PS Two-Stage Mechanical Stratigraphy and Extensional Fracturing in the Wind River Basin, Wyoming*

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Abstract

Open, extensional fractures observed in the Wind River Basin differ from what is expected of syn-Laramide extension and it is possible that a two-stage mechanical stratification influences these fractures with important implications for the prolific hydrocarbon and uranium resources of the WRB. Hypotheses for mechanisms forming the extensional fractures include: pre-Laramide regional compression or fore-bulge migration; syn-Laramide regional compression or fold-localized extension; syn to post-Laramide regional strike-slip faulting; post-Laramide regional extension; exhumation due to uplift and/or overburden removal, gravity collapse of topographic highs; release of an elastic strain component; back-sliding on Laramide thrusts; and proximity to major post-Laramide normal faults. Fracture data was collected in the eastern WRB from Cambrian to Eocene strata and compared to previous studies, digitized fracture traces from geologic maps, and a large industry data set from micro-resistivity image logs. Low-angle thrust faults generally trended NW while high angle strike-slip faults trended E and NE for left and right-slip faults, respectively. These were observed in strata as young as the Paleocene. Normal faults of moderately high angle, and systematic, bedding-perpendicular, primary joints had varying orientations, but not a constant rotation, between NW and WSW. Secondary joints, that abutted the primary joints, were sub-orthogonal and were not present in the micro-resistivity image logs. The majority of these normal faults and joints were taken from the shallow dipping, Eocene Wind River Formation, which is in angular unconformity with older strata and forms most of the surface. Seismic data, as interpreted, shows a change in structural style across the Cretaceous shales in the basin. Basement-involved compression, seen as thrusting, is present at depth, while extensional grabens are shallow. Neither obviously transects these shales. Further, a thin-skinned thrust, at the stratigraphic level of these shales and on the southern margin of the basin, supports the hypothesis of a layer-parallel detachment that acts as a plane of weakness to separate these two stages. In conclusion then, two distinct stages of deformation were observed and confirmed by the fracture data. NE-SW compression is consistent with the Laramide while the highly localized NE-SW to NNW-SSE extension is post-Laramide.

Two-Stage Structural Development & Fracturing in the Wind River Basin, Wyoming

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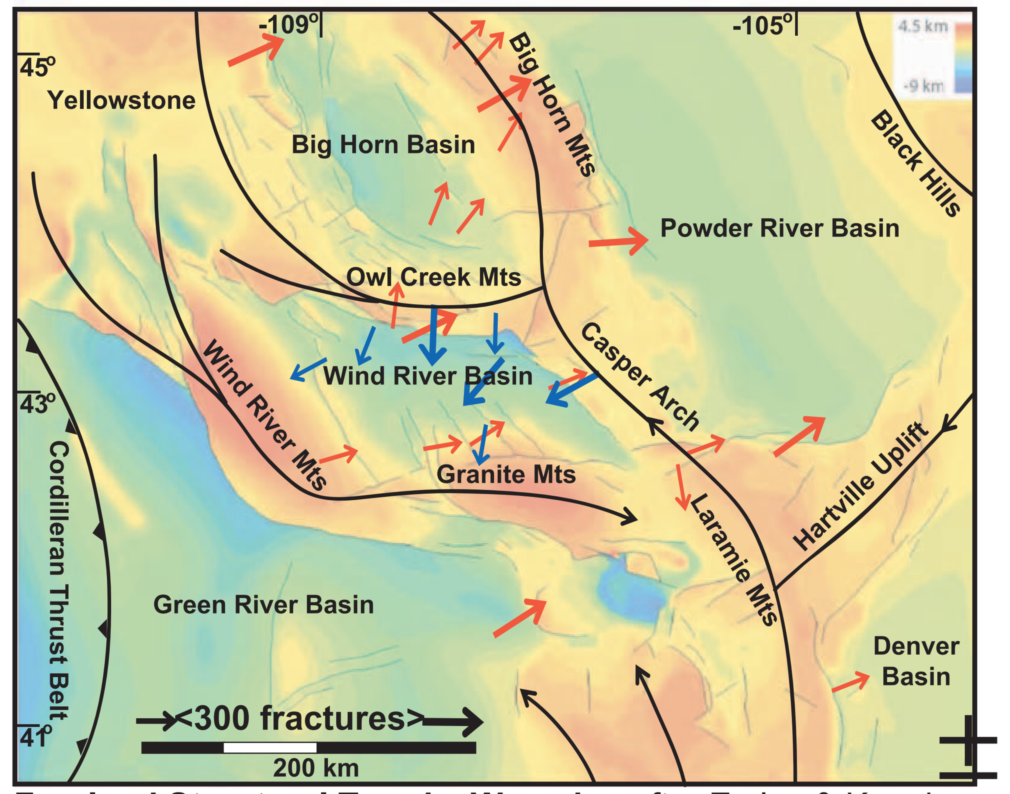


