

PS Timing and Mechanisms of Fracturing within the Irish Canyon-Vermillion Creek Area, Moffat County, Colorado*

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Abstract

Effective exploitation of low permeability reservoirs requires the understanding of the local tectonic history and the present day stress regime. The industry's current focus on fractured, liquids-rich gas and tight oil plays makes the southwestern Sand Wash Basin, with high-quality, lower maturity source rocks and structural complexity, an ideal place to study fracturing in tight rocks. Orientations of minor faults and extensional fractures within variably oriented structures formed during the Laramide Orogeny and Brown's Park Extension were analyzed to unravel modes and mechanisms of fracturing and paleostress trends. Cross-cutting relations observed in outcrop and geologic maps were used in an attempt to characterize the local Cenozoic strain history.

The 59° orientation of Laramide σ_1 suggests oblique thrust and left-lateral slip on the E-W striking North Boundary Fault. N-S trending Laramide extensional fractures and out-of-the-basin flexural-slip suggest strain partitioning within this zone of oblique deformation. NW-striking extensional fractures and compatible conjugate strike-slip faults cross-cut Laramide structures and show Brown's Park deformation resulted in extension of the hanging wall of the northeastern Uinta Arch and transtensional strike-slip along the Axial Fold Belt, southern Sand Wash and the North Park Basins. NW-SE and WNW-ESE trends of SH_{max} determined from wellbore failure observed in image logs suggest this early- to middle-Miocene stress field has been slightly perturbed or mostly unaffected by Basin and Range Extension and Rio Grande Rifting.

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Abstract

Effective exploitation of low permeability reservoirs requires the understanding of the local tectonic history and the control of fractures. This study focuses on fractured, liquids-rich gas and tight oil plays within the southwestern Sand Wash Basin, with high-quality, lower maturity source rocks and structural complexity, an ideal place to study fracturing in tight rocks. Orientations of minor faults and extensional fractures within variably-oriented structures formed during the Laramide Orogeny and Brown's Park Extension were analyzed to unravel modes and mechanisms of fracturing and paleostress trends. Cross-cutting relations observed in outcrop and geologic maps were used in an attempt to characterize the local Cenozoic strain history.

The 059° orientation of Laramide σ_1 suggests oblique thrust and left-lateral slip on the E-W striking North Boundary Fault. N-S trending Laramide extensional fractures and out-of-the-basin flexural-slip suggest strain-partitioning within this zone of oblique deformation. NW-striking extensional fractures and compatible conjugate strike-slip faults cross-cut Laramide structures and show Brown's Park deformation resulted in extension of the hanging wall of the northeastern Uinta Arch and transensional strike-slip along the Axial Fold Belt, southern Sand Wash and the North Park Basins. NW-SE and WNW-ESE trends of SH_{max} determined from borehole failure logs observed in image logs suggest this early- to mid-Miocene stress field has been slightly perturbed or mostly unaffected by Basin and Range Extension and Rio Grande Rifting.

Introduction

- Timing and mechanisms controlling fracture genesis
- Controls on post-orogenic fracturing

Hypotheses of Cenozoic Kinematics

- Oblique Reverse Slip
- Unidirectional slip
- Strain partitioning

Hypotheses of Fracture Mechanisms

- Post-orogenic extension (Nunn, 1982; Hansen, 1984, 1986b; Harthill, 1997)
- Rio Grande rifting or topographic release due to uplift and erosion (Hancock and Engelder, 1989)
- Syn-Laramide compression (Stone, 1995)
- Pre-Laramide compression (Condon, 1997; Silliphant and Engelder, 2001)
- Basin and Range extension (Anderson and Barnhard, 1993; Erslev, 2001)
- Miocene Browns Park extension (Stevens, 2002)
- Elastic rebound of Laramide strain (Ruf and Erslev, 2005)

