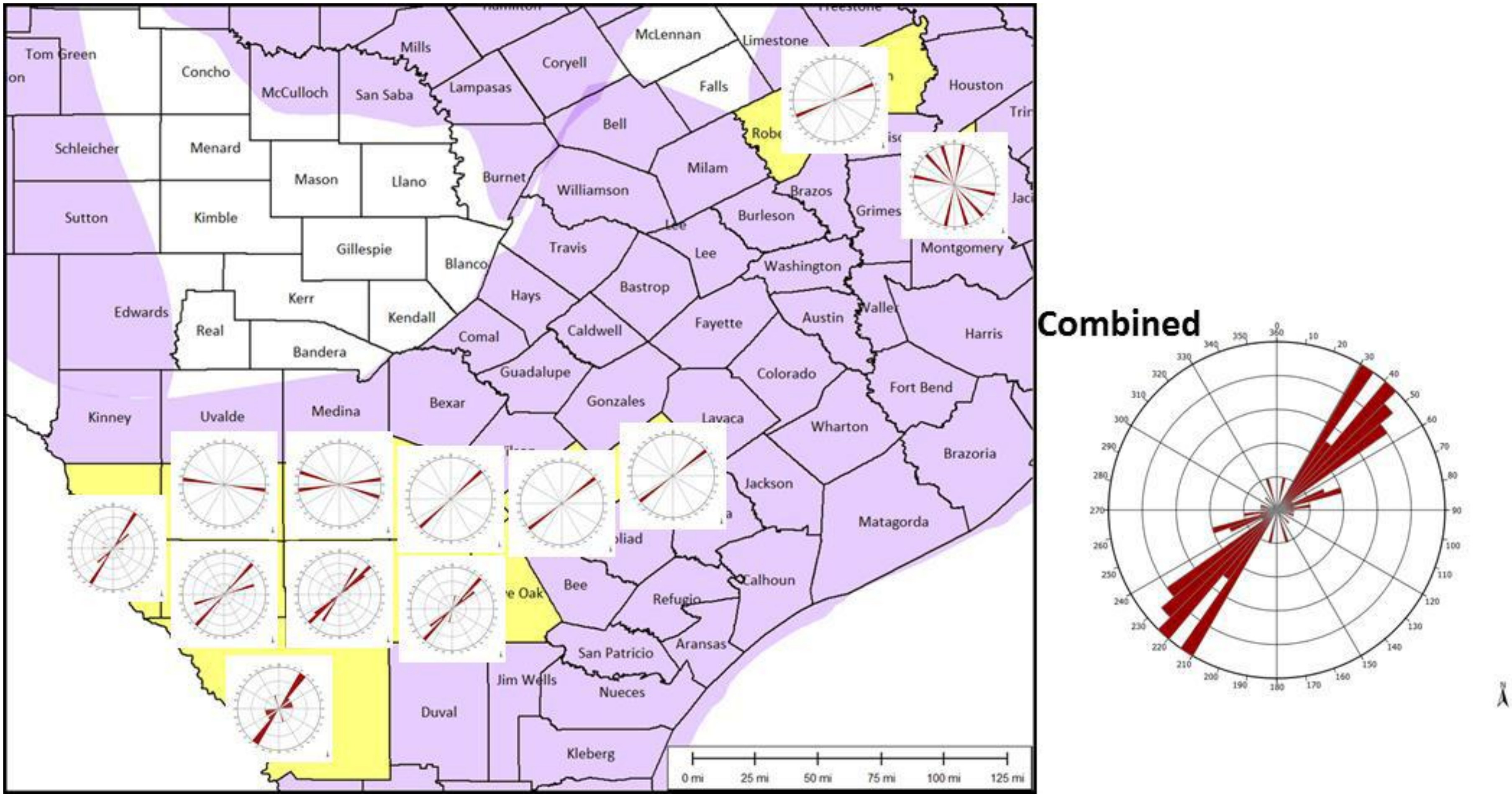

Figure 10. Rose diagrams showing the combined results of focal mechanism analysis in each count in the study. The combined rose diagram shows a composite of all 84 well treatments in this study.

