Microseismic Monitoring and Structural Interpretation of Reactivated Laramide Fractures North-Central New Mexico*

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Abstract

Existing geologic structure often has strong impacts on the geometry and failure mode of microseismicity mapped during hydraulic fracture stimulation treatments. A new interpretation of structural development that investigates the role of strike-slip faulting in north-central New Mexico is applied to the interpretation of two microseismic monitoring results. The Cenozoic geologic history of the north-central New Mexico region is dominated by two main tectonic events that occurred along the eastern boundary of the Colorado Plateau: the Laramide Orogeny and opening of the Rio Grande Rift. The San Juan Basin lies immediately west of the Nacimiento Uplift and marks the eastern boundary of the Colorado Plateau (Figure 1). Miocene extension disrupted the Laramide-age crustal structure by movement along Rio Grande rift-related normal fault systems, clastic and volcanic rock sequences, and formation of the Valles caldera. This disruption can make distinguishing Laramide deformation from Miocene extensional faulting difficult due to overprinting.

One outstanding controversy in our understanding of Laramide deformation is the role of strike-slip faulting and slip partitioning. This has remained a major issue primarily because of an insufficient understanding of the local fault system geometry between Laramide uplifts. North-trending Laramide age dextral faults in north-central New Mexico are primary features in models explaining the kinematic interaction between the Colorado Plateau and the North American Craton. Palinspastic reconstructions of aeromagnetic anomalies cut by these dextral faults do not explain local shortening patterns, and while interpreted regional fault geometries do explain shortening accommodated along the Nacimiento Fault system, they fail to explain Laramide age shortening in the Tusas-Brazos Mountains.

The alternative geometry interpreted in this study is supported by fracture trends mapped via microseismic monitoring of hydraulic fracture stimulation treatments in the area. The mapped trends are consistent with the assumption of bounding faults on the Nacimiento and Tusas-Brazos basement uplifts that are connected by an accommodation zone formed during transpressional deformation.

Theory and Method

Hydraulic fracturing of wells in Rio Arriba County immediately northwest of the Nacimiento Uplift in the San Juan Basin (Figure 1), target the Turonian Mancos Shale, a 643 meter thick gas shale resource deposited during the subsidence of the San Juan Basin (Cather, 2008). Deformation due to the onset set of the Laramide Orogeny is likely to be the control of fracture orientation in the Mancos Shale. Geologic mapping between the Nacimiento and Tusas-Brazos uplifts show the presence of a series of en echelon Laramide age monoclines. We interpret these structures as a diffuse accommodation/transfer zone. Fracture analysis of the monoclines is consistent with Laramide age deformation history and microseismicity trends of 130° and 172°. Microseismic monitoring of these wells, reflect trends that are also consistent with fracture patterns observed along the transfer zone (Figure 2). The oblique orientation of the microseismicity trends to current SHmax suggests that the fractures formed are likely reactivated Laramide features (Figure 3).

Example

The north-south microseismicity trends are parallel to the general trend of active faulting in north-central New Mexico and region fracture sets 1 and 3 (Figure 2). The NW-SE microseismicity trends are parallel to fractures formed during an earlier phase of Laramide deformation and given the evidence between current stresses and Laramide features, it is likely that these trends are also signifying reactivation of Laramide features. Fracture height in the results range from 100-400 meters, indicating that stimulation is localized within the targeted Mancos Shale.

Using kinematic modeling to analyze the monoclines in the transpressional accommodation zone with fault-propagation fold (FPF) kinematics, the presence of a blind thrust appears between 0.75 and 1.75 km below the forelimb of each fold. Geologic mapping of the monoclines and region surrounding found visible normal faults but no visible thrust faults. Based on the location, dip direction, dip angle, and orientation of the normal faults found in the forelimbs, it is likely that a pre-existing subsurface weakness influenced the location of the faults. Many of the normal faults in this region are interpreted to exploit Laramide thrusts evident by the orientation and trends. Field work and FPF modeling imply an interaction between the modeled blind thrust and a Miocene aged extensional fault, resulting in fault reactivation. This interaction suggests that pre-existing weaknesses formed during the Laramide are likely to influence the orientation of fractures that are formed during hydraulic fracturing, explaining why microseismicity trends are not parallel to present day SHmax.