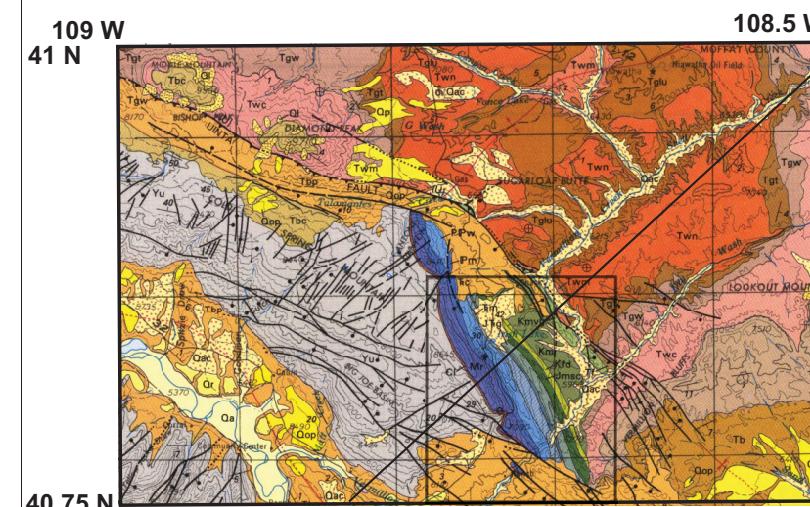


Figure 1. Greater Green River Basin Region with Laramide arches and basins labeled and boxes showing areal extents of detailed maps. Figure adapted from USGS.

Methods

- Detailed field mapping
- 722 minor fault and 996 joint measurements
- Ideal σ_1 determined using Compton's (1966) method
- Eigenvector and Eigenvalue analyses of σ_1 axes and slickenline data

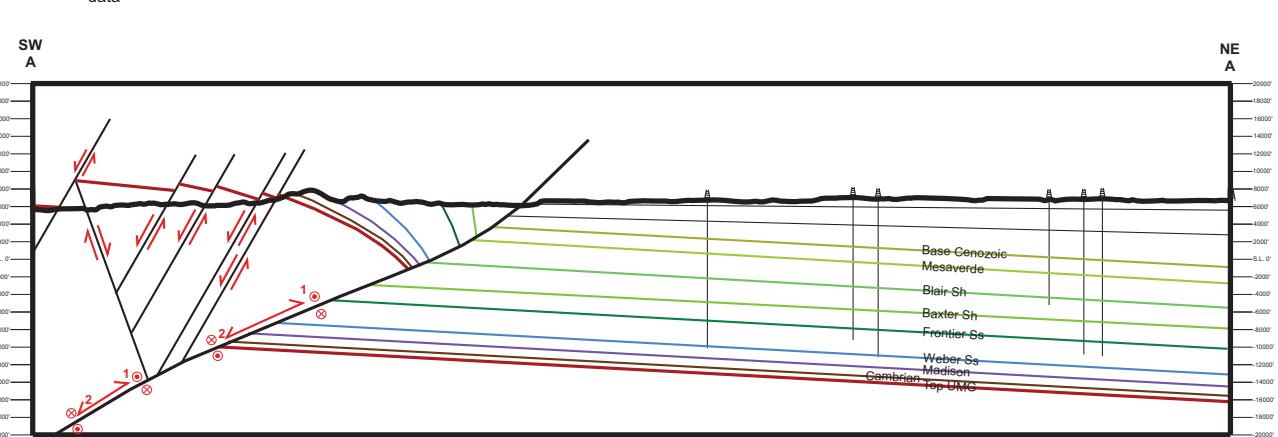


Figure 2. Geologic map of NW Colorado. Field area denoted by translucent box. Structural cross-section marked by black line. Modified from Rowley et al., 1985.

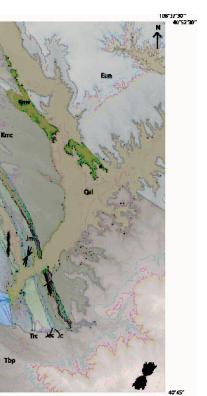


Figure 3. Rose diagrams of average ideal σ_1 axes superimposed on the geologic map. Rose diagram of full data set in bottom right corner.

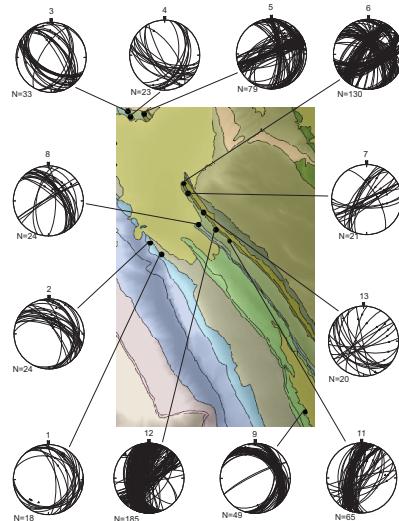


Figure 4. Stereonets overlain on field map illustrating fault planes superimposed on the geologic map.