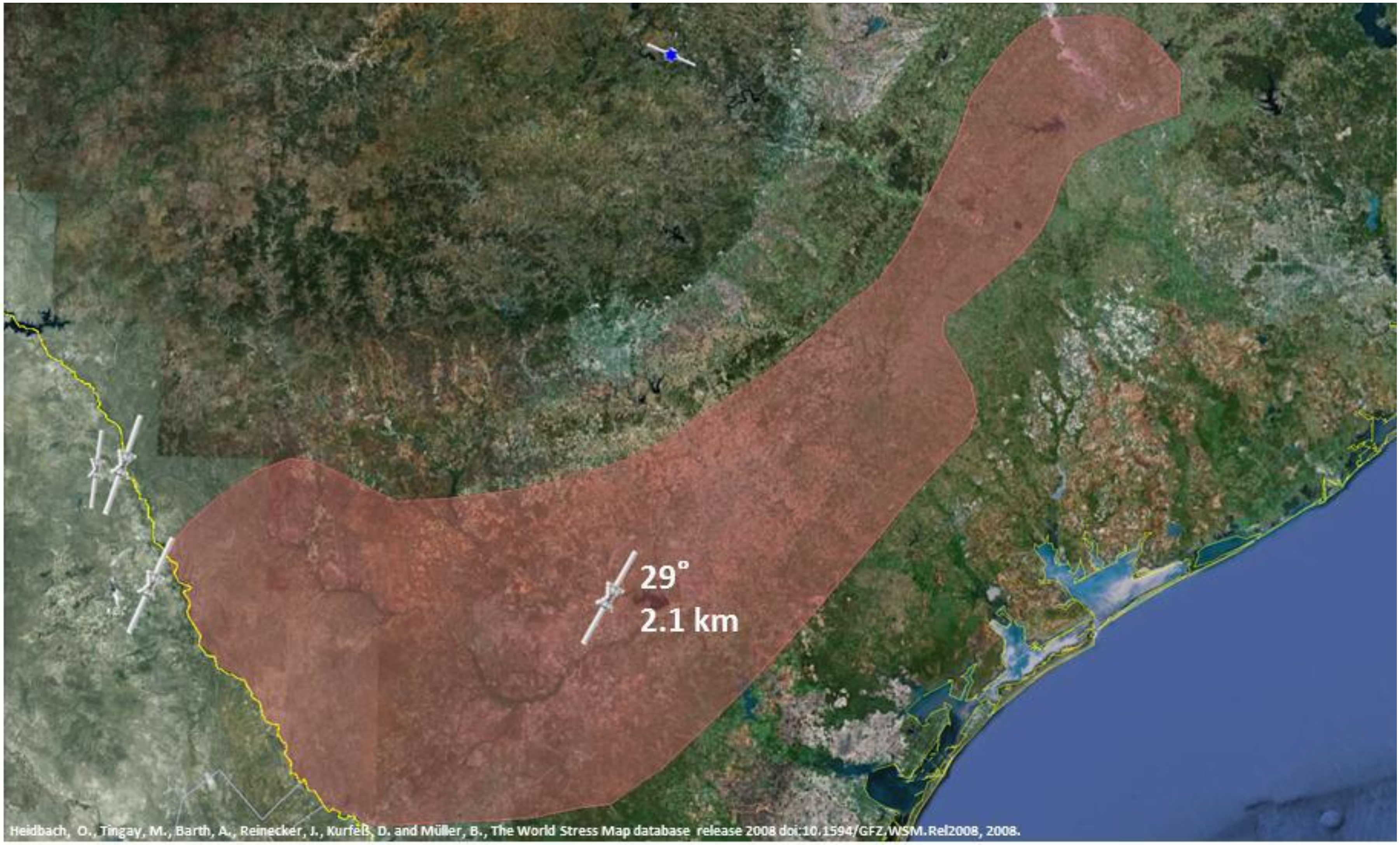

Figure 11. World Stress Map showing a single break-out orientation measurement within the Eagle Ford Shale (WSM, 2008).

