Structurally Controlled Fluid Migration Through Thrusts of the Stewart Peak Culmination in Northern Salt River Range, Wyoming*

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Abstract

The Stewart Peak Culmination (SPC) is a topographic and structural culmination of the Absaroka thrust sheet in western Wyoming that lies structurally up dip from known subsurface accumulations of CO_2 in southeast Idaho. It is likely that the SPC was also a CO_2 trap prior to Neogene Basin-and-Range extension. The SPC has been uplifted and breached, exposing the structural and lithologic elements analogous to the CO_2 traps in SE Idaho. Investigation of this exposed trap allows for characterization of migration pathways and determination of the relative timing of fluid migration episodes.

Paleozoic-Mesozoic rocks have been highly deformed by movement of the Absaroka thrust sheet and its associated imbricate thrusts. Faulting led to extensive fracturing and brecciation that locally enhanced porosity and permeability. Brecciated fault zones are up to 4 m thick. Highly fractured damage zones extend for tens of meters into the hanging walls of large-displacement thrust faults. Fractures that developed in the culmination are the cumulative result of multiple slip events and aseismic processes. Fractures measured in the field have systematic geometric patterns associated with faulting and folding. The dominant fracture set consists of vertical to sub-vertical, ENE striking fractures that generally parallel the direction of thrust transport (Mode I dilational fractures). Crack-seal vein textures and multiple overprinting breccia textures suggest episodic seismic rupture. Fluid migration in the culmination was focused through faults, fractures, and breccia zones. Hydrothermal fluids likely enhanced these conduits via the processes of dolomitization, dissolution, fracturing, and brecciation.

Late-stage breccia bodies form discrete pipes that cross-cut stratigraphy and sometimes fault damage zones. Some breccia pipes developed by dissolution and collapse along tectonic fractures. These breccia bodies are linear in map view and parallel the main thrust transport direction (ENE). Other pipes exhibit dilational, ‘floating clast’ breccia that likely developed by isothermal boiling of CO_2, which lead to hydro-fracturing of host rocks. Secondary mineralization (saddle dolomite and disseminated sulfides) and related rock fabrics suggest a low temperature hydrothermal origin for most breccia pipes. Hydrothermal dolomitization of carbonate reservoir rocks is evident in the field

area, and the extent and location of dolomitized bodies appear to be controlled by thrust-related fractures. Fieldwork and petrographic evidence suggest that fracture sets kinematically associated with thrusting served as conduits for multiple episodes of fluid flow including CO_2-charged hydrothermal brines and hydrocarbons.

References

Budai, J.M., and D.V. Wiltschko, 1987, Structural controls on syntectonic diagenesis within the Haystack Peak region of the Absaroka thrust sheet, Idaho-Wyoming-Utah thrust belt *in* W. R. Miller, (ed.) The Thrust Belt Revisted: Wyoming Geological Association Guidebook, v. 38, p. 55-68.

Lageson, D.R., 1986, Geologic map of the Stewart Peak Quadrangle, Lincoln County, Wyoming: Map Series, Geological Survey of Wyoming, Laramie, Wyoming, MS 22, 1 map, Scale 1:00024000.

Lageson, D.R., 1984, Structural geology of Stewart Peak Culmination, Idaho-Wyoming thrust belt: AAPG Bulletin, v. 68/4, p. 401-416.

Schroeder, M.L., H.F. Albee, and R.A. Lunceford, 1981, Geologic map of the Pine Creek Quadrangle, Lincoln and Teton counties, Wyoming: Geologic Quadrangle Map USGS, U.S. Geological Survey Reston, Virginia, Report #GQ-1549, 1 map, Scale 1:24,000.

Structurally controlled fluid migration through thrusts of the Stewart Peak Culmination in northern Salt River Range, Wyoming