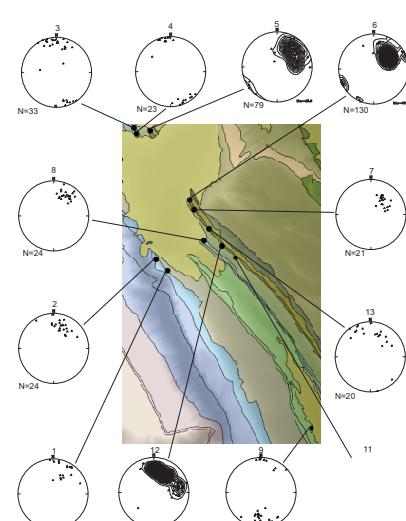


Figure 5. Stereonets of contoured slickenline trends superimposed on the geologic map.

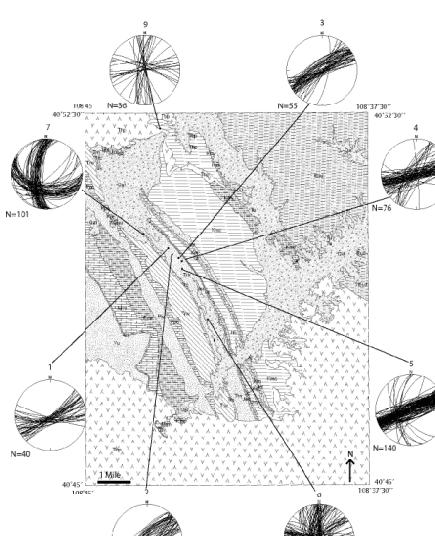


Figure 6. Stereonets of joint planes within the Navajo Sandstone superimposed on the geologic map.

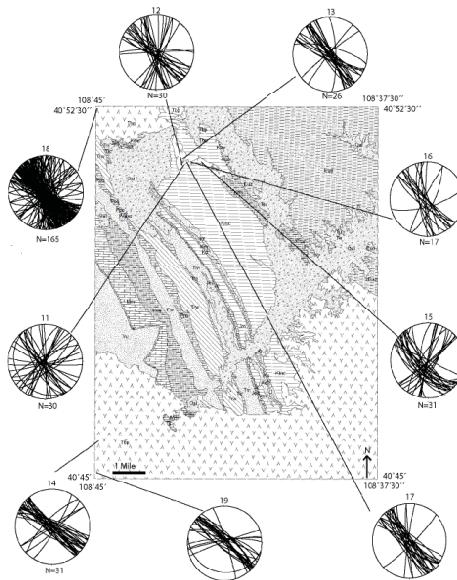


Figure 7. Stereonets of joint planes within the Miocene Browns Park Formation superimposed on the geologic map.