Foreland Structural Trends, Wyoming after Erslev & Koenig, in press; compression arrows (red), extension arrows (blue); color contours from Neely, unpublished; based on Precambrian structure countours, Blackstone, 1993

Problem

What are the mechanisims and timing of open, extensional fractures in basement-involved foreland basins?

Significance

Fractures test hypothesis of structural mechanisms, possible multi-stage development, and are crucial to hydrocarbon production

Hypotheses

Pre-LAR fracturing from:
a. distal compression or forebulge migration

Syn-LAR fracturing from:
a. E to N rotating compression or strain partitioning
b. ENE compression, oblique slip, & associated extension

Post-LAR fracturing from:
a. strike-slip transtension
b. surficial processes
c. regional extension
d. localized extension

Methods

Collected fracture data from outcrop, micro-resistivity logs, and geologic maps

Computed compression & extension directions using ideal sigma-1, eigen analysis, vector mean (bed dips >15° rotated to horizontal)

Interpreted proprietary seismic

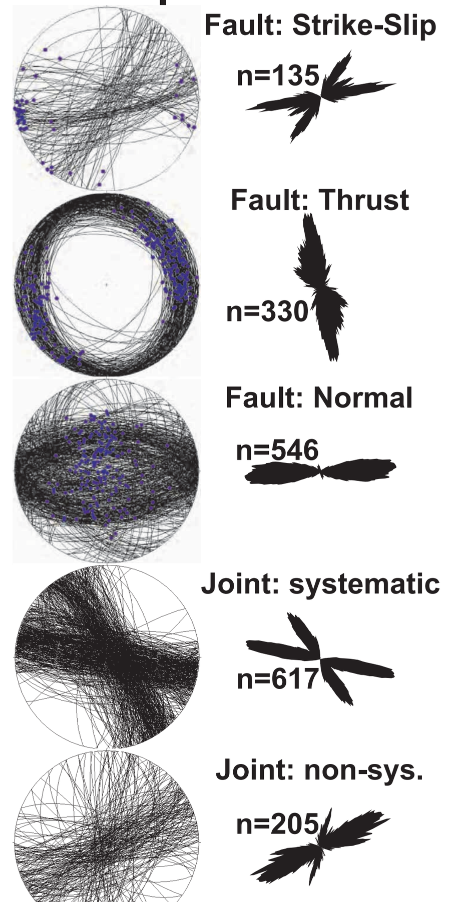
Seismic Observations

* Thick-skinned thrusting at depth & along margins
* Thin-skinned thrusting & detachment in Cody Shale
* Normal faulting above Cody Shale & paralleling margins
* Reversal of fold concavity in hangingwall of listric fault

Fracture Data

See poster at right for detailed joint and normal fault data

Outcrop Fractures:

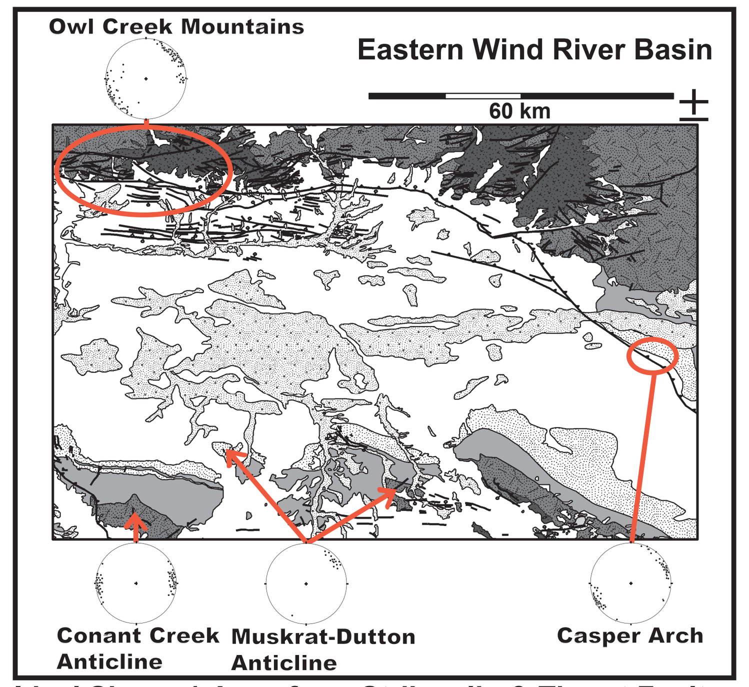


Subsurface Fractures:

Schmidt contours, 2% intervals
*All fractures interpreted from micro-resistivity logs except induced

Mapped Faults:

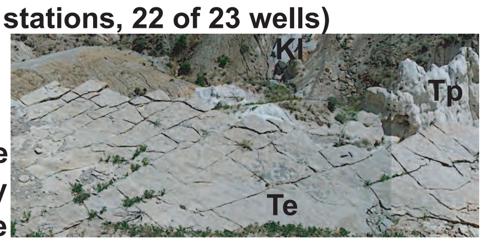
1447 digitized segments broken into 9 domains: p€-Miocene
(No summary)



Ideal Sigma-1 Axes from Strike-slip & Thrust Faults

Tests of Pre-Laramide Hypothesis

Predictions: Limited to pre-LAR units & independent of LAR
Observations: Fractures in pre-LAR units are similar to those in younger units (26 of 42 outcrop stations, 22 of 23 wells)
✗

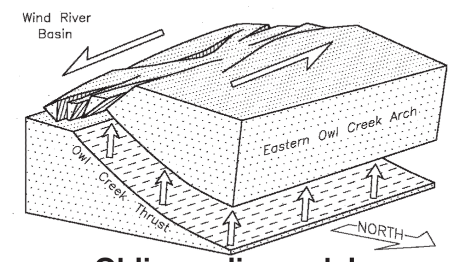


Hell's Half Acre
Angular Unconformity
Eocene above Paleocene

Tests of Syn-Laramide Hypothesis

E to N Rotating Compression or Strain Partitioning

Predictions: Compression perpendicular to arch trend
Observations: Strike-slip & thrust faults consistent with N66°E compression, oblique to E-W arches ✗

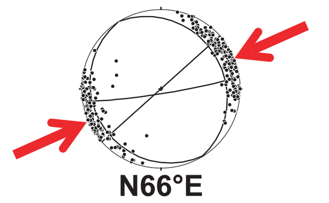


Oblique slip model (Molzer & Erslev, 1995)
n=718

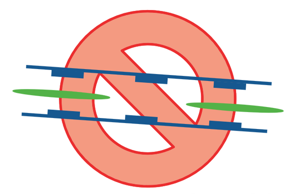
ENE Compression, Oblique Slip, & Associated Extension

Predictions: ENE compression despite diverse, basin-bounding arch trends (NW-SE & E-W); associated extension includes either:
a. ENE splitting fractures
b. NW outer arc extension fractures