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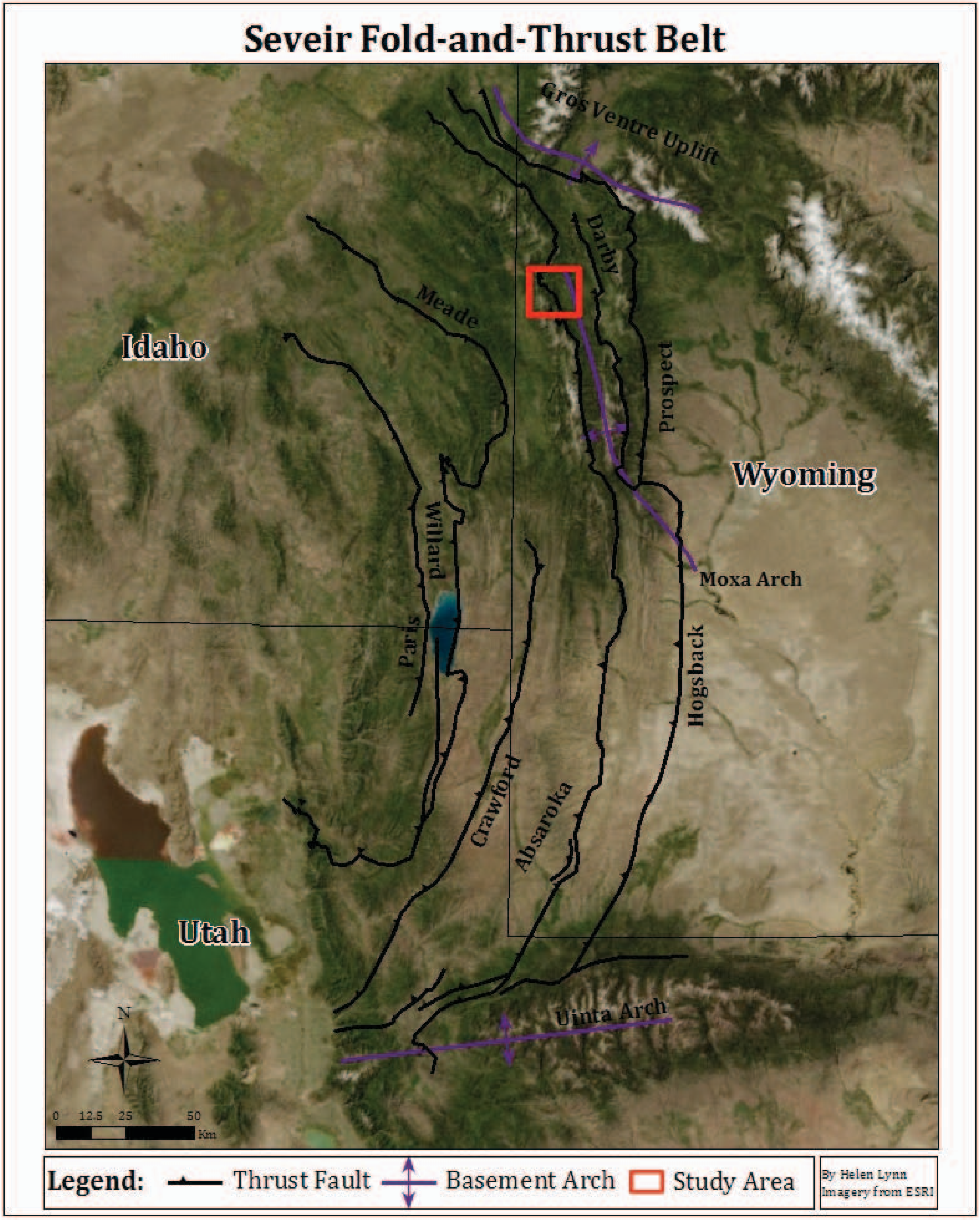
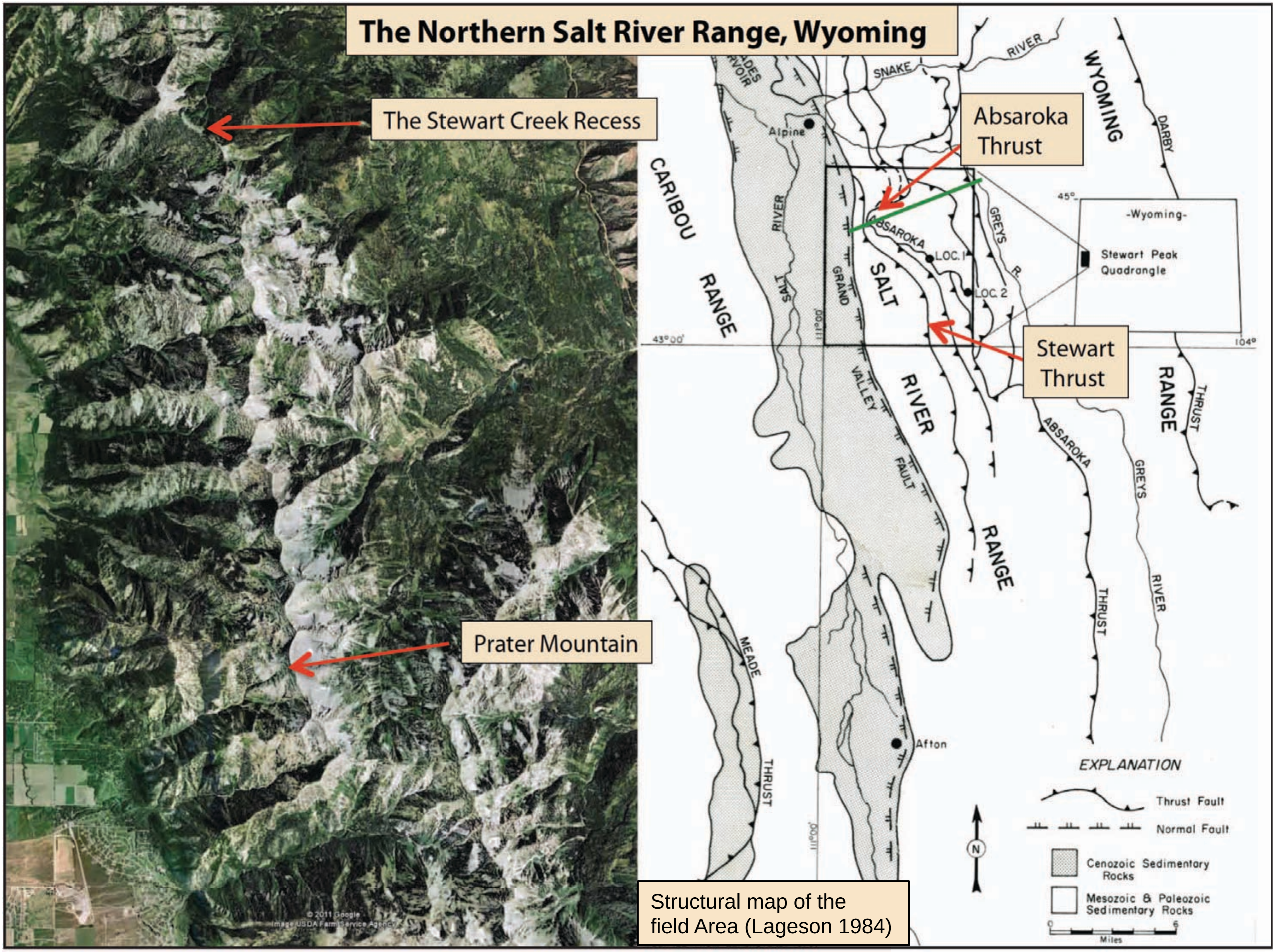
Montana State University
MARATHON
MONTANA STATE UNIVERSITY
ZERT Zero Emissions Research and Technology