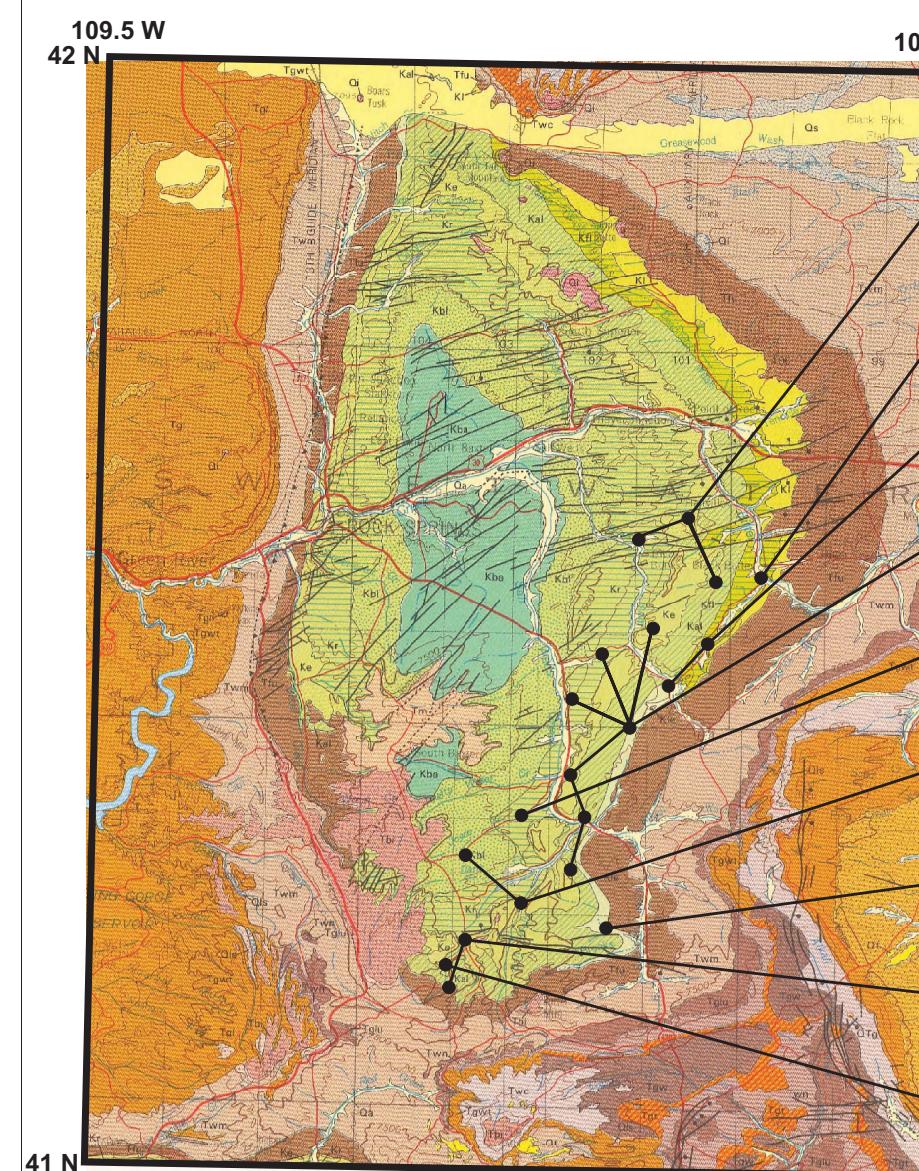


Figure 9. Geologic map of the Rock Springs uplift with stereonets of joint planes. Fracture data from Grout and Verbeek, 1992. Map modified from Love and Christiansen, 1985.