Observations: 23 stations & 6 digitized domains have W-WNW extensional fractures, most in flat-lying Eocene units



N66°E
Laramidecompression, from ideal sigma-1 axes & strike-slip/thrust conjugates
n=465



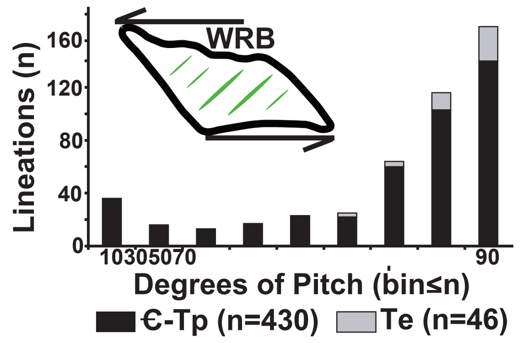
East-west extensional joints & normal faults: incompatible with Laramide stress field

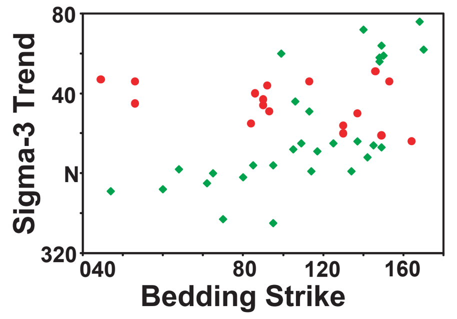
✓ (strike-slip & thrust faults)
? (NW normal faults & joints)
✗ (W-WNW normal faults & joints)

Tests of Post-Laramide Hypotheses

Strike-Slip Transtension

Predictions: Trapezoidal basin from left-slip with strike-slip faults & NE joints in all units
Observations: Strike-slip faults not observed in Eocene units, those in €-Paleocene units consistent with LAR; NW joints ✗





Surficial Processes

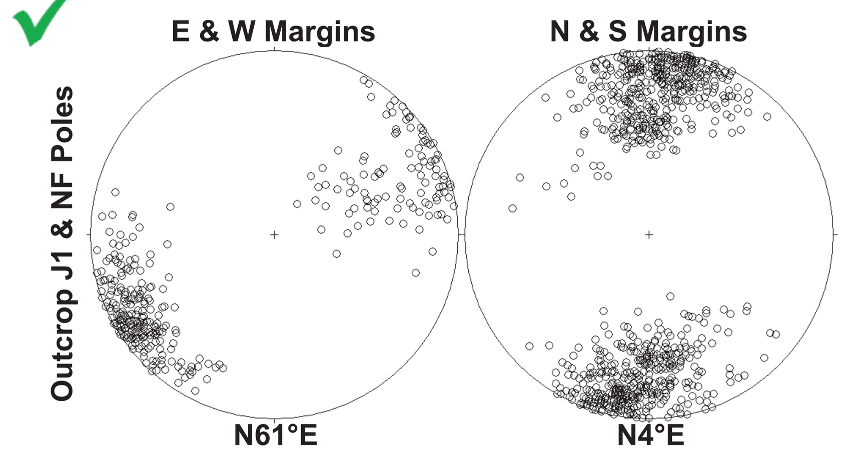
Predictions: Gravity sliding down bed dip; exhumation related joints only present @ surface
Observations: No correlation between extension & bed strike; NW systematic joints (J1) @ 6-11,000 feet, orthogonal, non-systematic joints (J2) only at surface
✗ (except non-systematic joints)

