

Mapping Rocky Mountain Fractures: GIS Methods for Resource Plays*

Laura Kennedy¹, Eric Erslev¹, and Karen Aydinian¹

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¹University of Wyoming, Laramie, WY (laura.eve.kennedy@gmail.com)

Abstract

Fracture orientations in rocks hosting unconventional resource plays (e.g., the Niobrara Formation in eastern Colorado and Wyoming) provide important controls on the permeability and economic success of tight reservoirs. As part of the University of Wyoming School of Energy Resources NioFracture initiative, a GIS database integrating surface and subsurface fracture data is being assembled to reveal regional and local fracture trends. Minor fault and joint data in ArcGIS were plotted over satellite imagery and geologic bedrock maps as rose diagrams of fracture strike, using color to represent fracture mode: green for joints, yellow for faults, and red for ideal compression orientations as determined from fault geometries and slip patterns. At a local (outcrop) scale, rose diagrams are overlain by a point at their actual geographic location. The point size is scaled to the number of fractures for each locality. Local fracture data were combined at subregional and regional scales to provide larger perspectives. Data attributes for each rose diagram include fracture characteristics (orientation, clustering, etc.), geology, inferred stress directions, and timing. Stereonets of 3D data, available field photos, and diagrams from the published data source were also linked to each rose plot. This compilation makes public domain data available in one comprehensive database, allowing potential users to make informed models for reservoir fracture permeability. Initial results show a remarkable uniformity of Laramide east-northeast compressive stress orientations despite major local variations in structural trends. Joint patterns can be considerably more diverse, with east-northeast-striking, northwest-striking, and west-northwest-striking joints found regionally. East-northeast-striking joints are typically the earliest joints (J1) in Mesozoic and Paleozoic strata and commonly parallel Laramide compression directions calculated from minor faults. Northwest-striking joints (J2) are found in pre-, syn-, and post-Laramide rocks, indicating regional northeast-southwest extension after Laramide tectonics ceased. Based on these regional patterns, horizontal drilling legs should be NW-SE if Laramide joints and minor faults are crucial for reservoir permeability. If most reservoir permeability is created by NW-SE post-Laramide jointing, NE-SW horizontal legs may be more ideal.



School of
Energy Resources

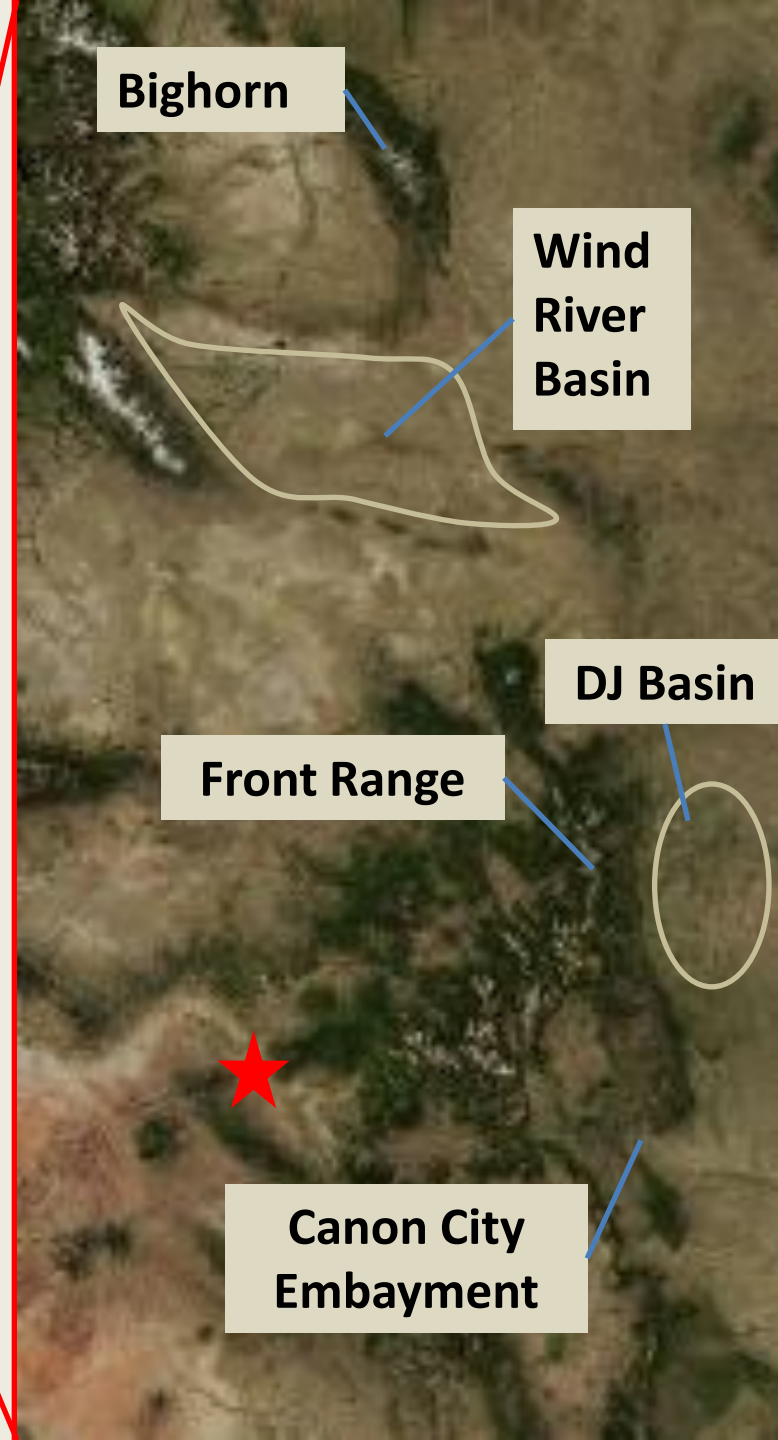
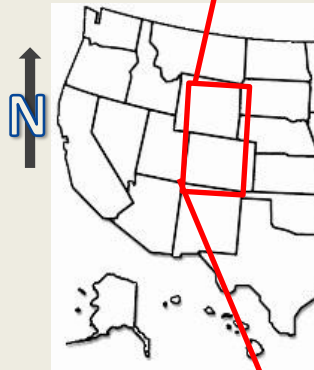
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Problem:

How do you predict natural fracture orientations?

- Knowledge of fracture characteristics are essential to success!
- Horizontal drilling guide in unconventional resource plays (e.g. Niobrara)
- UW/SER NioFracture initiative 12/2011-present



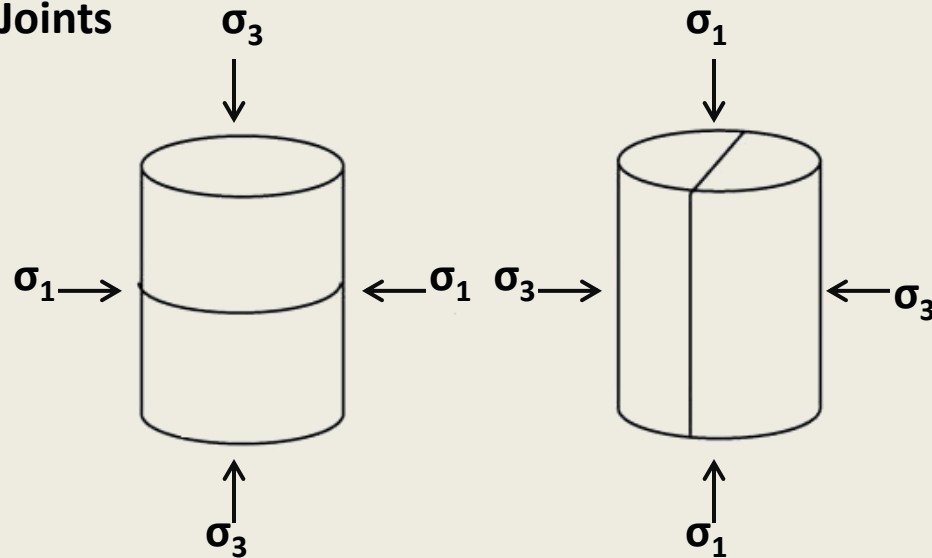
Niofracture Project Goals

- **Fully utilize modern GIS technology to compile Rocky Mountain fracture data at a range of scales in a public database**
- **Use fracture characteristics to test tectonic and structural models**
- **Identify new fracture patterns and processes (e.g., controls on the % strike-slip and thrust faulting described in the next talk by Karen Aydinian)**
- **Predict fracture orientations and types for fracture permeability models in unconventional reservoir plays**

