Syn-seismic deposition or syndepositional seismicity: Paleoseismites record 10 m.y. of Early Paleogene Laramide seismicity in San Juan Basin, north-central New Mexico

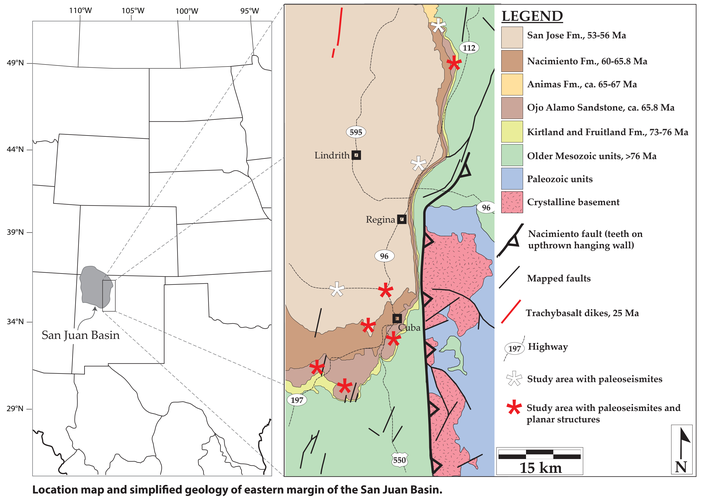
Kevin Hobbs and Jacob O. Thacker, *New Mexico Bureau of Geology and Mineral Resources, New Mexico Tech*

Abstract

Features interpreted as paleoseismites in eastern San Juan Basin are observed in Paleocene–Eocene fluvial siliciclastic sedimentary rocks proximal to the basin-bounding Nacimiento fault. Features include clastic dikes, convolute bedding, diapir-like structures, vents, anastomosing vein-like structures, and potential thixotropic bowls in the early Paleocene (ca. 66.0 Ma) Ojo Alamo Sandstone and early Eocene (ca. 56.0 Ma) Cuba Mesa Member of the San Jose Formation. Observations to date suggest that these features are limited to areas within 20 km of the Nacimiento fault, and have not been found farther north where the Nacimiento fault terminates northward into the Archuleta anticlinorium or to the west farther into the basin. Convolute bedding is often truncated by overlying beds, indicating soft-sediment deformation at or near the surface before deposition of overlying strata. Clastic dike measurements thus far reveal two major strike orientations: 055° (dominant) and 160° (subsidiary). The dominant clastic dike orientation is sub-parallel to prior estimates of Cretaceous–Paleogene WSW-ENE intraforeland (i.e., Laramide) shortening at the local to regional scale. Cross-cutting planar features that strike 020° may post-date the clastic dikes, but their relationship is not yet clear. The presence of paleoseismites in earliest Paleocene (Puercan North American Land Mammal Age) through early Eocene (Clarkforkian–Wasatchian age) indicates that seismicity occurred for at least approximately 10 million years in the early Paleogene San Juan Basin, consistent with stratigraphic evidence of tectonism at this time. The presence of San Juan Basin paleoseismites could suggest early Cenozoic intraforeland earthquakes on the order M ≥ 5 that disrupted sedimentation patterns prior to lithification. These preliminary data suggest a 10 m.y. episode of intermittent seismicity associated with the Cenozoic structural and depositional evolution of the San Juan Basin during the Laramide orogeny. Results from this work will be integrated into regional studies on the paleoenvironmental, depositional, and Laramide tectonic development of the area.

Introduction and Importance

- Features described were first noted in the Ojo Alamo Sandstone in 2014. NMBGMR mapping in the area in 2021 brought similar structures in the San Jose Formation to light.
- Soft-sediment deformation structures (SSDSs) compatible with seismites exist in Paleogene sandstones near the eastern margin of the San Juan Basin, New Mexico, USA.
- These SSDSs include clastic dikes, convolute bedding, diapir-like structures, vents, and enigmatic planar structures with consistent strike orientations.
- SSDSs decrease in abundance with distance west and north from the basin-bounding Nacimiento fault.
- SSDSs are found in the well-dated Ojo Alamo Sandstone (<65.69 Ma) and the San Jose Formation (<56 Ma), indicating ~10 m.y. of syndepositional seismicity in the eastern San Juan Basin.
- The distribution of SSDSs reported here suggests that the Nacimiento fault is the likely candidate for Paleogene earthquake foci.
- The dominant strike orientations of enigmatic planar structures reported here are subparallel to previously reported local and regional ENE-WSW Laramide shortening.