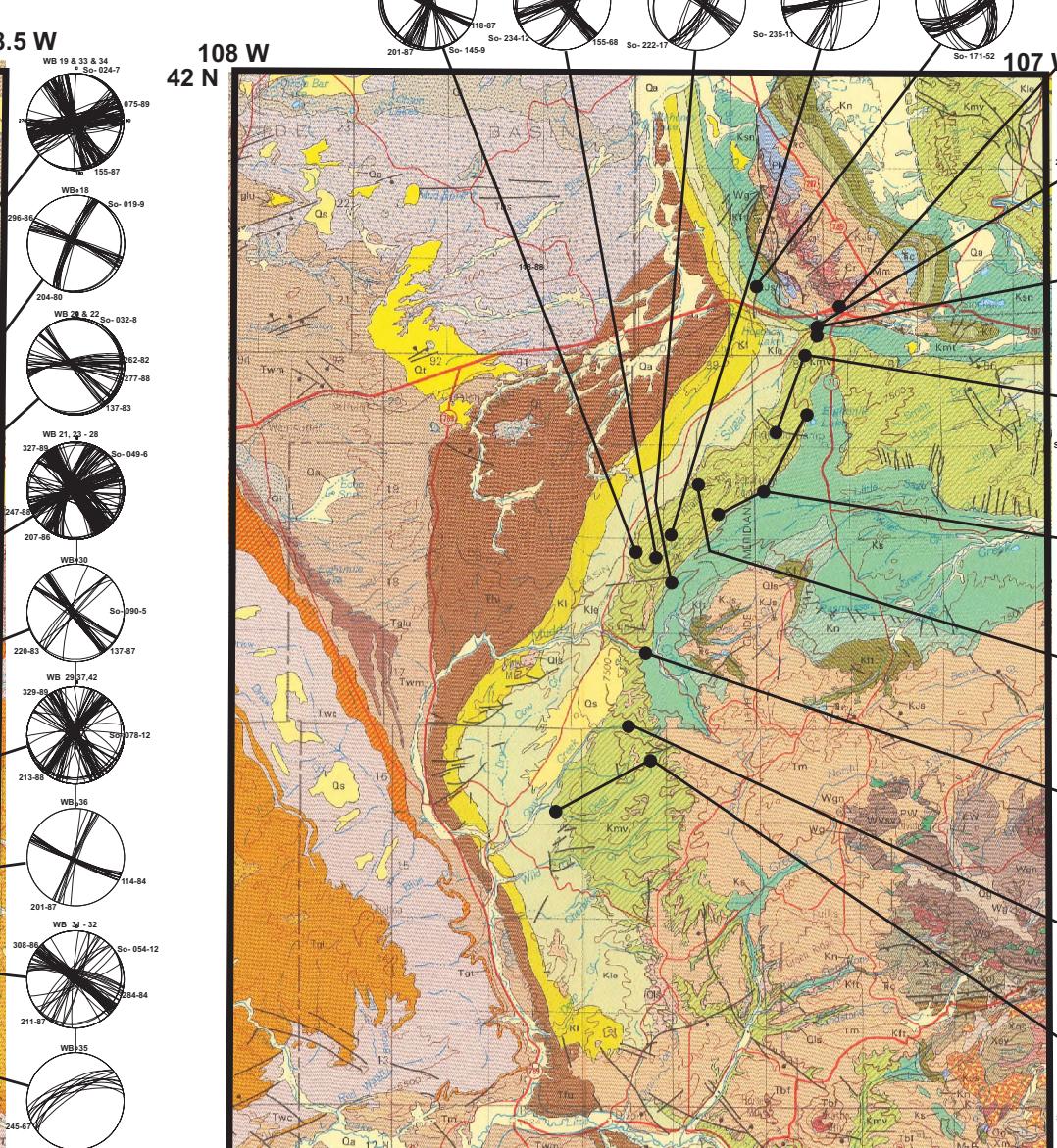


Figure 10. Geologic map of the Rawlings uplift with stereonets of joint planes. Fracture data from Grout and Verbeek, 1992. Map modified from Love and Christiansen, 1985.

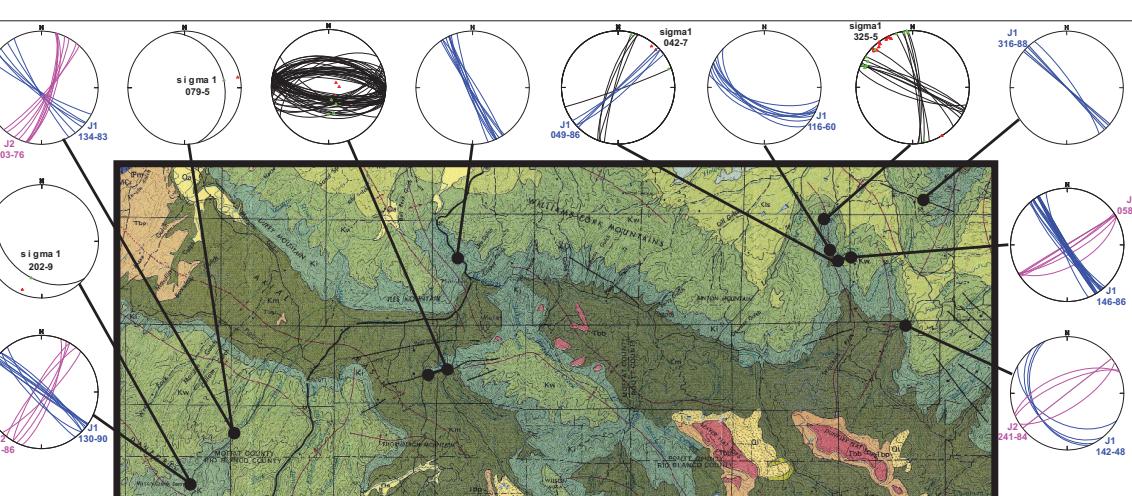


Figure 11. Geologic map of Craig with stereonets of joint planes superimposed on the geologic map. Modified from the Craig Quadrangle map.