Introduction

- The Stewart Peak Culmination – a structural culmination in the Absaroka thrust sheet of western Wyoming
- Exhumed duplex fault zone breached by erosion
- Up-dip from known CO2 reservoirs in SE Idaho and therefore can be used as a surface analogue for potential CO2 storage sites including the proximal Moxa Arch, a naturally occurring CO2 reservoir and an excellent hydrocarbon trap
- Understanding fluid migration is critical for evaluating CO2 storage sites and potential oil and gas reservoirs
- Structural diagenesis ⇨ faults, fractures and breccia zones can facilitate fluid migration, create secondary porosity in tight reservoirs, compartmentalize reservoirs, and create anisotropy in fluid flow systems; the diagenetic products of fluid/rock interactions can both enhance and hinder fluid flow


Seveir Fold-and-Thrust Belt
Gros Ventre Uplift
Darby
Meade
Idaho
Prospect
Wyoming
Willard
Moxa Arch
Paris
Hogsback
Crawford
Absaroka
Utah
Uinta Arch
N
0 12.5 25 50
Km
Legend:
Thrust Fault
Basement Arch
Study Area
By Helen Lynn
Imagery from ESRI

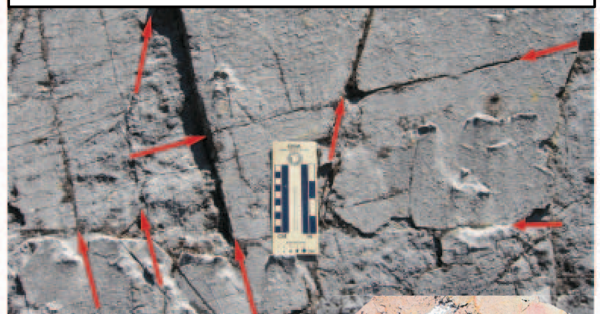

The Northern Salt River Range, Wyoming
The Stewart Creek Recess
Prater Mountain
© 2011 Google
Image USDA Farm Service Agency
SNAKE
RIVER
WYOMING
DARBY
Alpine
Absaroka Thrust
CARIBOU
RANGE
RIVER
SALT
GRAND
SALT
ABSAROKA
LOC. 1
LOC. 2
GREYS
R.
45°
-Wyoming-
Stewart Peak Quadrangle
43°00'
111°00'
104°
Stewart Thrust
VALLEY
FAULT
RIVER
RANGE
ABSAROKA
THRUST
GREYS
RIVER
RANGE
THRUST
MEADE
THRUST
Afton
EXPLANATION
Thrust Fault
Normal Fault
Cenozoic Sedimentary Rocks
Mesozoic & Paleozoic Sedimentary Rocks
N
0
6
Miles
Structural map of the field Area (Lageson 1984)

Methods

- Collection of fracture data from fracture stations in each of the 4 structural domains
- Sample collection
- Characterization of fault zones, breccia pipes, fracture swarms, and reservoir rocks
- Geometric and kinematic analysis of fracture data
- Spatial and statistical studies of fracture attributes
- Sample stains and peels
- Thin section petrography
- FEM and SEM and CL imaging

- *Stable isotope analyses (C, O, Sr)*
- *Fluid inclusion analyses*

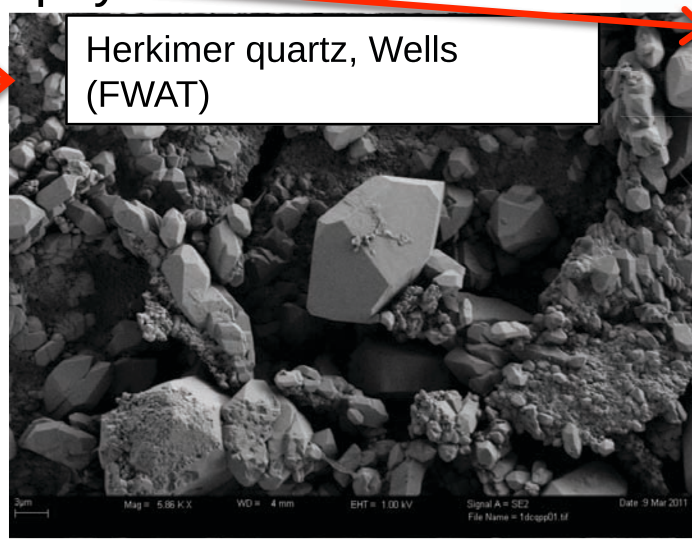
Systematic fractures - Cambrian Gros Ventre (FWST)



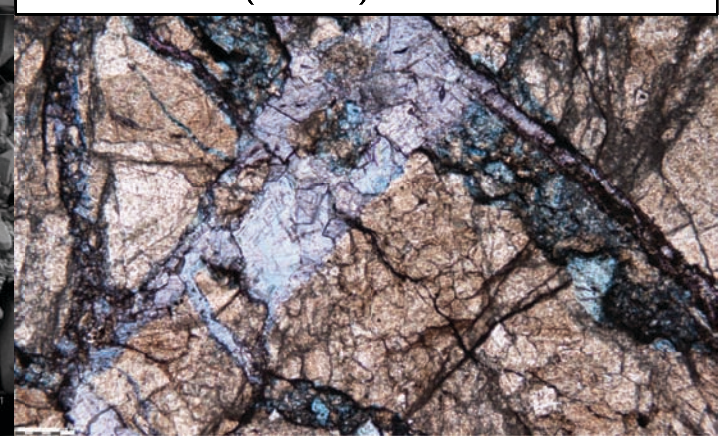
Jurassic Twin Creek - Damage zone (FWAT)