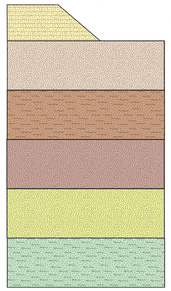


Location map and simplified geology of eastern margin of the San Juan Basin.

Lithology

The SSDSs described here are found in the Paleocene Ojo Alamo Sandstone (PEoa) and Eocene Cuba Mesa Member of the San Jose Formation (PEsjc), both of which are fluvial arkosic arenites with subordinate feldspathic wackes and feldspathic conglomerates. In our study areas, the predominant lithologic composition is a fine- to coarse-grained (predominantly medU to coarseL), moderately- to well-sorted, subangular laminated to medium-bedded (predominant thin bedded) feldspathic arenite (45-75% Q; 25-50% F; 2-10% L) with predominate clay and subordinate calcite and silica cement. Primary structures include horizontal plane beds, trough cross-beds, cut-and-fill structures, and massive bedding. Tops and bottoms of sandstone bodies are often obscured due to the nonresistant nature of the sub- and superjacent mudstones; where observed, the boundaries are sharp or gradational over centimeters. Both units are dominated by amalgamated sandstone bedsets; mudstone and conglomerate interbeds make up <5% of the volume of the units.

Stratigraphy



Quaternary surficial deposits

San Jose Formation - 600-1000 m thick - SSDSs present in basal member. Upper 3 members not yet investigated.

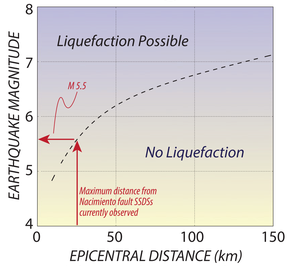
Nacimiento Formation - 420-600 m thick - SSDSs not yet investigated.

Ojo Alamo Sandstone - 5-120 m thick - SSDSs present throughout the unit in SE San Juan Basin.

Kirtland/Fruitland Formations - 150 m thick - SSDSs not observed

Older Cretaceous units - SSDSs not observed

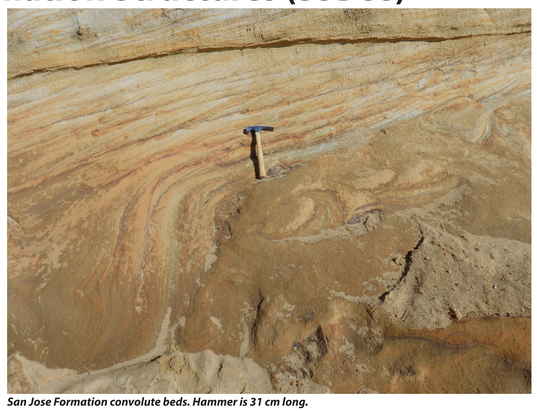
Magnitude



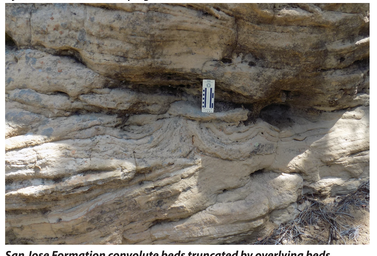
Magnitude vs. epicenter distance (Rowe, 2013) for presence of liquefaction features suggests M ≥ 5 earthquakes.

Soft Sediment Deformation Structures (SSDSs)

San Jose Formation injectite. Mud-clast conglomerate injected 70 cm into overlying arkosic arenite.



San Jose Formation convolute beds. Hammer is 31 cm long.



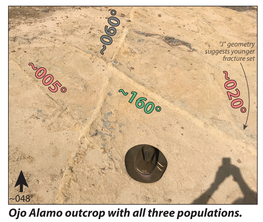
San Jose Formation convolute beds truncated by overlying beds, indicating that deformation occurred while sediments were at or very near surface. Black scale bars are 10 cm long.

Ojo Alamo Sandstone injectites. Bold line marks top of injected layer; finer lines indicate relict bedding in overlying layers. Both layers contain arkosic arenite. Hat in lower right is ~35 cm long.