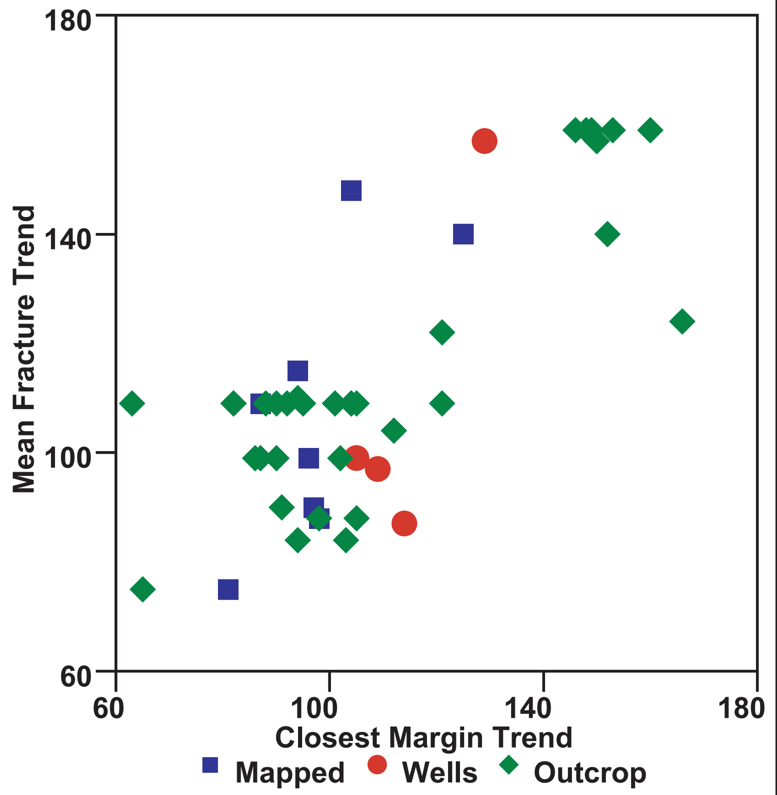
Regional Extension

Predictions: Regionally consistent NW extensional fractures from elastic strain release, epeirogenic uplift, or extensional plate interactions
Observations: NW extensional fractures across region, induced also NW; W-WNW also present (@ different stations)
? (NW normal faults & joints)

Localized Extension

Predictions: Extension coupled to collapse & backsliding of basin-bounding LAR arches
Observations:
a. One-to-one correlation between fracture & closest margin trends
b. two distinct extensional fracture orientations
c. E-W fractures to 20km from northern & southern arches
d. previous workers identified northern & southern arches down-dropped relative to basin by as much as 760m
e. fractures further localized in proximity to Owl Creek Thrust
✓





Conclusions

Two-stage structural development:
1. N66°E Laramide compression
2. Post-Laramide extension
a. N61°E regional extension, continuing to present
b. N4°E localized extension, continuing to present, coupled to collapse of northern & southern basin-bounding LAR arches; collapse of northern arch associated with backsliding of Owl Creek Thrust

Mechanical stratification: units below the Cody Shale dominated by thrust faulting/folding; units above dominated by normal faulting

Future Work

2D or 3D models of listric thrusts backsliding as listric normal faults in order to:
1. Compute strain and predict zones of higher intensity extensional fracturing
2. Better model reservoir development, especially at Frenchie Draw gas field