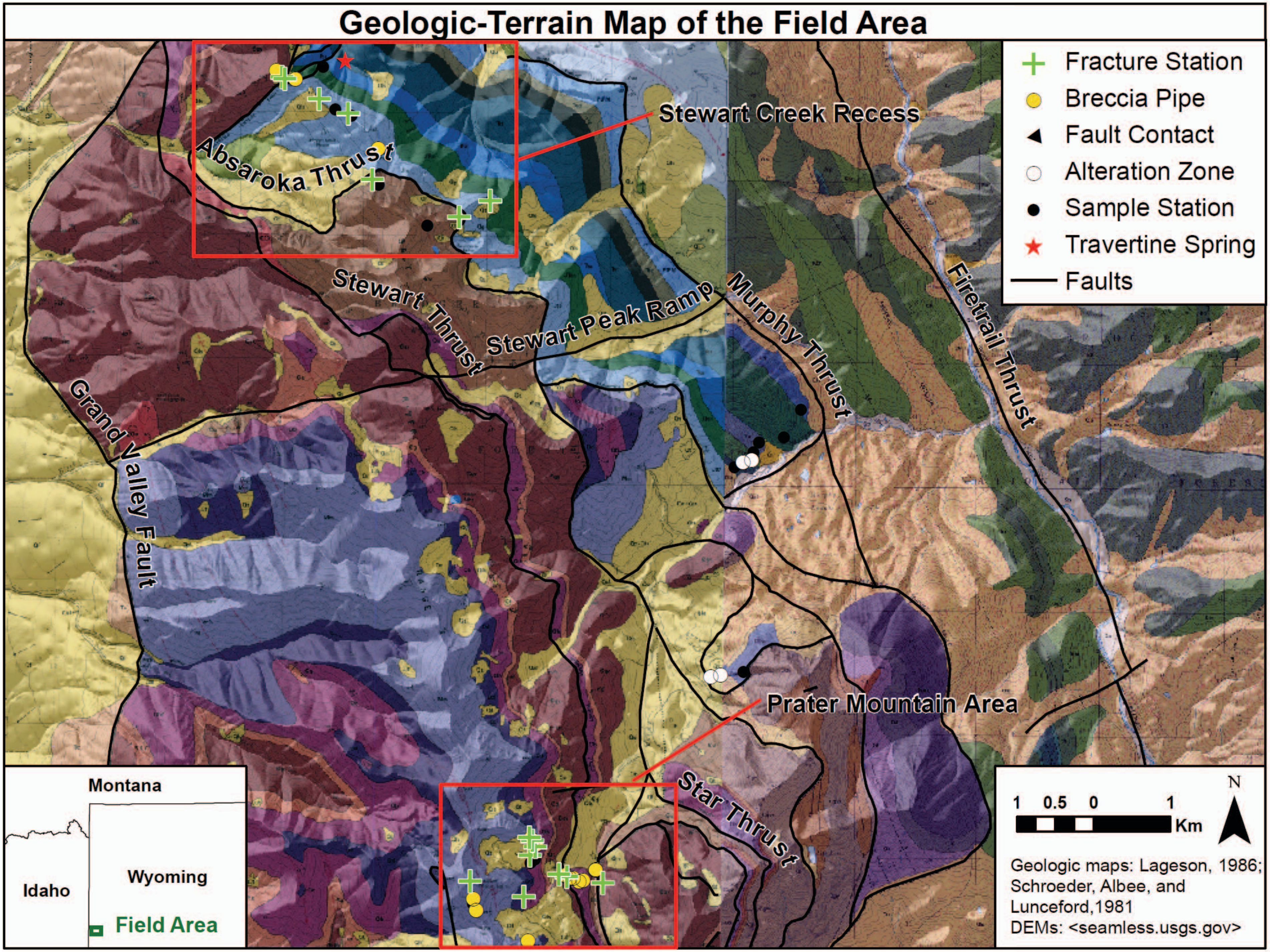
Ordovician Bighorn
reccia Pipe (FWST)

Herkimer quartz, Wells (FWAT)