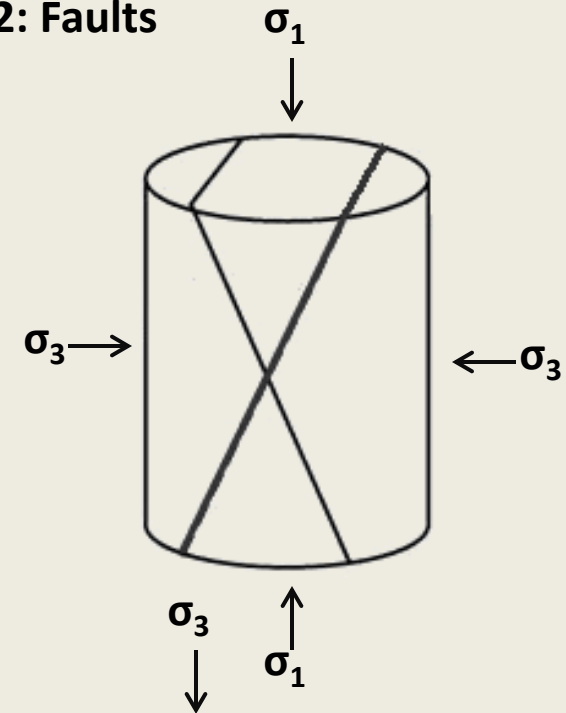
Why is this important?

Fracture mode and fault type:

Mode 1: Joints



Mode 2: Faults

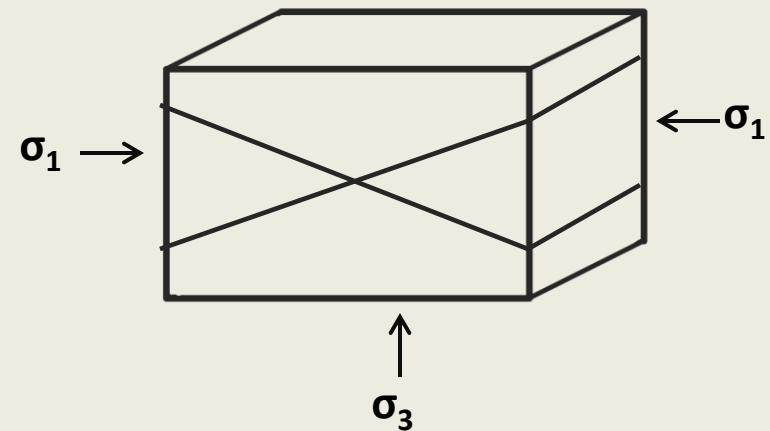


Fracture Orientation:

- With respect to in-situ stress
- Optimize horizontal drilling

Timing of fracturing:

- Sealed/open



Laramide minor faults, Huerfano Valley, CO



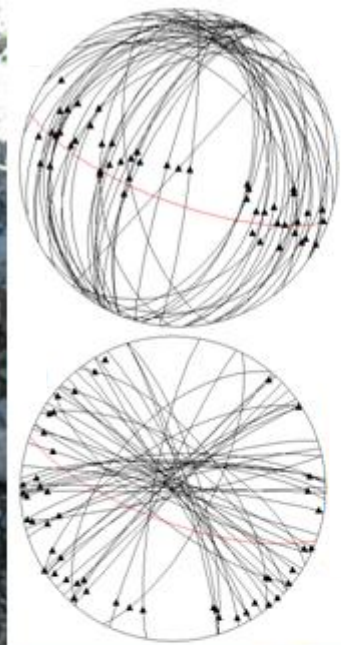
Photos from E. Erslev

What attributes should be included?

Some Examples:

1. Fracture Characteristics

- Type (Joint vs. fault)
- Orientation (averages from Eigendata (clustering) and rose diagram vector mean)
- Inferred stress directions

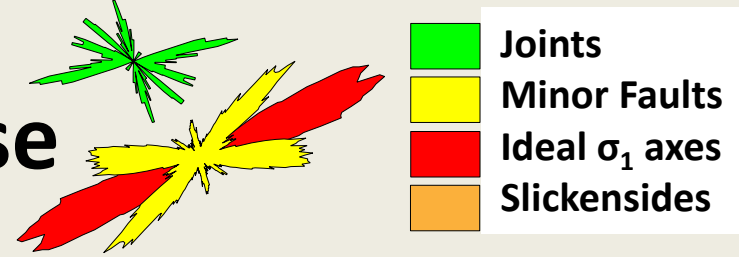


2. Other essential attributes

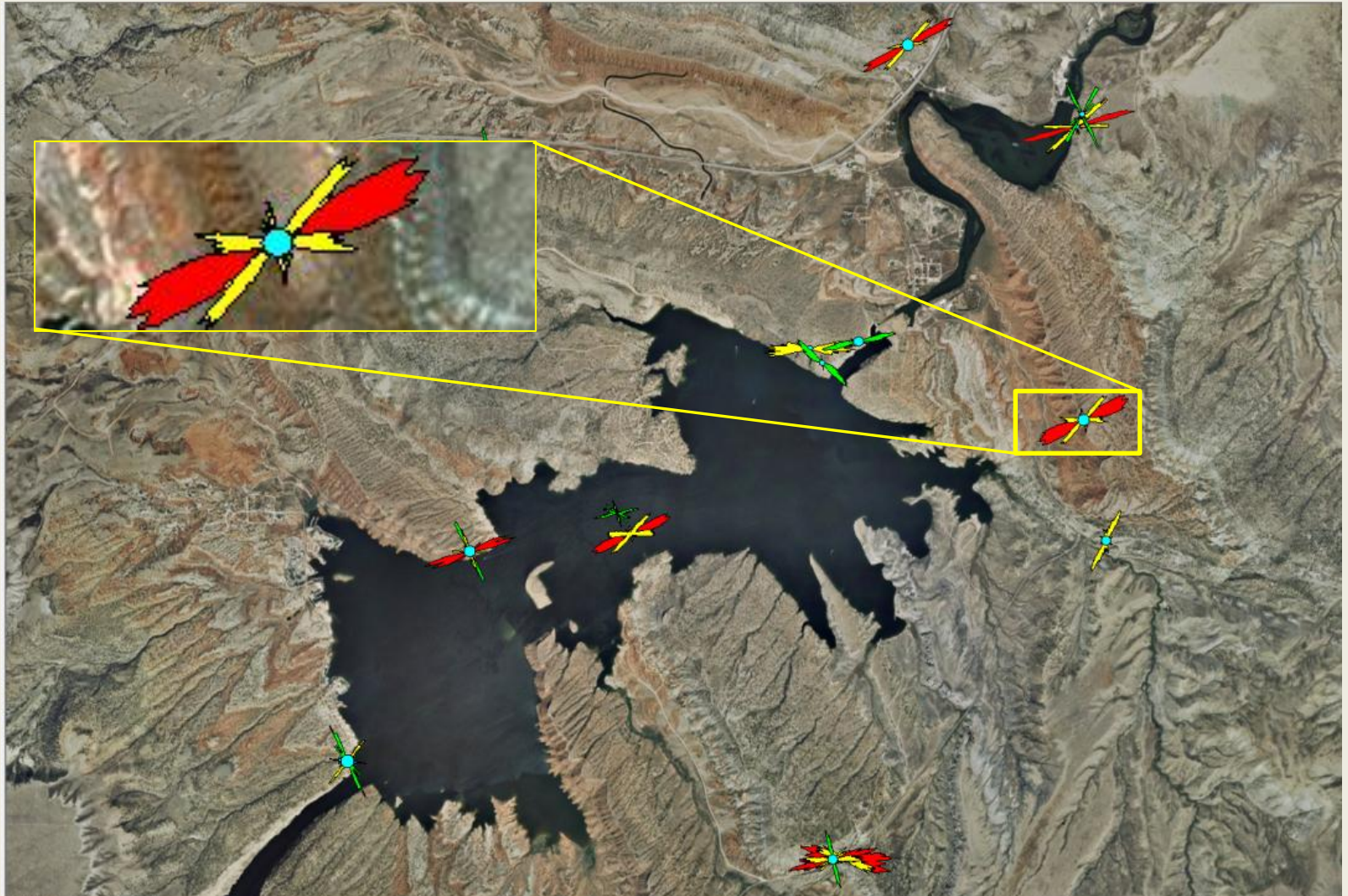
- Lithology (Timing indicator)
- Field photos