Conclusions

Several en echelon shortening structures trending northeast, including the two prominent monoclines addressed in this study, provide evidence for transpressional linkage between the two Laramide uplifts. Given the strong relationship between pre-existing weaknesses and recent extension, and orientation of the microseismicity trends parallel to Laramide fracture sets (Figure 2), it is likely that trends observed in the stimulated wells from the San Juan Basin are also reactivated Laramide features. The reactivated shortening features found in the accommodation zone are interpreted to be indicators in the evolution of this region through the Late Cretaceous and into the period of Cenozoic rifting. Shortening calculations across the region suggest a link between the two uplifts and favors an east-west orientation of $\sigma 1$, followed by a series of counter-clockwise rotations to account for a small component of dextral slip. Coincidently, the reassessed fault geometry proposed in this study mimics the geometry of the Rio Grande Rift, providing a possible explanation for its shape and polarity reversal.

Acknowledgements

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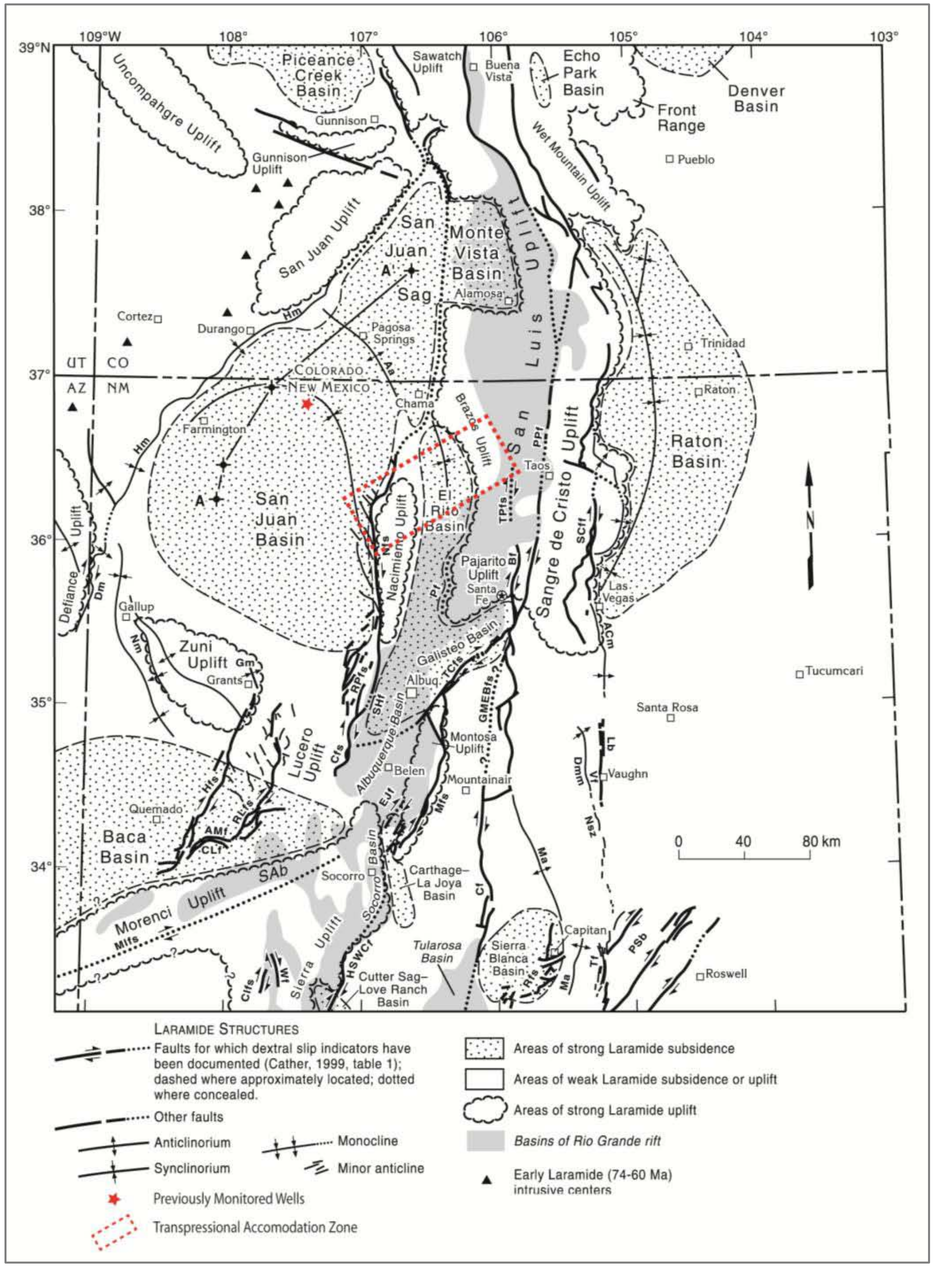