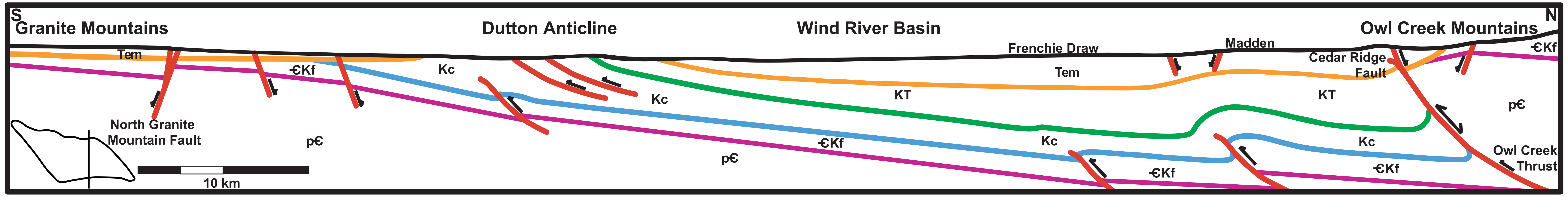
References

* Bauer, C.M., 1934, Wind River Basin: GSA Bulletin, v. 45, no. 4, p. 665-696
* Bergbauer, S., and D.D. Pollard, 2004, A new conceptual fold-fracture model including prefolding joints, based on the Emigrant Gap anticline, Wyoming: GSA Bulletin, v. 116, no. 3/4, p. 294-307.
* Fanshawe, J.R., 1939, Structural Geology of the Wind River Canyon Area, Wyoming: AAPG Bulletin, v. 23, no. 10, p. 1439-1492
* Hennings, P.H., J.E. Olson, and L.B. Thompson, 2000, Combining Outcrop Data and Three-Dimensional Structural Models to Characterize Fractured Reservoirs: An Example from Wyoming: AAPG Bulletin, v. 84, no. 6, p. 830-849.
* Keefer, W.R., 1970, Structural Geology of the Wind River Basin, Wyoming: Washington, U.S. Gov't Printing Office, 35 p.
* Molzer, P.C., & E.A. Erslev, 1995, Oblique convergence during northeast-southwest Laramide compression along the east-west Owl Creek & Casper Mountain arches, central Wyoming: AAPG Bulletin, v. 79, no. 9, p. 1377-1394
* Wise, D.U., 1963, Keystone Faulting & Gravity Sliding Driven by Basement Uplift of Owl Creek Mountains, Wyoming: AAPG Bulletin, v. 47, no. 4, p. 586-598

Great-Horned Owl & Conjugate Fractures

1931 Cable Rig Walking Beam

This poster is based on first author's masters research project in collaboration with EnCana Oil & Gas (USA)



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Field Research Funded By:

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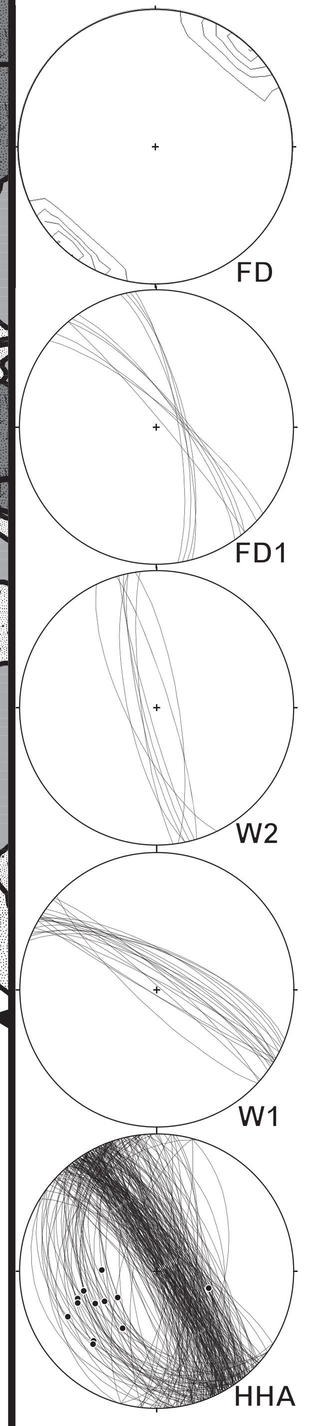
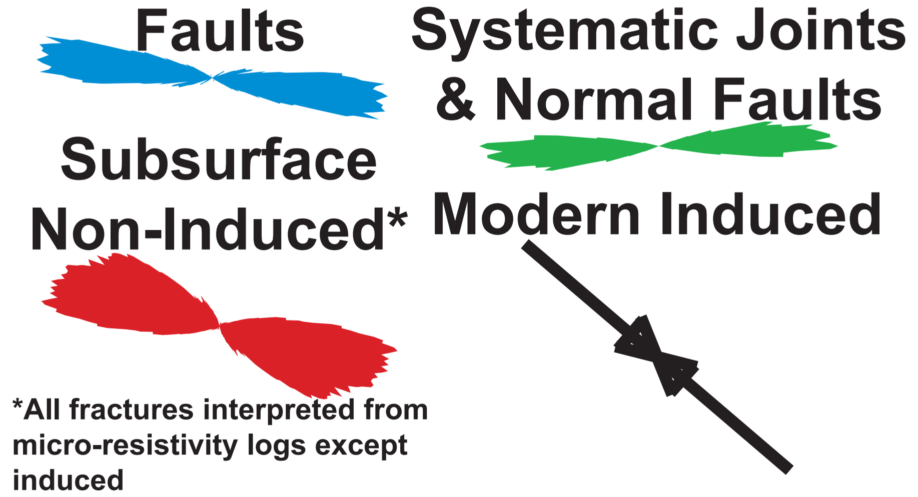
Wind River Basin: Joint & Normal Fault Data