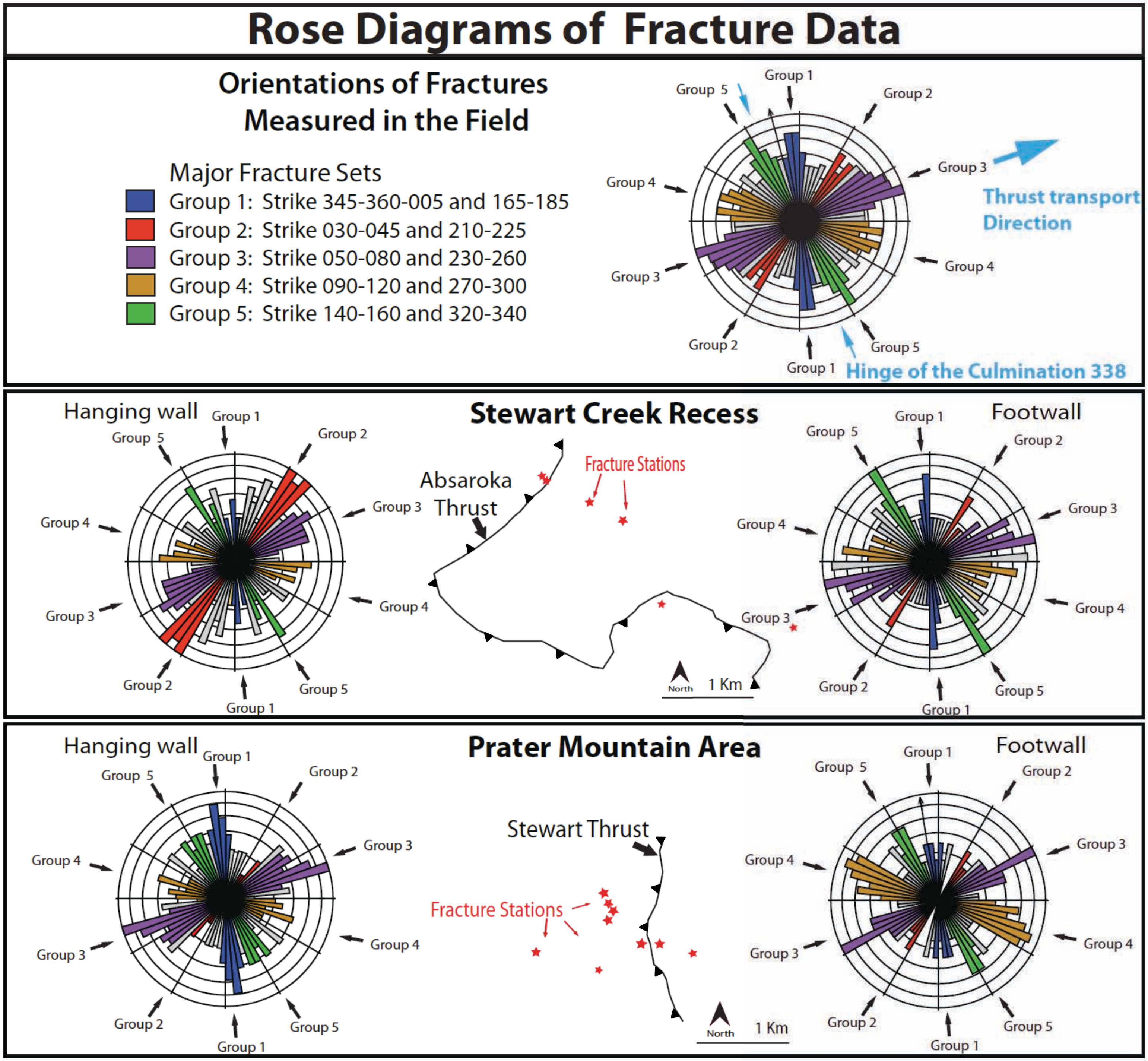


Fe-calcite and Fe-dolomite Cambrian Gros Ventre (FWST)