Figure 1. Structure map of north-central New Mexico showing Laramide-age uplifts, basins, and faults (modified after Cather, 2006).

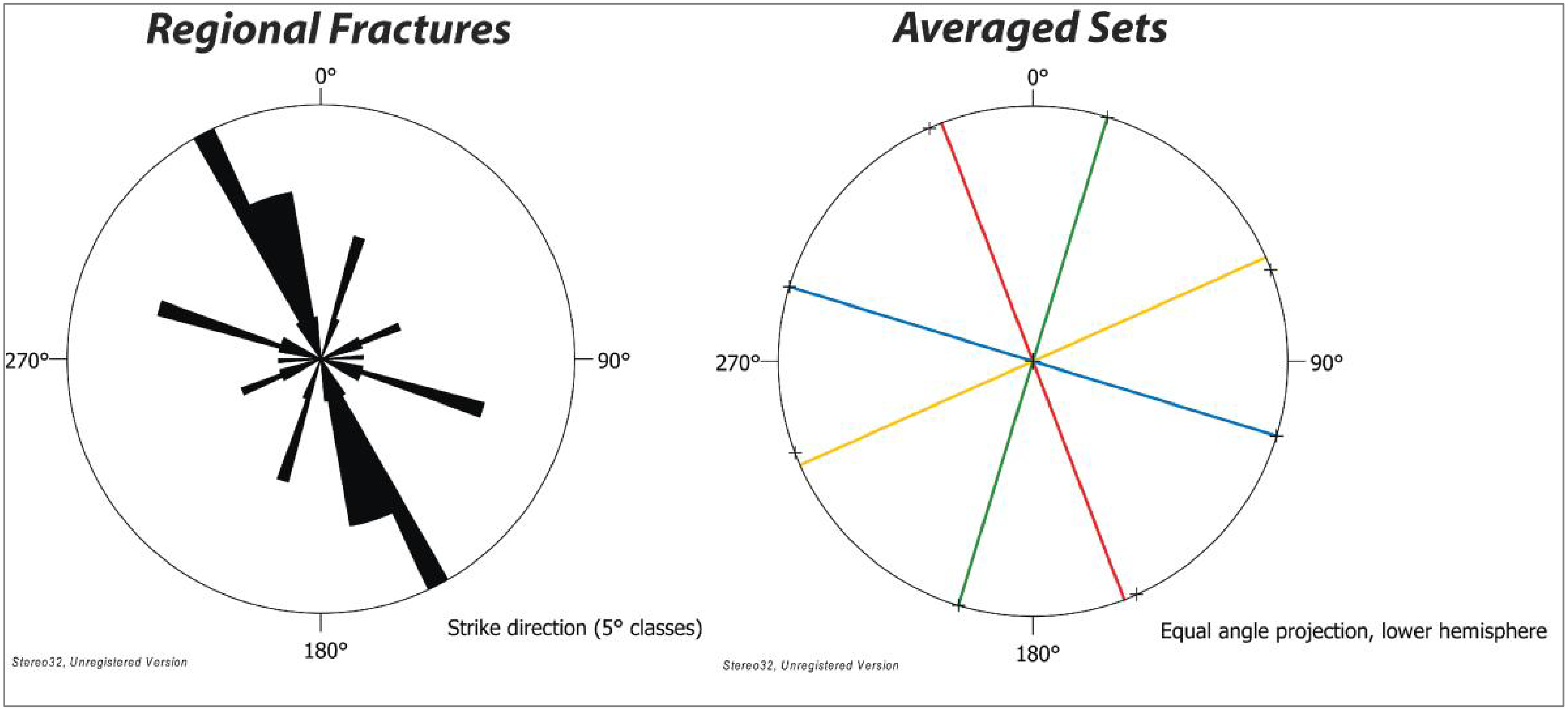

Figure 2. All regional fractures plotted and averaged in Stereo32. Set I (Red) = N21W, Set II (Blue) = N73W, Set