Stereonets & Strike Rose Diagrams



Stratigraphic Column

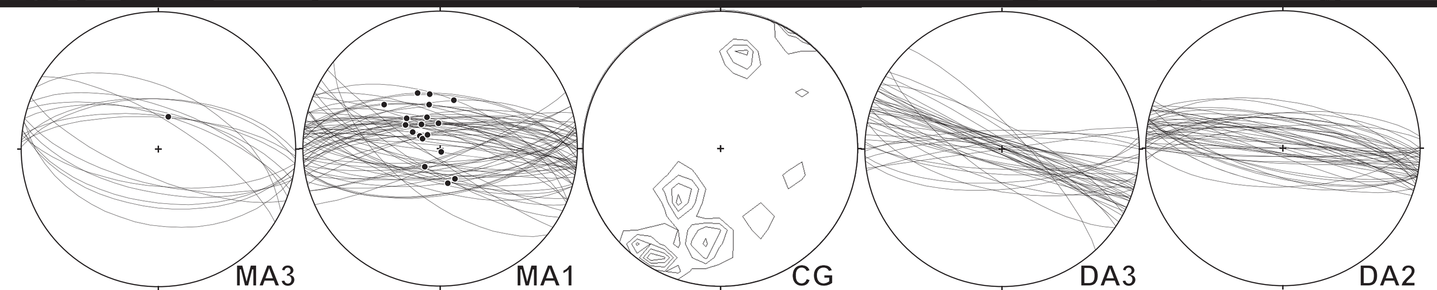
Period	Formation	Thickness	Map unit
Quaternary	Alluvium, loess, & gravel		Q
Miocene	Split Rock	?	Tem
Oligocene	White River	?	Tem
Eocene	Wagon Bed Wind River	570m	Tem
Paleocene	Fort Union	300m	KT
Cretaceous	Lance Meteetsee Mesa Verde	870m	KT
Cretaceous	Cody Shale	1270m	Kc
Cretaceous	Frontier Mowry-Thermopolis Cloverly	450m	€Kf
Jurassic Triassic	Morrison Sundance Chugwater Dinwoody	580m	€Kf
Paleozoic	Phosphoria Tensleep-Amsden Madison Bighorn Gallatin Gros Ventre-Flathead	770m	€Kf
Precambrian	Granite, gneiss, metasediments, & metavolcanics		p€



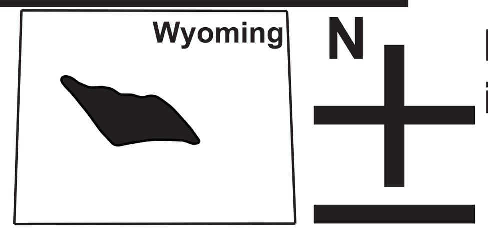
*All fractures interpreted from micro-resistivity logs except induced

Frenchie Draw includes data from 20 wells

Non-Induced stereonets: Schmidt contours, 2% interval.



Basemap after Love & Christiansen, 1985; Stratigraphy after Bauer, 1934.



Data Collected by Ryan Thompson, MS Candidate, in Collaboration with EnCana Oil & Gas (USA) Inc.

References

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