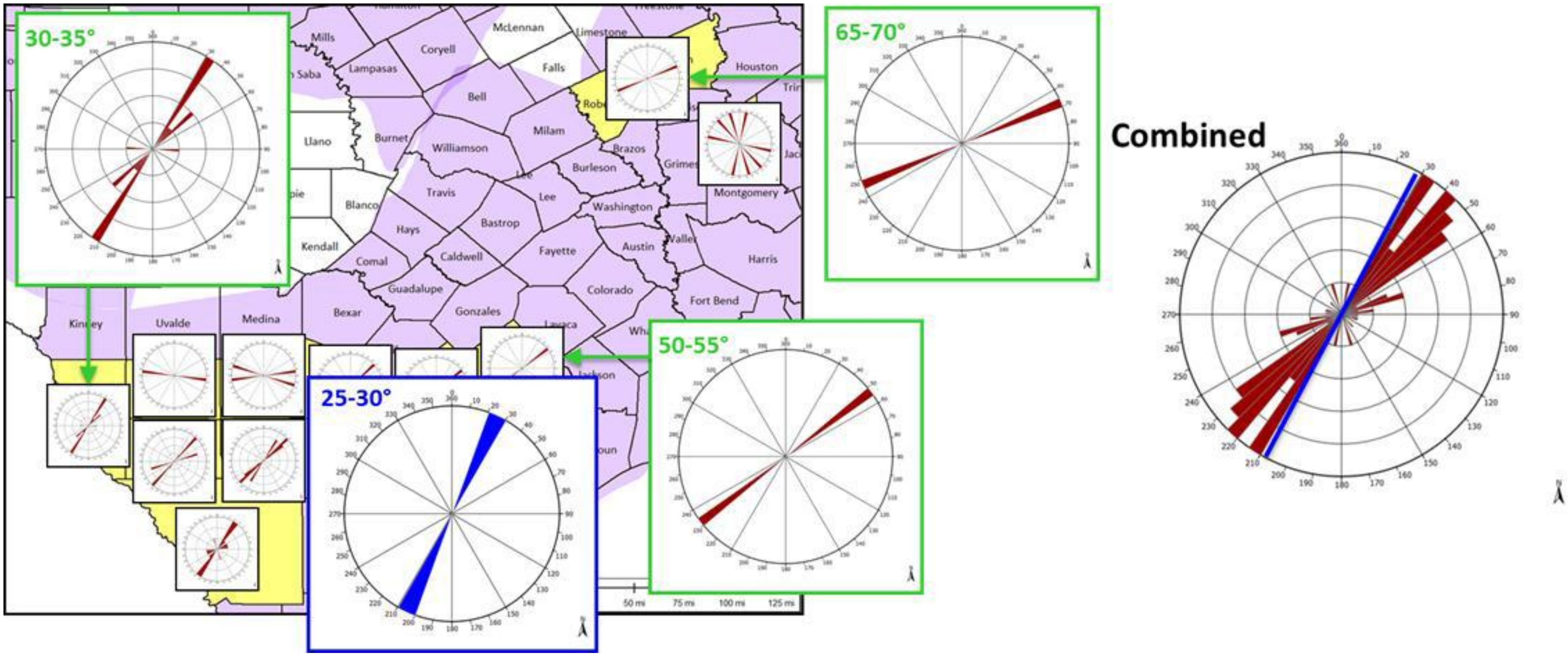

Figure 12. WSM rose diagram shown in blue indicates a maximum horizontal stress axis between 25 ° and 30 °. Rose diagrams created from focal mechanism data from three locations within the study area measure at minimum 30° and suggest a more easterly oriented stress direction.