Elements of the GIS Database



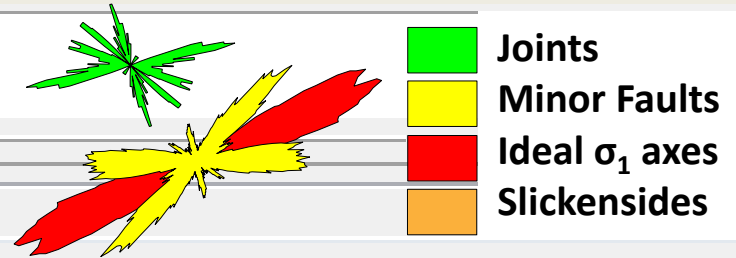
- Rose diagrams of fracture strike



Data Attribute Table

[-] Alcova
 [...] LEK-23

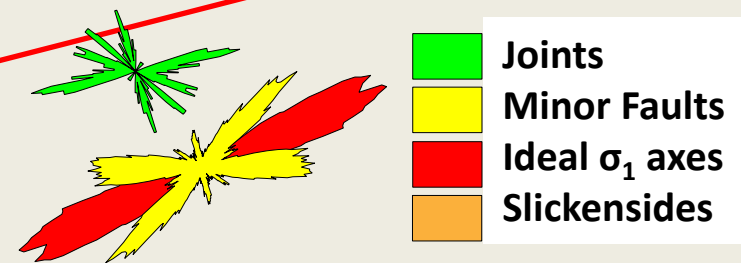
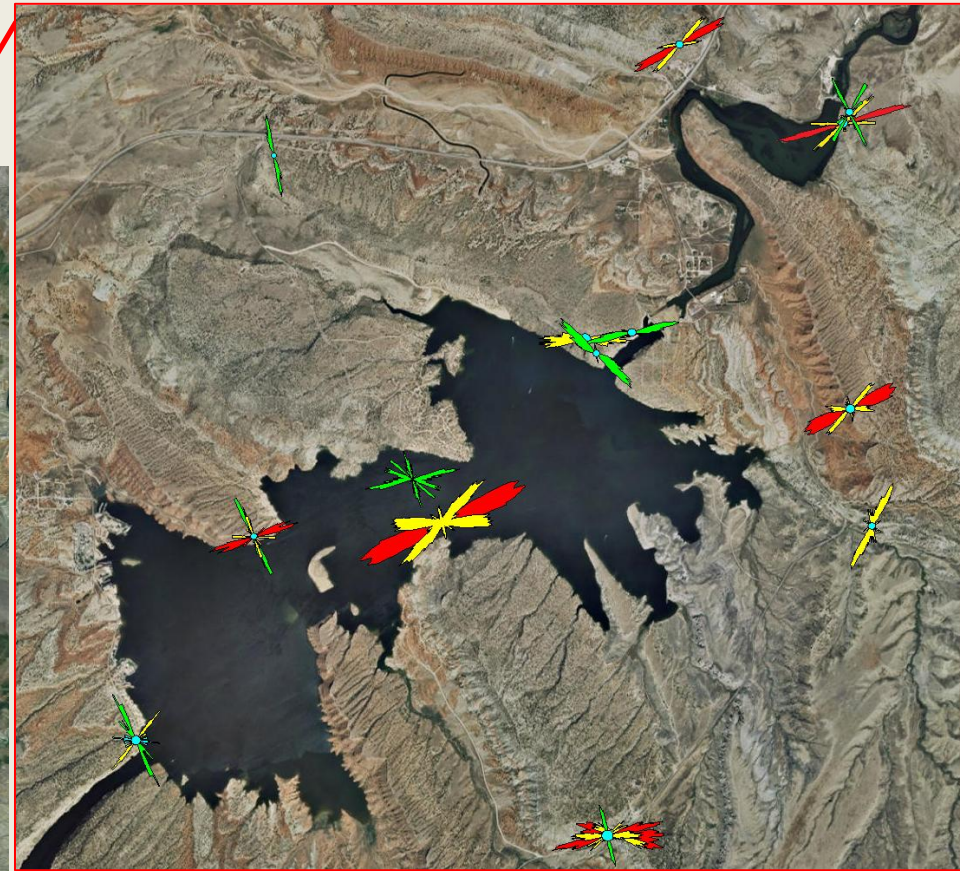
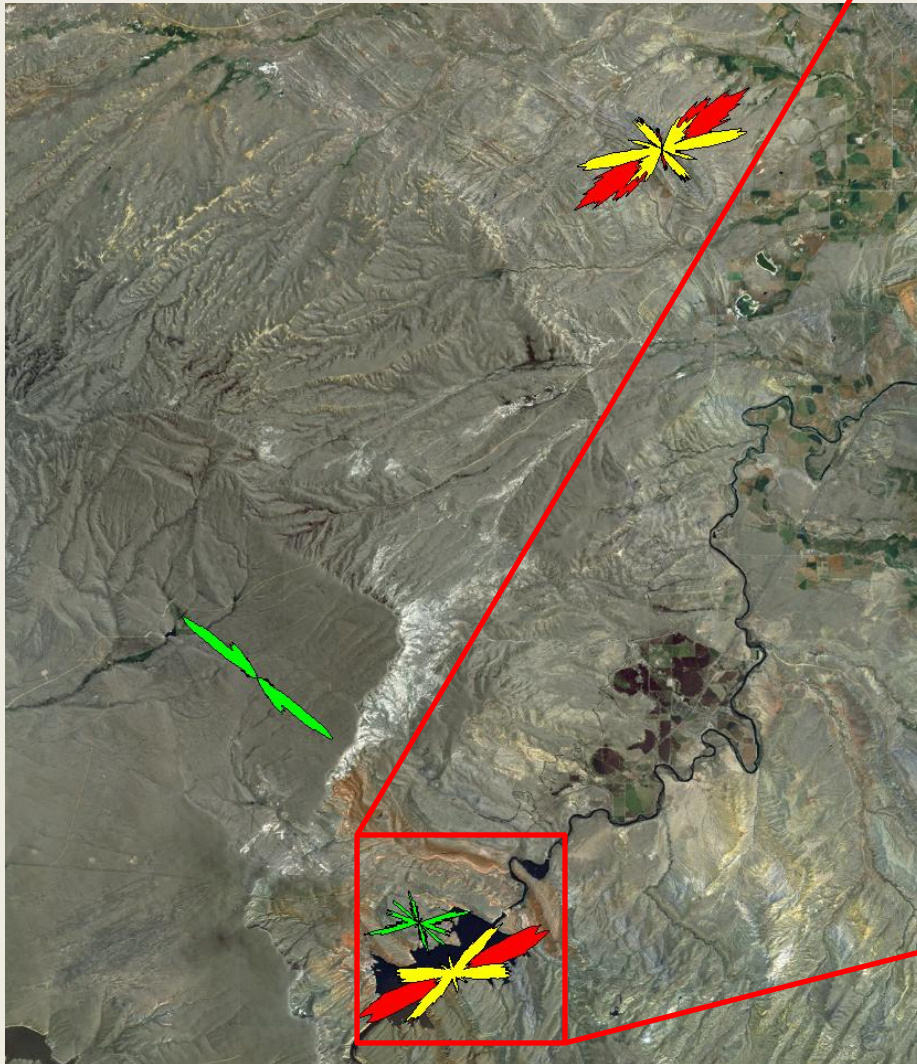
Location: -11,880,607.442 5,237,538.942 Meters