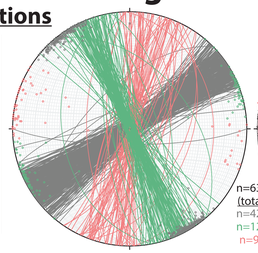
Structural Analysis of Enigmatic Planar SSDSs

***(Stereonet11**: Allmendinger et al., 2011; Cardozo and Allmendinger, 2013)*

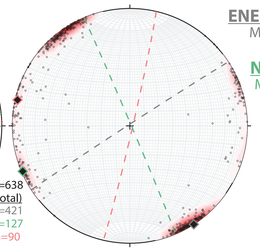
Three Dominant Populations



Ojo Alamo outcrop with all three populations.



n=638 (total)
n=421
n=127
n=90



ENE-WSW (*dominant*)
Mean Plane: 237, 89NW
Eigenvalue = 0.981

NW-SE (*subsidiary*)
Mean Plane: 337, 89NE
Eigenvalue = 0.964

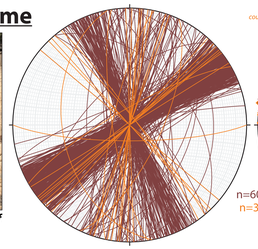
NNE-SSW
Mean Plane: 013, 88E
Eigenvalue = 0.936

Kamb Contour
Contour Interval = 5σ
Significance Level = 3σ
Calculated from all 638 data points (not in individual populations)

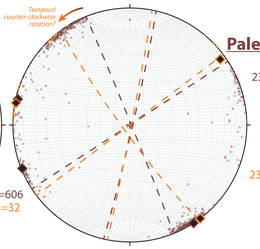
All mean planes are calculated from color-coded segmented populations using a cylindrical best fit of poles to planes (color-coded diamonds are mean poles)

Orientations Through Time

Ojo Alamo outcrop showing possible injection of ~160° feature.



n=606
n=32



Paleocene Ojo Alamo
Mean Planes:
237, 90 - 338, 89NE - 013, 88E
Eigenvalues:
0.981 - 0.972 - 0.929

Eocene San Jose
Mean Planes:
233, 90 - 144, 85SW - 011, 89E
Eigenvalues:
0.948 - 0.865 - 0.972

Geometric Observations and Interpretations

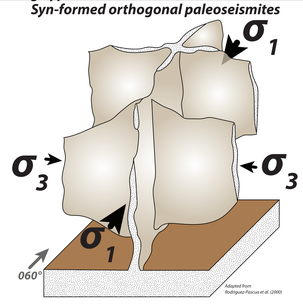
- Field observations show ENE-WSW and NW-SE features are coeval.
- Slight comminution of material and coincidence of NNE-SSW features with proximal NNE-SSW Jemez Lineament features led to interpretation these were Late Cenozoic deformation bands.
- NNE-SSW population appears coeval in some locations, however.
- Thin-section analysis and continued field measurements will better determine the character and significance of all populations.

ENE-WSW: Filling of Mode I fractures (|| to σ_1)

NW-SE: Filling of subordinate fractures (|| to σ_3)

NNE-SSW: Significance and timing currently undetermined

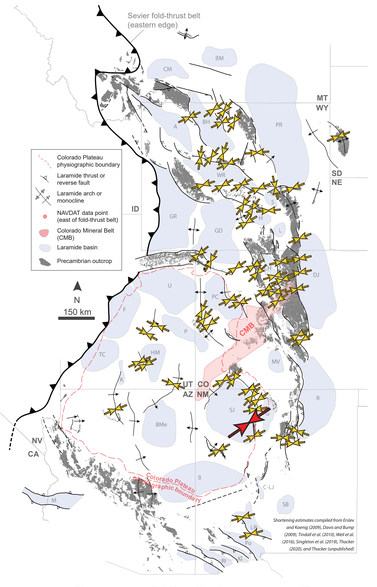
Working hypothesis of ENE-WSW and NW-SE features:
Syn-formed orthogonal paleoseismites



Temporal Observations and Interpretations

- Consistent slight counter-clockwise shift in dominant orientations of all three populations from Paleocene to Eocene.
- Apparent shift may be artificial due to limited data and will be tested with continued field measurements.
- May reflect subtle change in Laramide shortening through time.

Regional Laramide Shortening



Eastern SJB, Paleocene–Eocene
057°/237° Laramide Shortening
based on interpretation of dominant population as Mode I