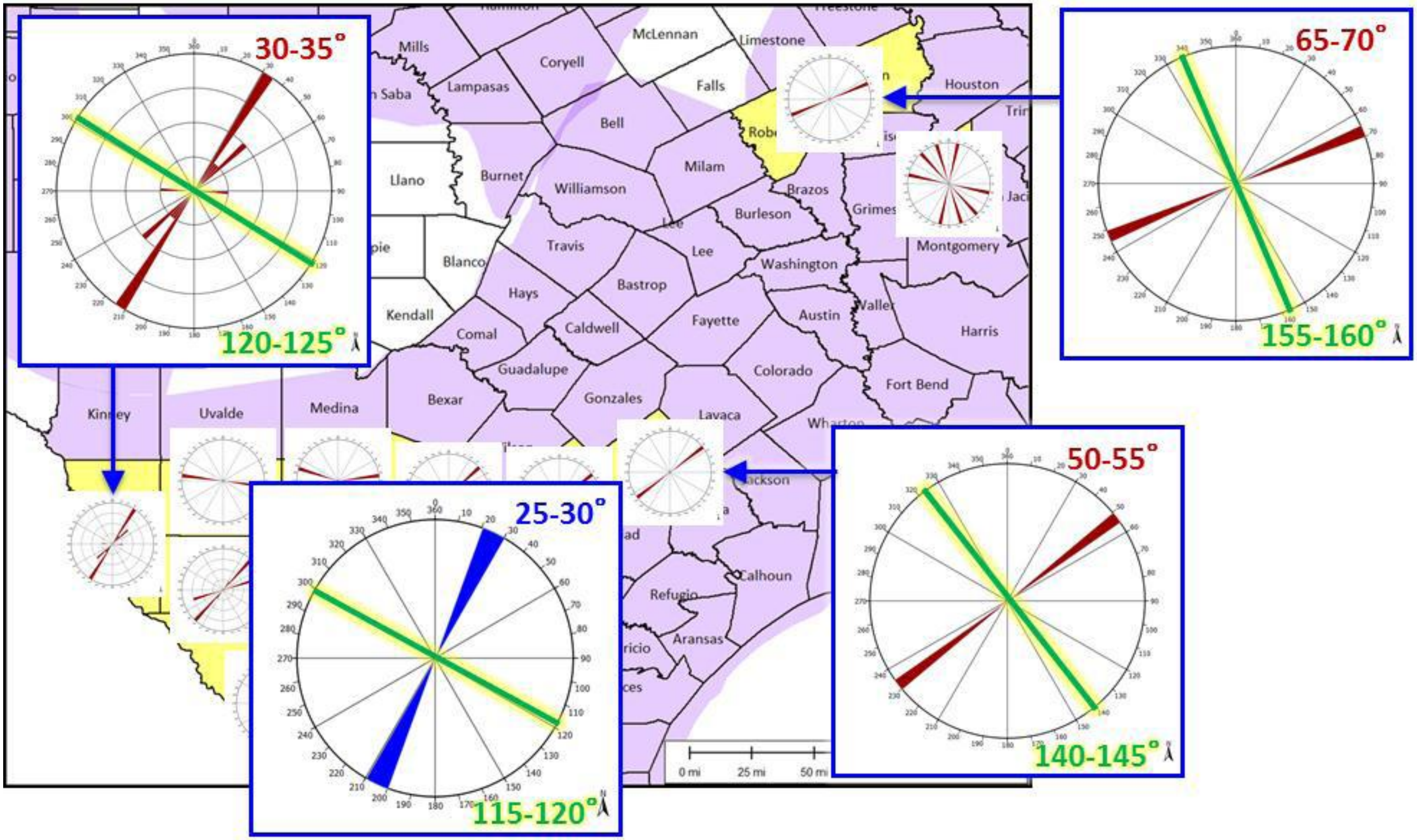

Figure 13. Orientation of optimum wellbore configuration is shown in green for each of three areas within the Eagle Ford play.