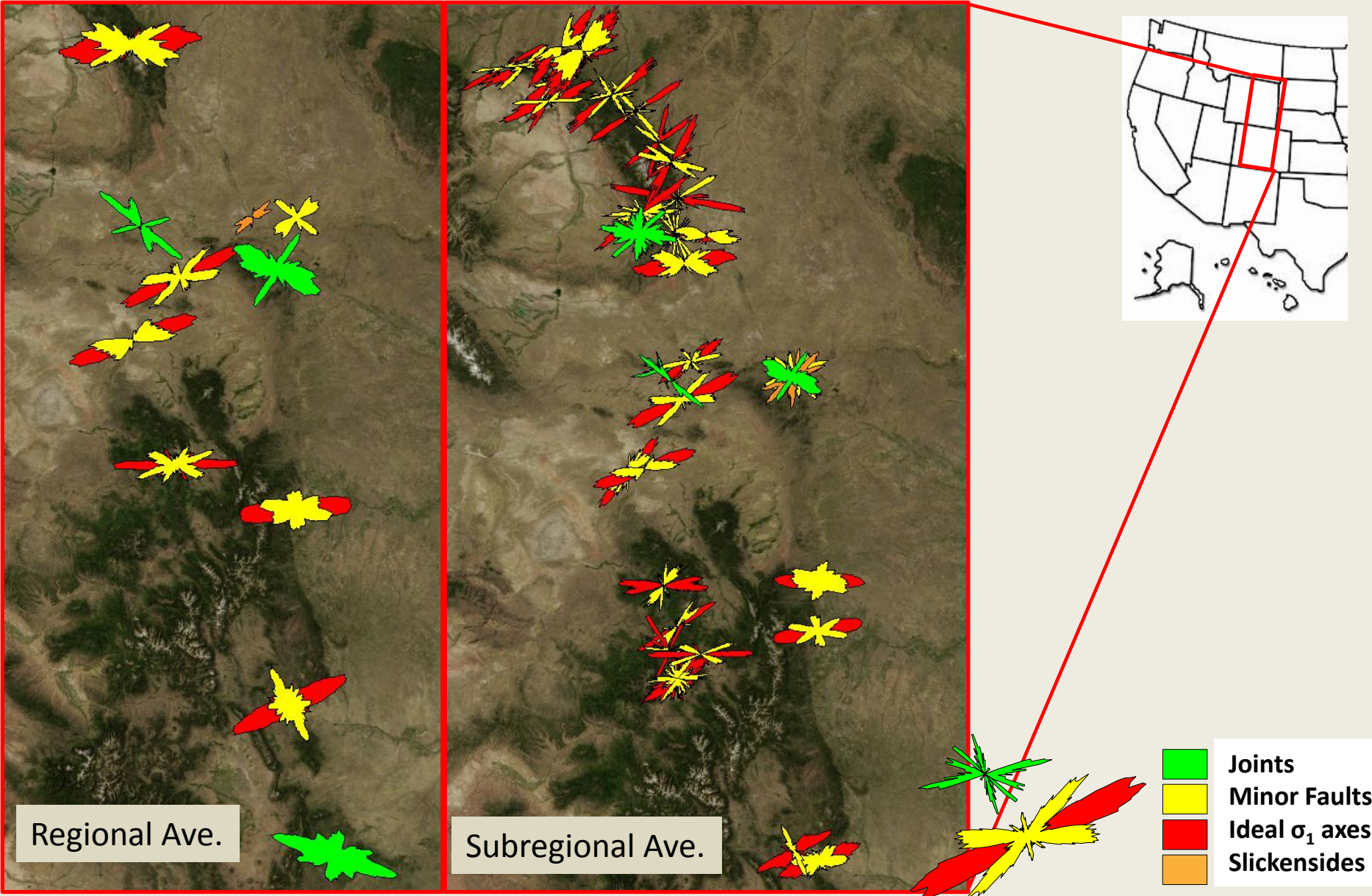
Field	Value
OBJECTID	8
Shape	Point
Id	0
Reference File	LEK-23
Fracture Type	Fault and Joint
Data Type	Outcrop
Structural Position	Alcova Syndline
Unit	Sundance
E1_E2_E3 For Planes	340/11; 073/17; 219/70; 077/04; 344/25; 176/65
Eigenvalue For Planes	0.8345; 0.1207; 0.0448; 0.9647; 0.0241; 0.0112
n	62
Data Source	Laura Kennedy; MS Thesis; University of Wyoming; 2011
Interpreted Timing	Faults:Lar; Joints:post-Lar
Images	C:\Users\hamlin\Documents\ArcGIS\Images\Alcova\LEK_23\LEK_23_faults_Stereonet.pr
Sigma1_Eig	065/10; 334/08; 206/77
Sigma1_Val	0.9482; 0.0465; 0.0053