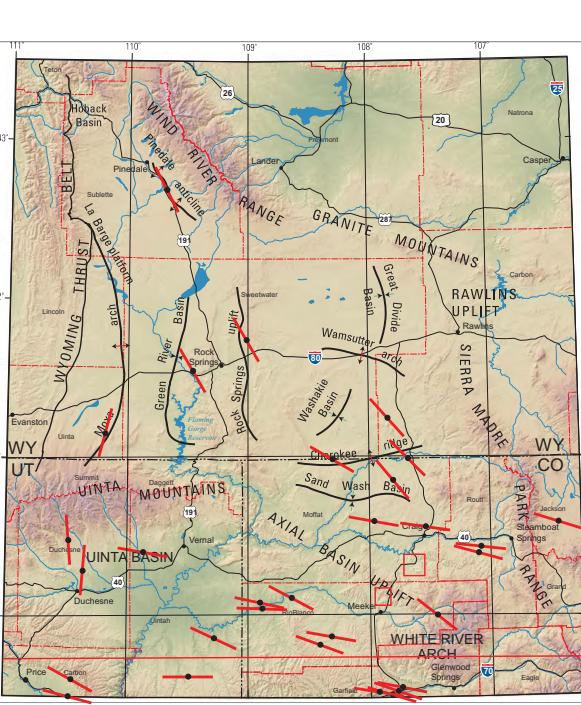


Figure 12. Simplified map of the Greater Green River basin with SH_{max} superimposed on the geologic map.

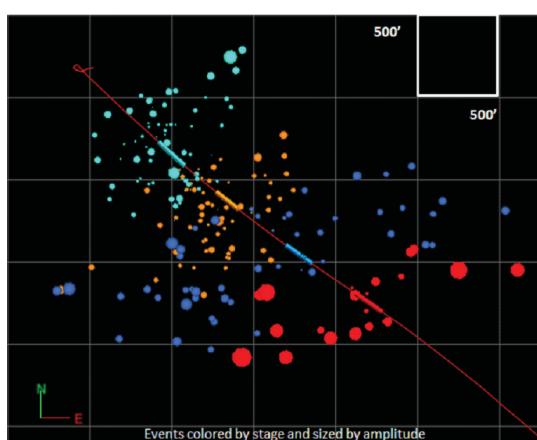


Figure 13. Map view of microseismic events from a hydraulic fracture stimulation in the Frontier Formation, Moxa Arch.

Conclusions

- Minor Fault Analyses show Laramide σ_1 axes average 059° (n=722).
- Oblique Left-Lateral / Reverse Slip on WNW-ESE striking North Uinta Thrust (NUT), dominance of right-lateral minor faults.
- Variable trends of σ_1 axes suggest partitioning of strike-slip and dip-slip strain in the hanging wall of the NUT.
- Basin-dipping minor thrusts indicate top-to-SW, out-of-the-basin flexural shear within Lower Cretaceous Strata.
- Strikes of Navajo Sandstone Joints average 071° (n=641).
- Navajo joint strikes are compatible but not parallel to 059° minor fault σ_1 axes, possibly indicating a slight shift in stress field as Laramide strain rates increased and later decreased.
- Lesser populations of N-S and NW-SE-striking joints indicate multiple mechanisms and modes of extensional fracturing, i.e. partitioned contractional strain due to gravitational spreading of the Uinta Arch and subsequent backsliding on NUT.
- Strikes of Brown's Park Formation Joints average 320° (n=355).
- Browns Park joint strikes are compatible with map- and regional-scale extensional structures cutting Oligocene and Miocene strata in Uinta Arch and Axial Fold Belt.
- Post-Laramide compression and NE-SW extension resulted in oblique extension of the Uinta Arch and Axial Fold Belt and transensional extension of adjacent basins.
- Orientations of borehole breakouts and tensile fractures observed in acoustic and resistivity image logs indicate the tectonic stress regime has changed little since the early Miocene.
- Observations of microseismicity during hydraulic fracturing shows reactivation of pre-existing ENE-striking Laramide fractures and NNE-striking Moxa Arch parallel fractures. The NNE-striking set is likely parallel to the current SH_{max} and the ENE-striking set is 70° oblique to the present day SH_{max}.