III (Green) = N17E, and Set IV (Yellow) = N66E.

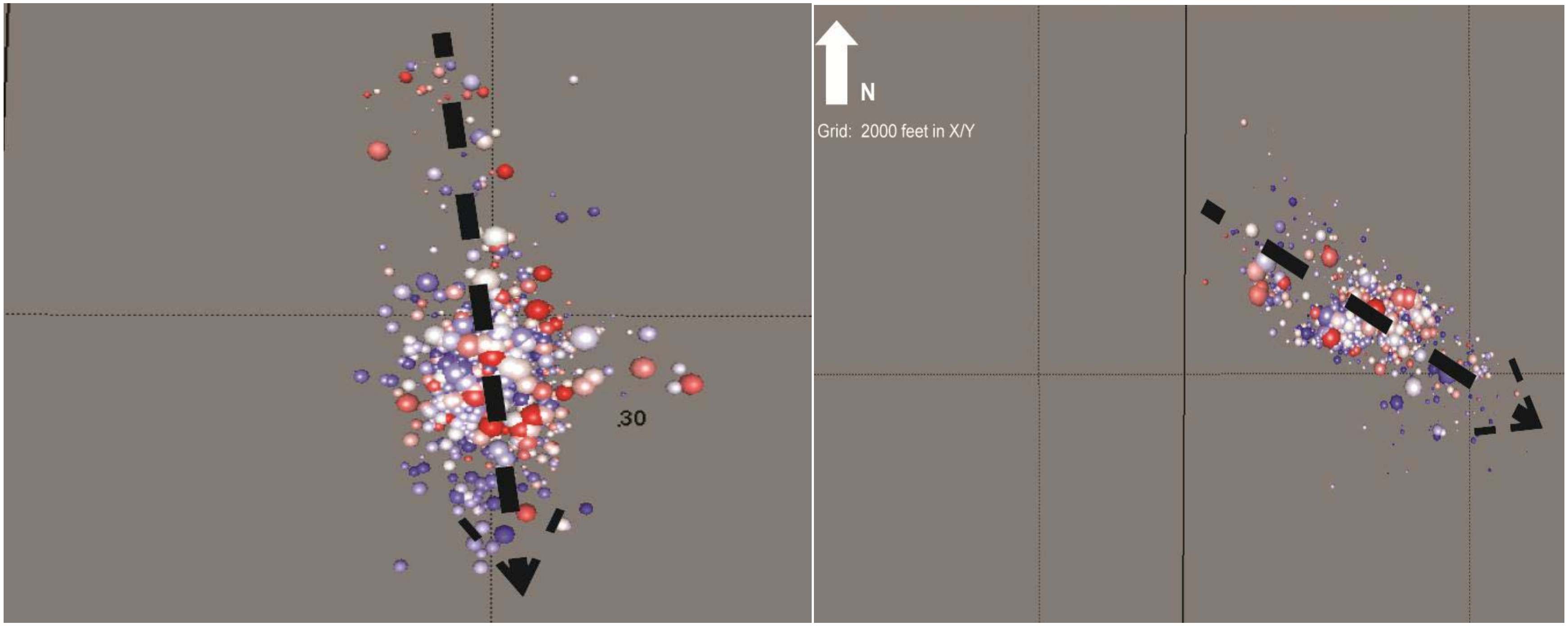

Figure 3. Observed microseismicity trends in the San Juan Basin of Rio Arriba County, New Mexico. Well 1 (left) = 172° azimuth (Fracture Set I); Well 2 (right) = 130° azimuth (Fracture Set II).