Averaging Local Data at Regional Scales

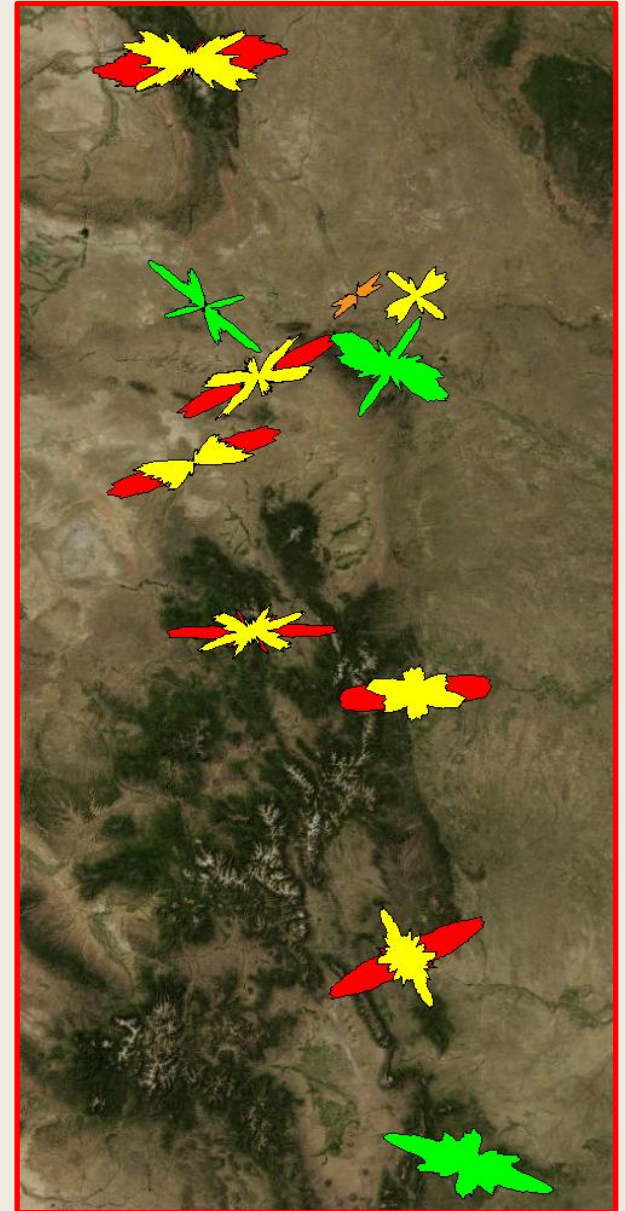


Results: Regional /Subregional Averages

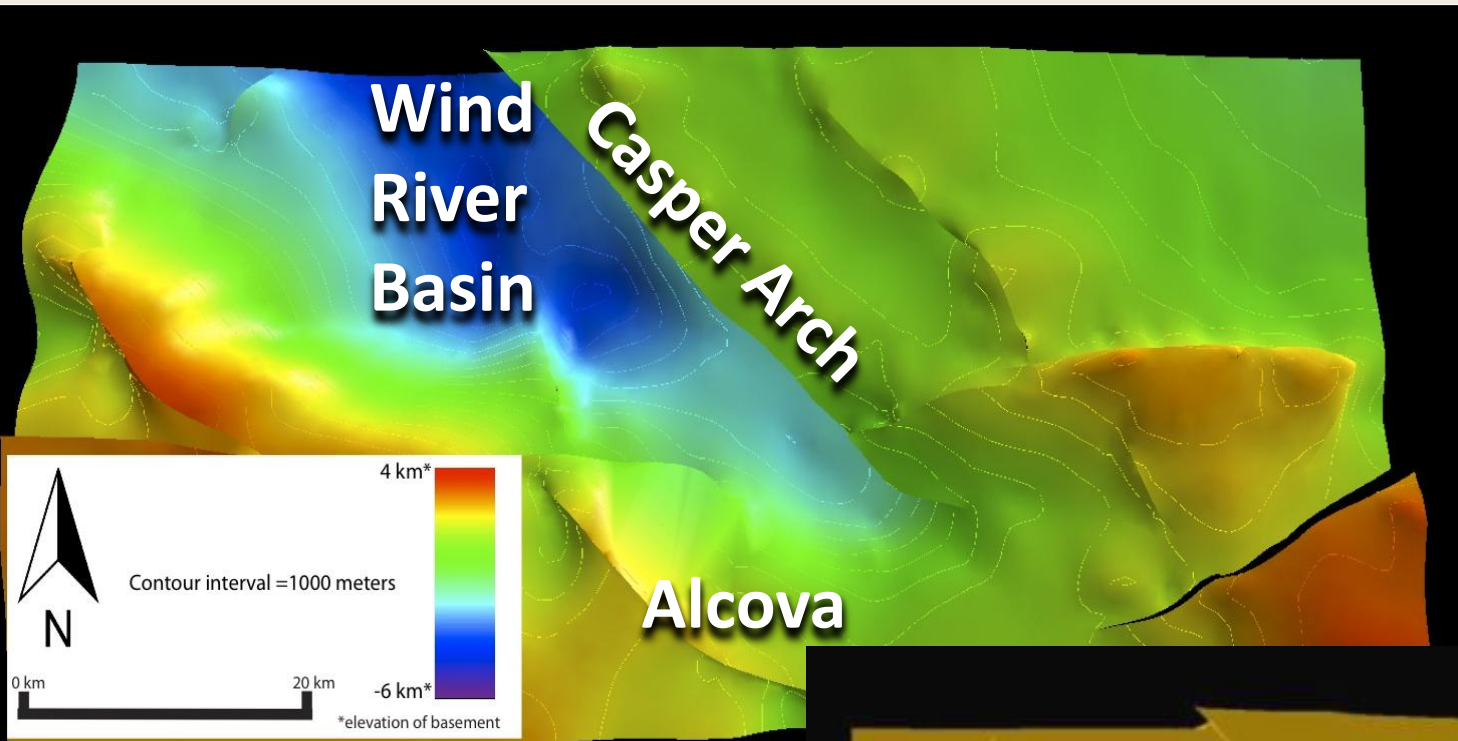


Regional/Subregional Averages

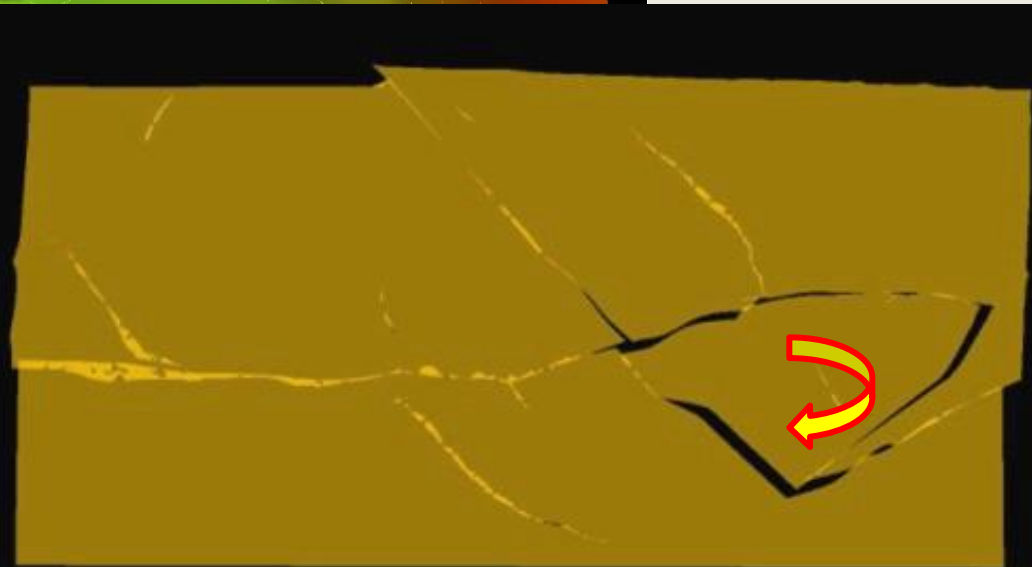
- Remarkably consistent fault and joint patterns
- E-W to ENE-trending compression from faults
- NE-SW to ENE-striking joints and NNW- to WNW-striking joints
- Some regions need a closer look!



East Wind River Basin Transfer Zone Example:

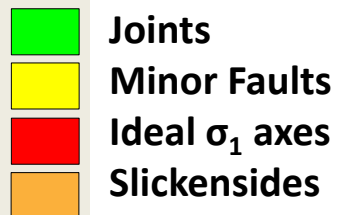
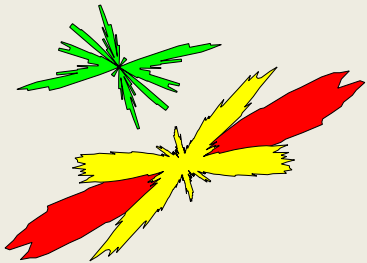