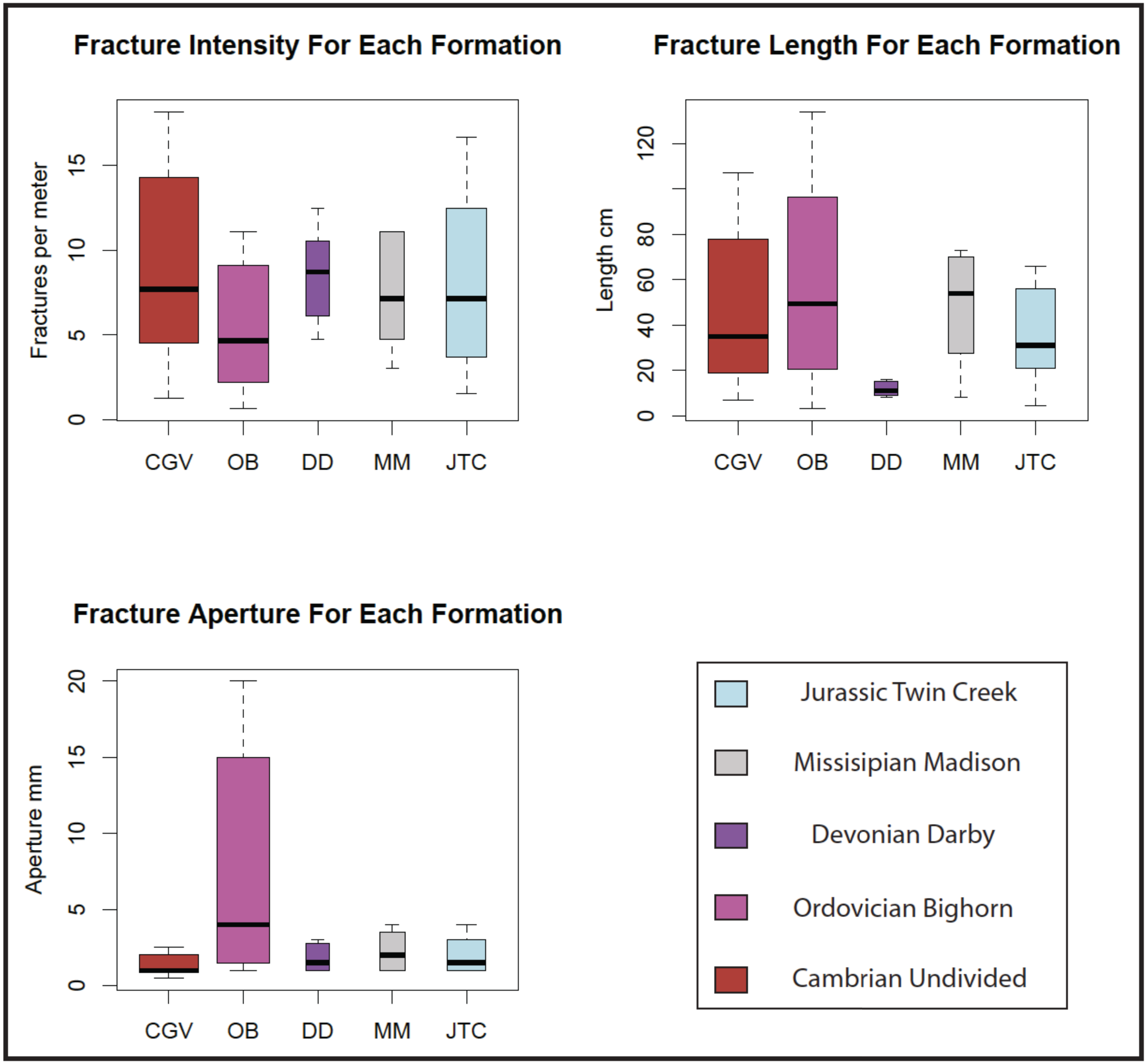


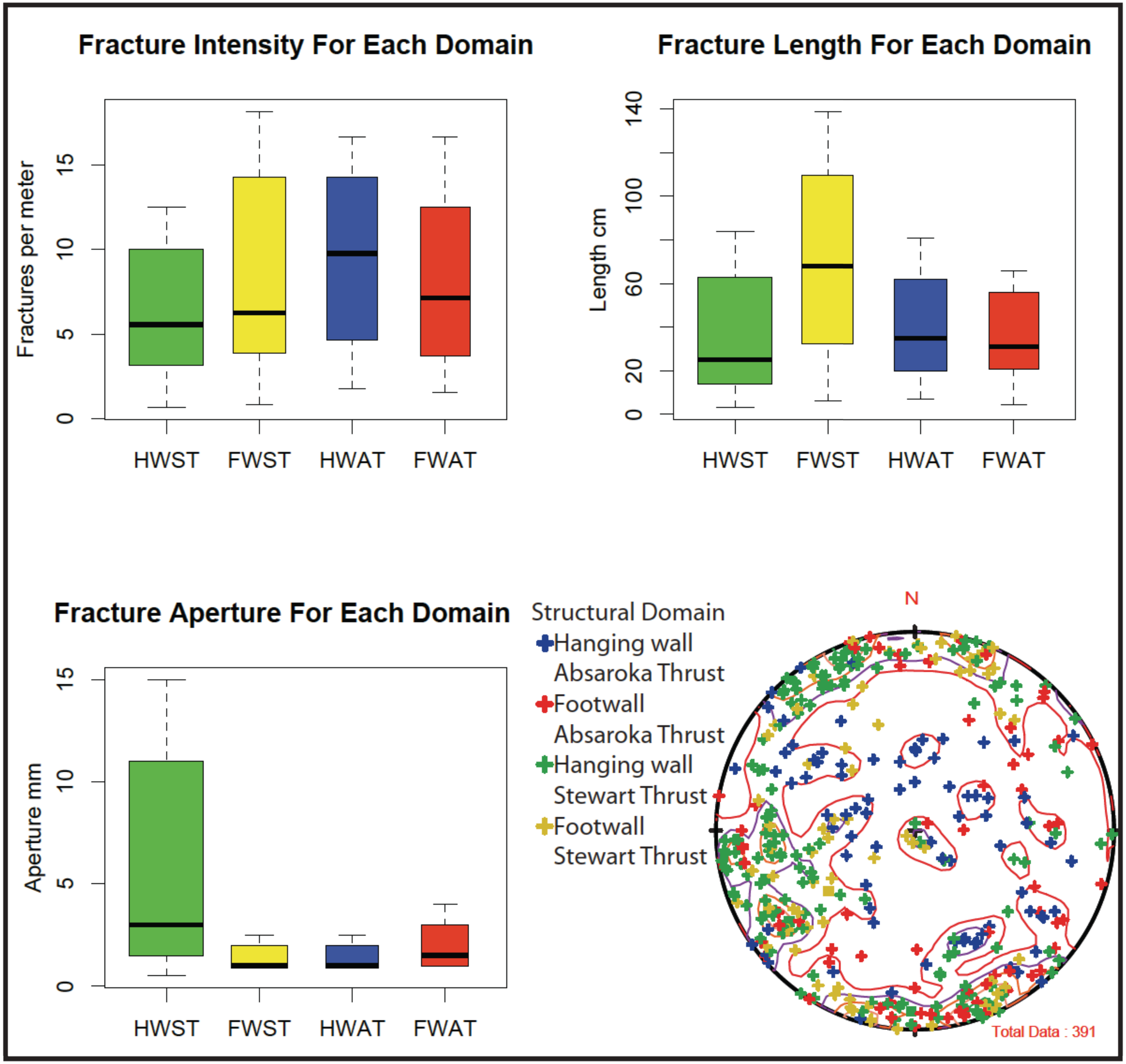


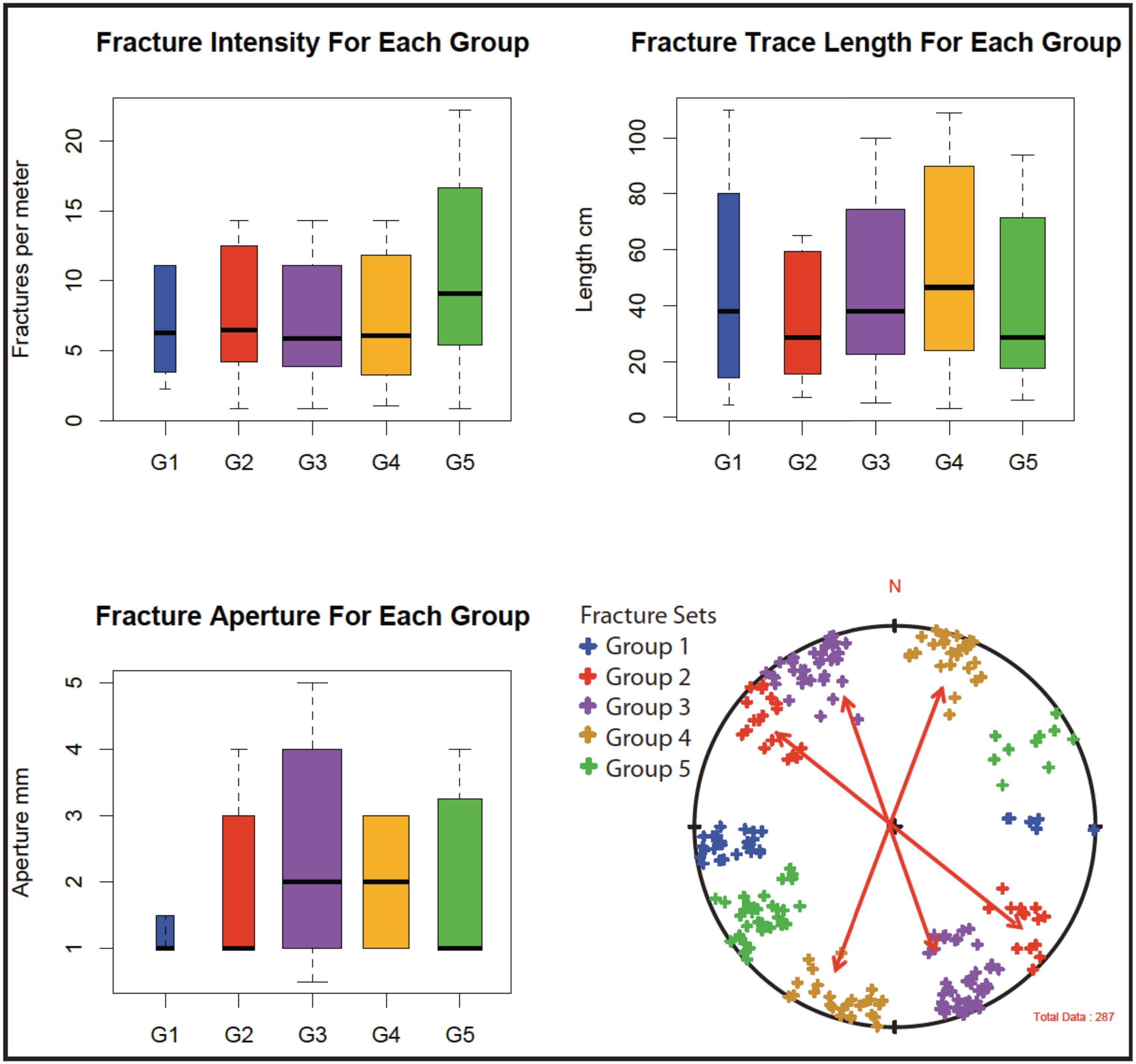
Geologic-Terrain Map of the Field Area
Fracture Station
Breccia Pipe
Fault Contact
Alteration Zone
Sample Station
Travertine Spring
Faults
Stewart Creek Recess
Absaroka Thrust
Stewart Thrust
Stewart Peak Ramp
Murphy Thrust
Firetrail Thrust
Grand Valley Fault
Prater Mountain Area
Star Thrust
Montana
Idaho
Wyoming
Field Area
1 0.5 0 1
Km
N
Geologic maps: Lageson, 1986; Schroeder, Albee, and Lunceford,1981
DEMs: <seamless.usgs.gov>