3D modeling and restoration show left-lateral convergence and block rotation



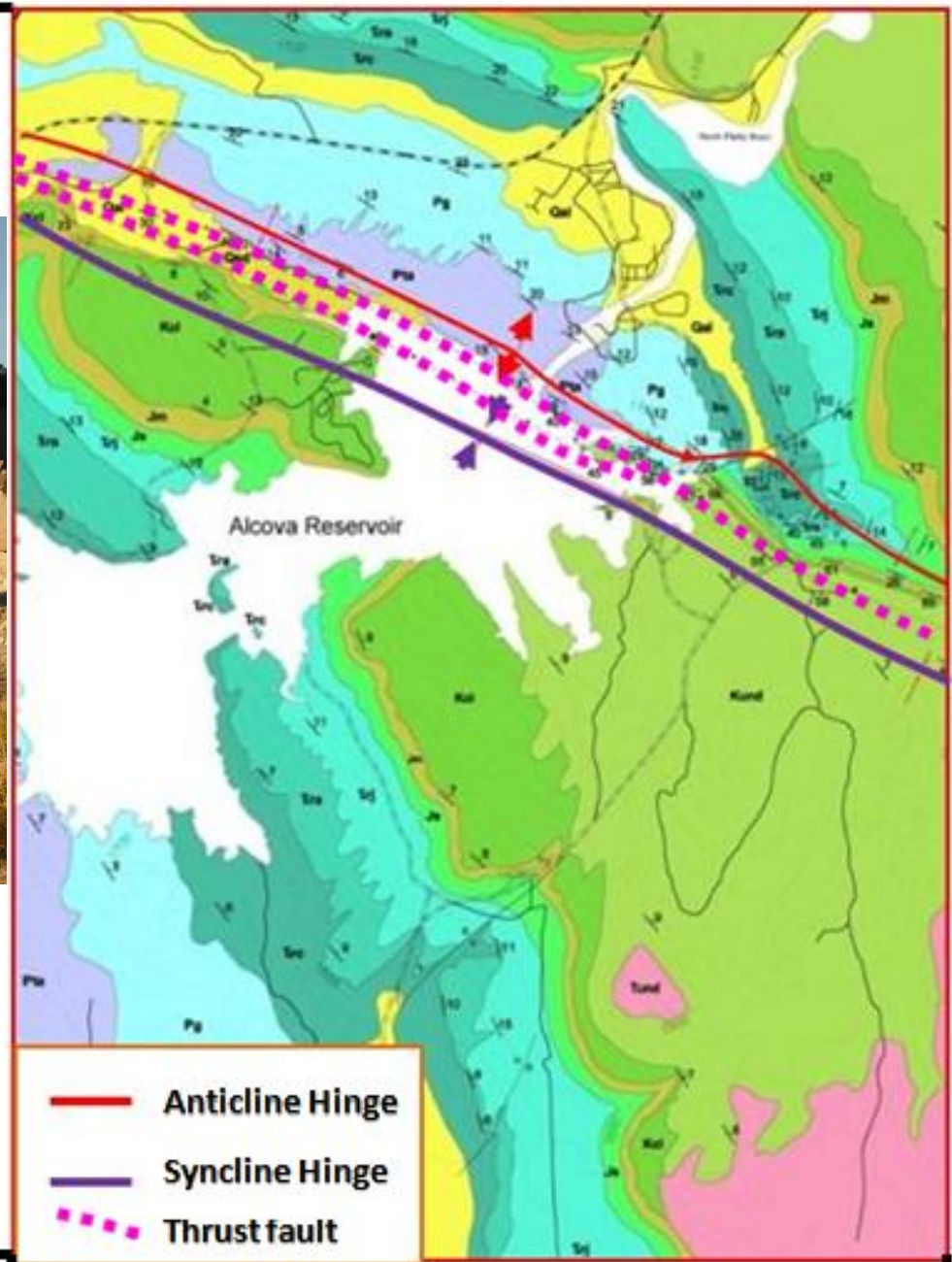
Eastern Wind River Fractures

- n= 1027
- 543 joints
- 67% Strike-slip
- Thrust mostly in vertical beds or in Alcova Limestone



Alcova

42°34'29"N



42°28'48"N

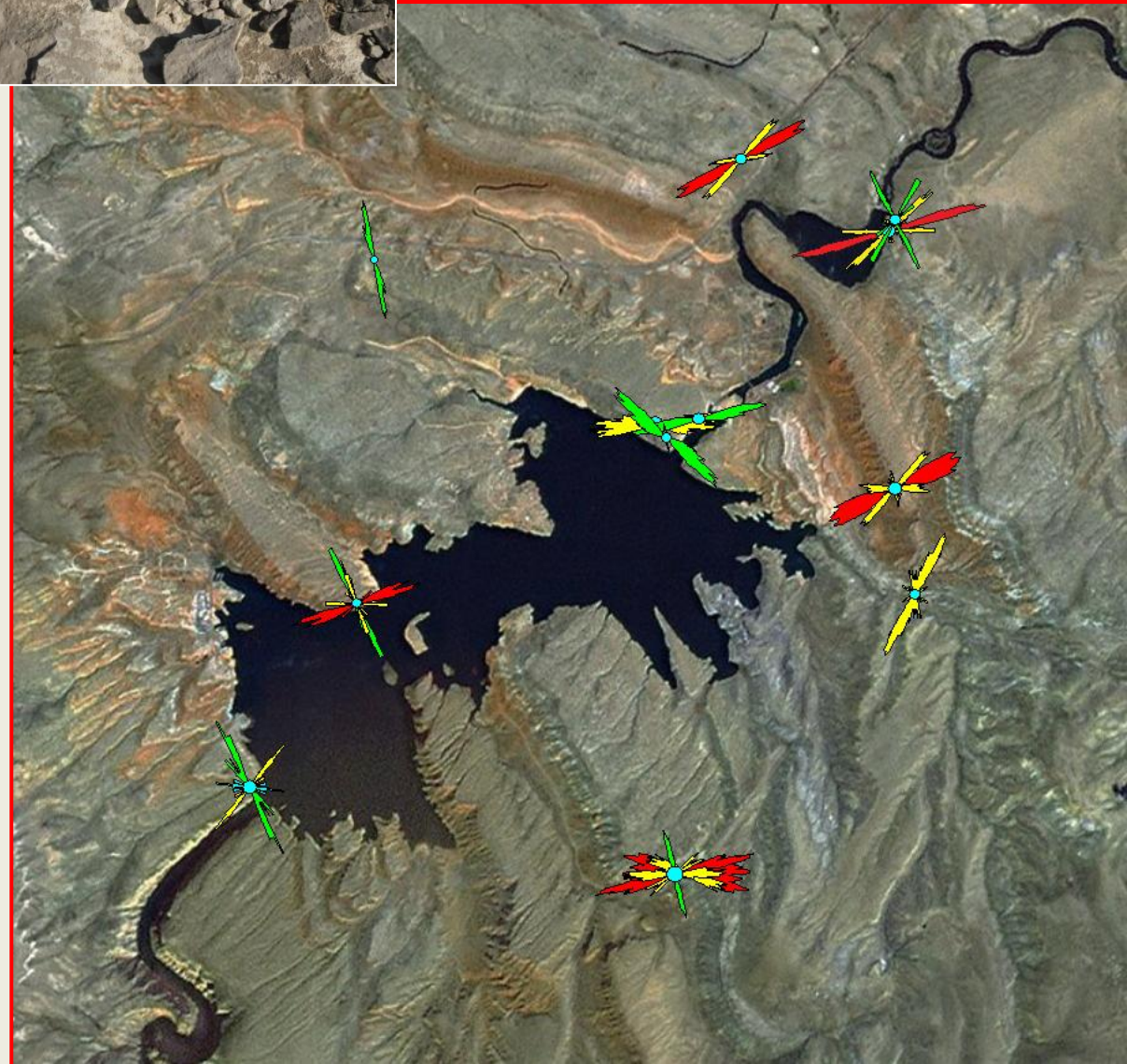
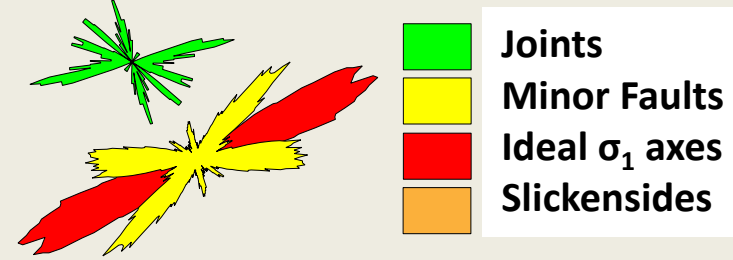
106°46'31"W

2.5 km

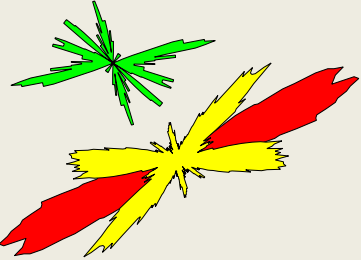
106°40'30"W

Alcova

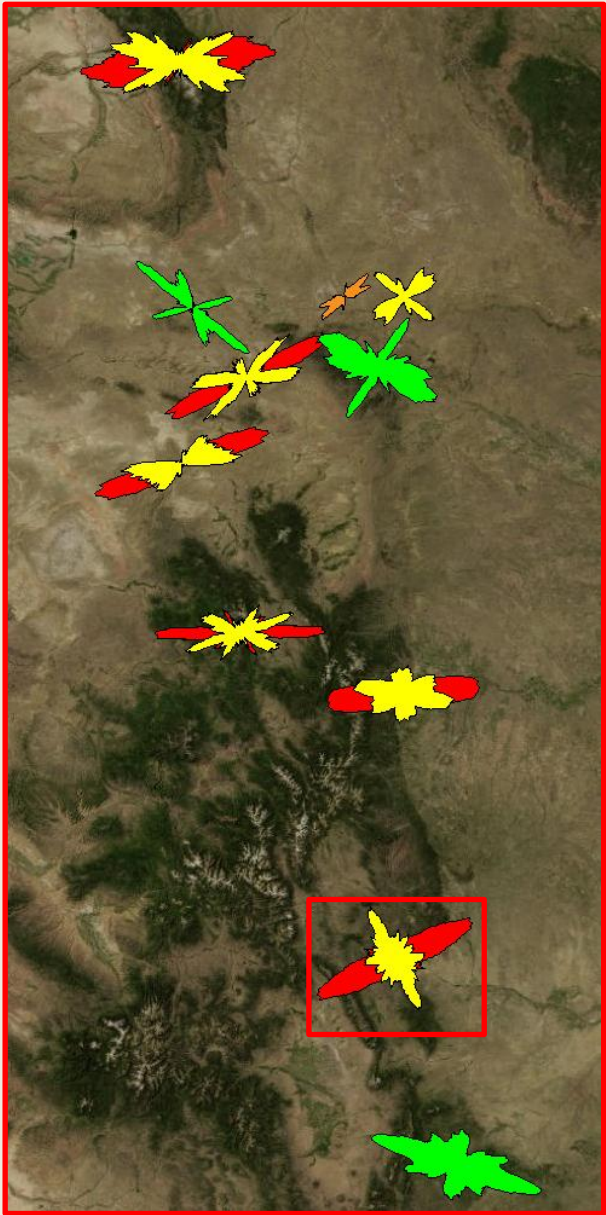
- n= 261 faults
- 72% Strike-slip
- Mean σ_1 : 068°



Canon City Embayment

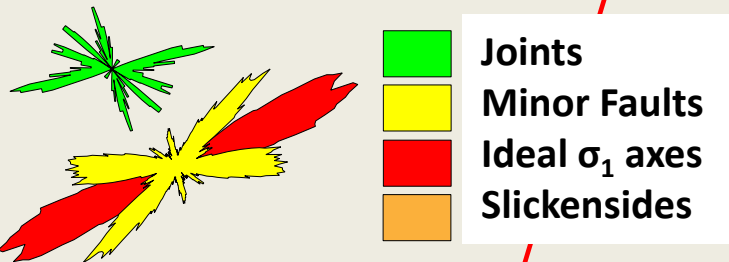
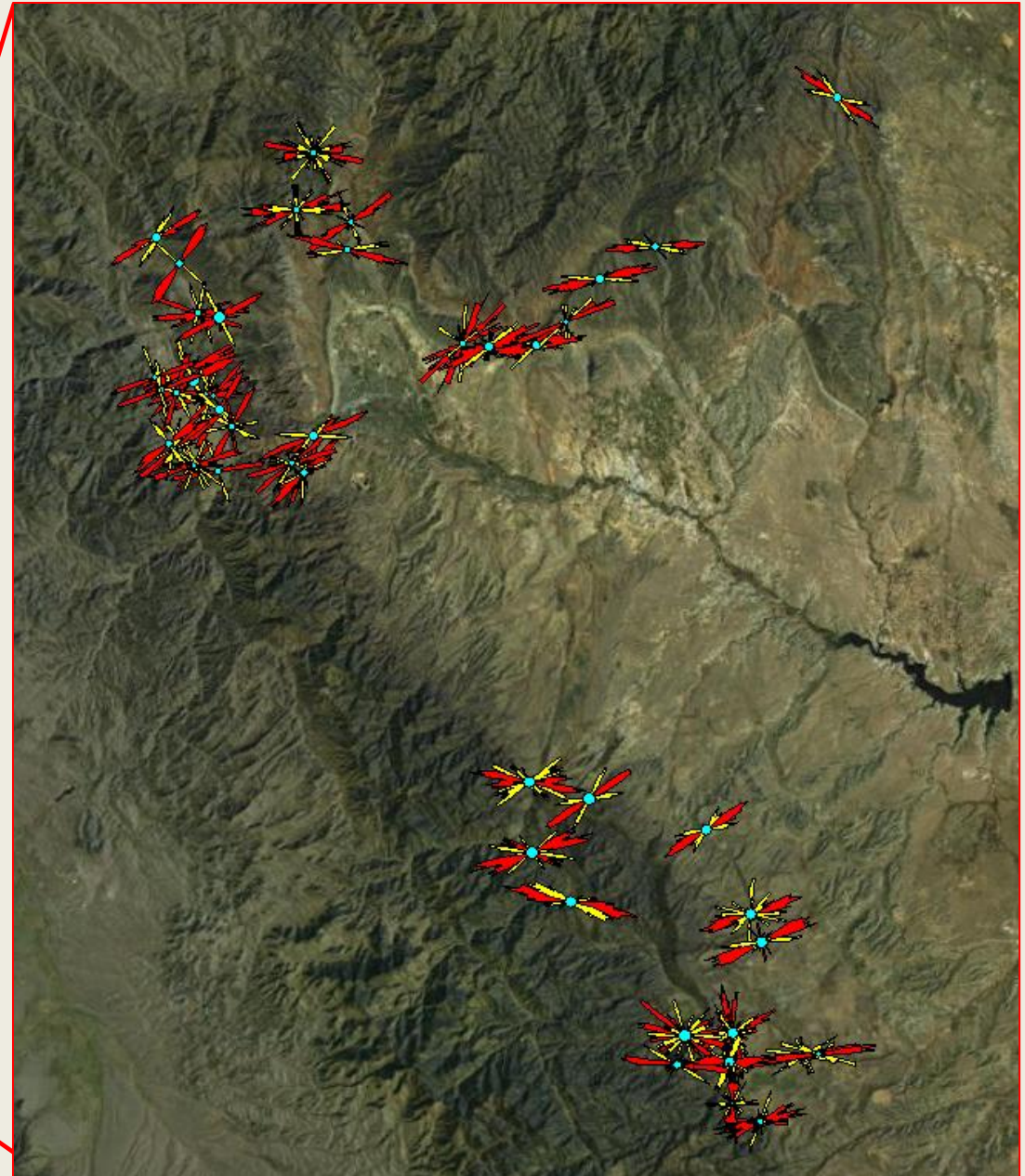


-  Joints
-  Minor Faults
-  Ideal σ_1 axes
-  Slickensides



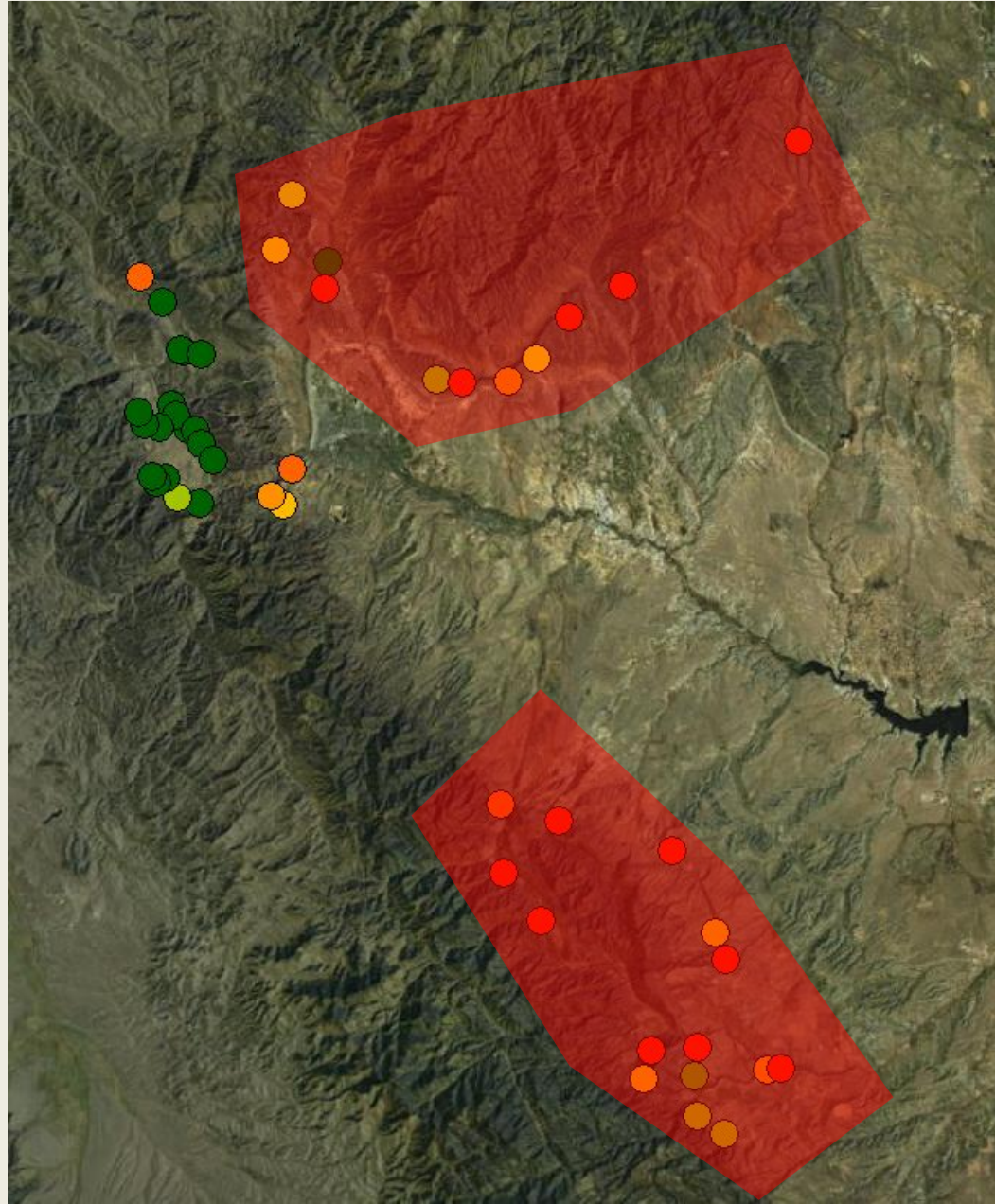
Canon City Embayment

- n=642 (faults)
- 79% Strike-slip
- Mean σ_1 : 075°



Canon City Embayment

Well defined
strike-slip
and thrust
domains

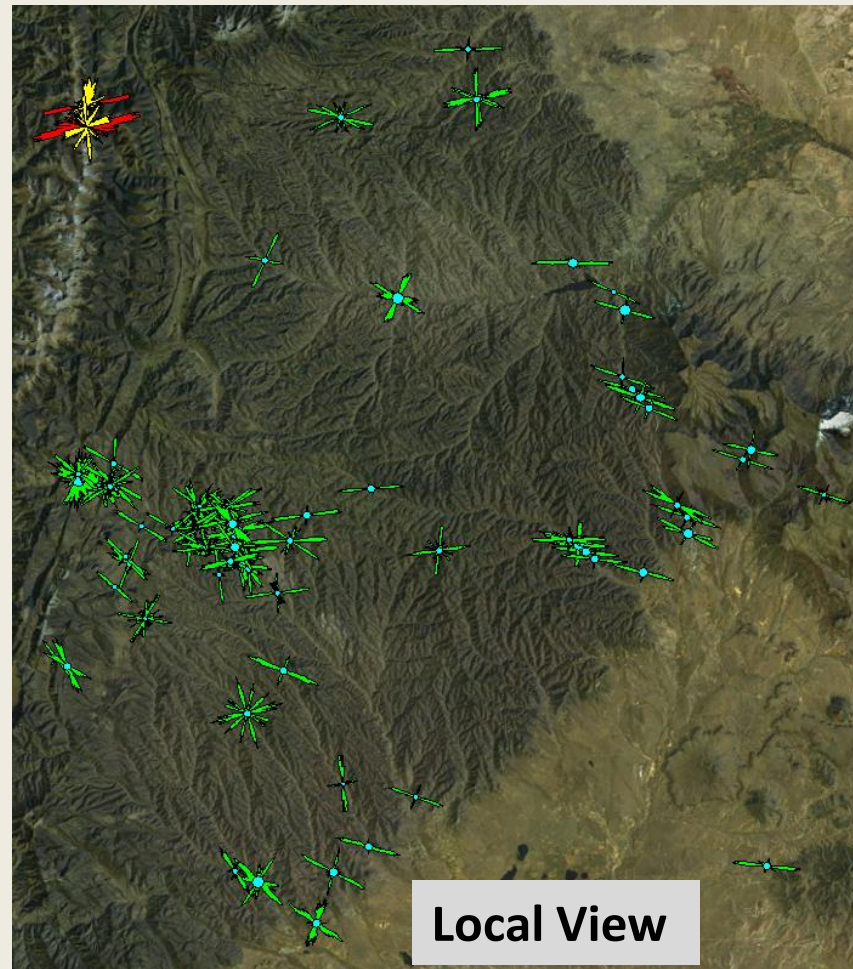
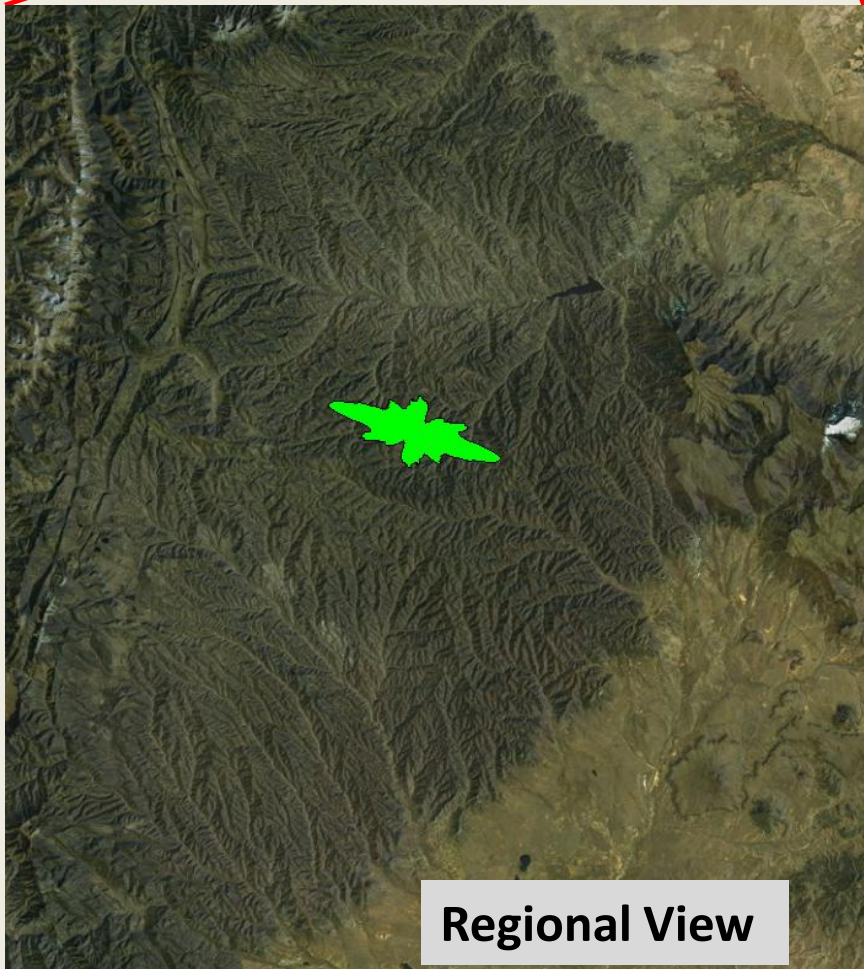
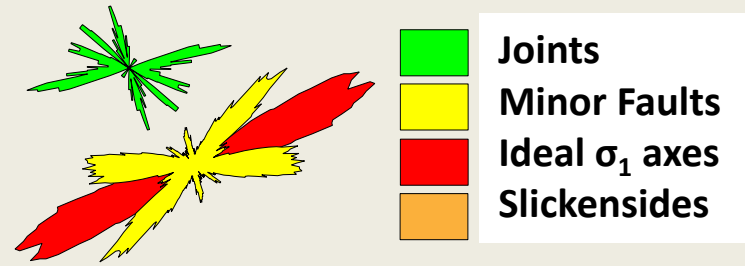


% Strike-slip



Raton Basin

- 4099 Joints



Local Perspective Summary

- **Local variability:**
 - **Fault type**
 - **Joint orientation**

- **Some consistencies:**
 - **NE-SW-trending to E-W-trending compression**
 - **NW-striking joints are found in post-Laramide units**

- **Discrete domains of strike-slip vs. thrust faulting**

Conclusion

- **East-northeast compression for Laramide structures from strike-slip and thrust faults**
- **Local diversity of joints; Regionally consistent**
 - **E-NE, NW-SE, and W-NW-striking joints (post-Laramide)**
- **Strike-slip minor fault zones are often confined to discrete zones**
- **This is a powerful tool that can be used for detailed analog development OR regional dynamic analysis!**

Implications

- **E-W and NE-striking vertical minor faults often confined to strike-slip zones (e.g. wrench faults in D-J basin!)**
- **Horizontal drilling reorientation to NE if permeability is created by NW-striking post-Laramide fractures, or NNW if by Laramide-age minor faults or joints**

THIS IS ONLY THE TIP OF THE ICEBERG!

Questions?