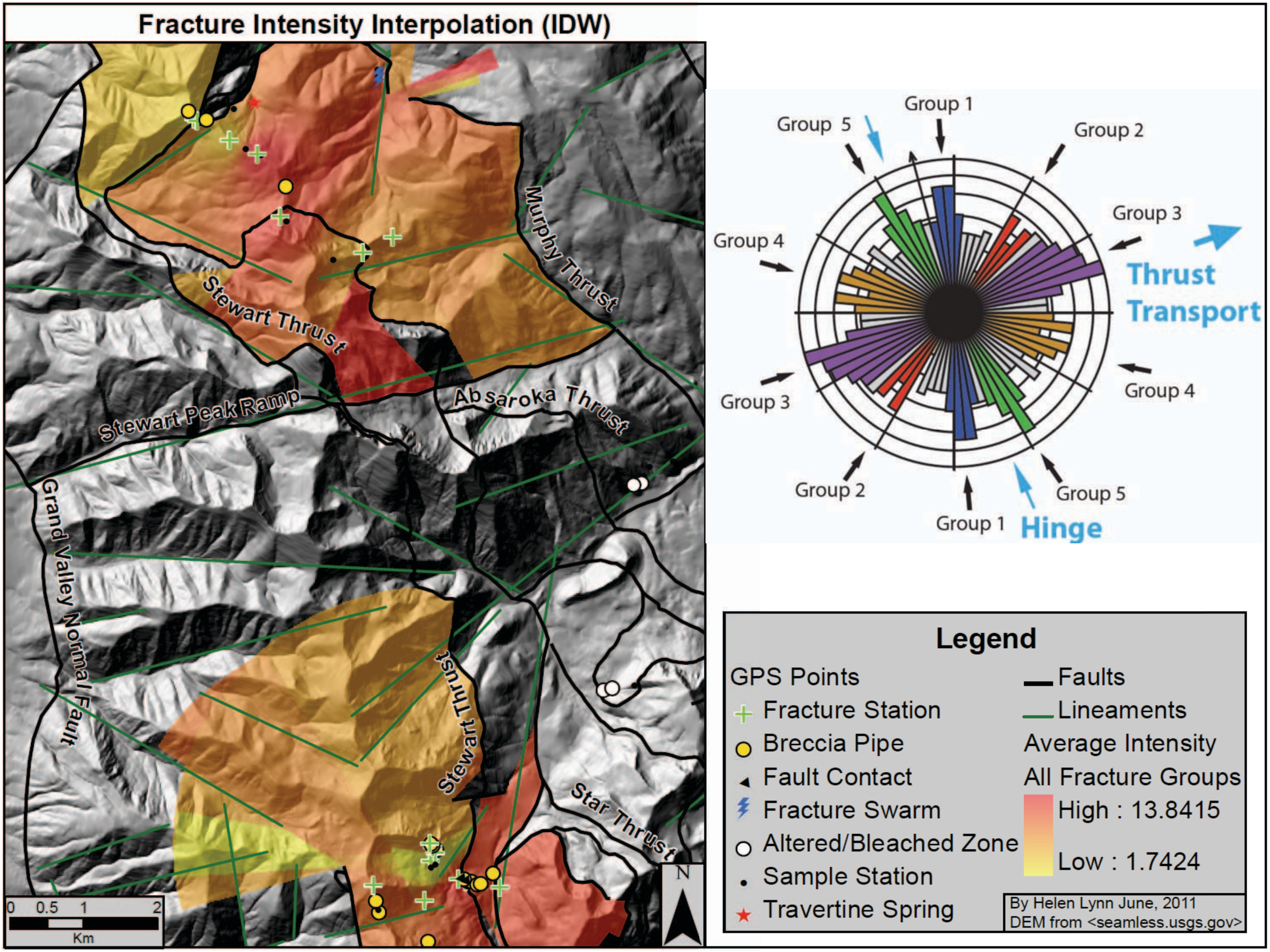


Rose Diagrams of Fracture Data
Orientations of Fractures Measured in the Field
Major Fracture Sets
Group 1: Strike 345-360-005 and 165-185
Group 2: Strike 030-045 and 210-225
Group 3: Strike 050-080 and 230-260
Group 4: Strike 090-120 and 270-300
Group 5: Strike 140-160 and 320-340
Group 1
Group 2
Group 3
Group 4
Group 5
Thrust transport Direction
Hinge of the Culmination 338
Stewart Creek Recess
Hanging wall
Footwall
Absaroka Thrust
Fracture Stations
North
1 Km
Prater Mountain Area
Hanging wall
Footwall
Stewart Thrust
Fracture Stations
North
1 Km

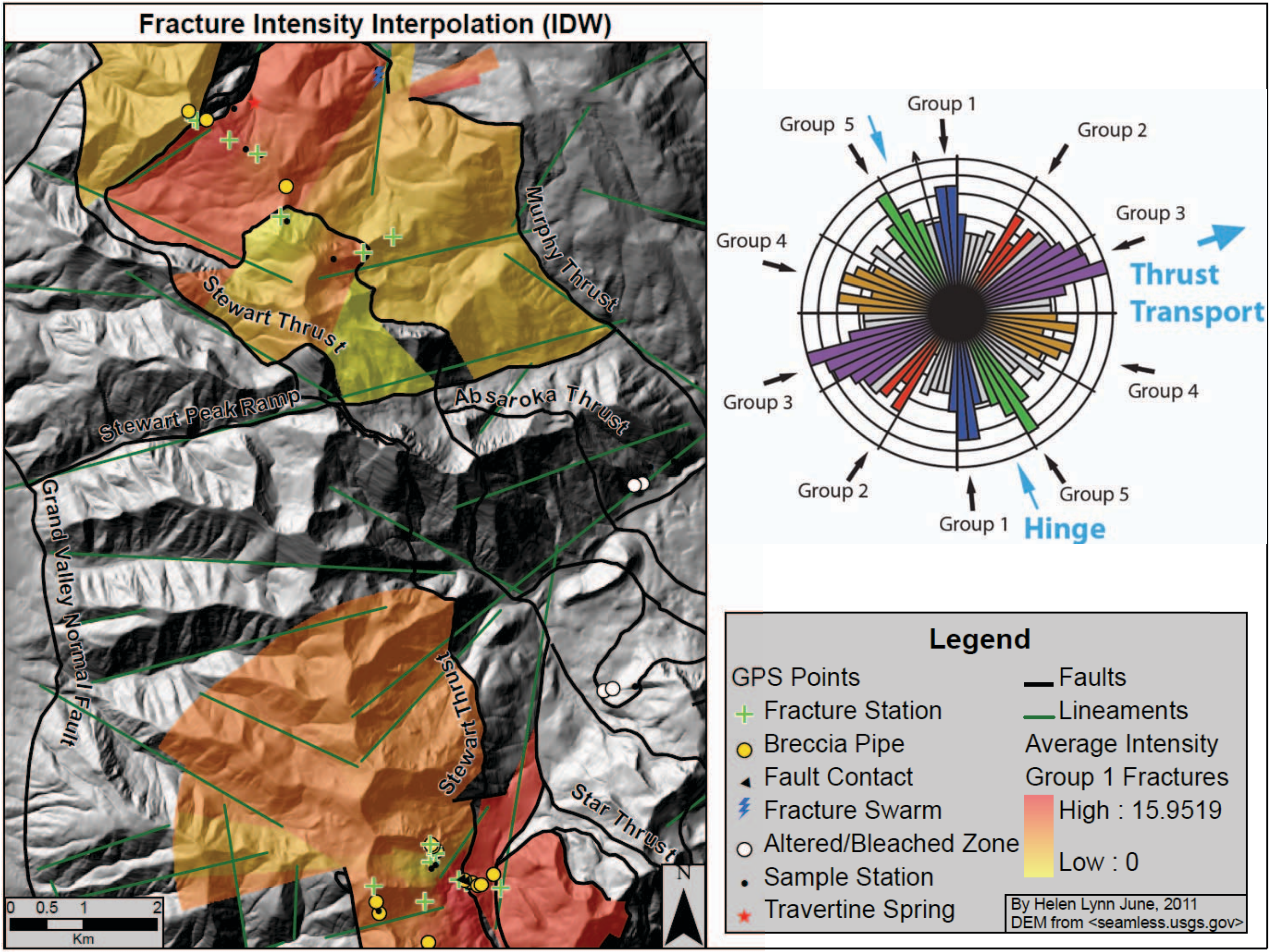

Fracture Intensity For Each Formation
Fractures per meter
0
5
10
15
CGV
OB
DD
MM
JTC
Fracture Length For Each Formation
Length cm
0
20
40
60
80
120
CGV
OB
DD
MM
JTC
Fracture Aperture For Each Formation
Aperture mm
0
5
10
15
20
CGV
OB
DD
MM
JTC
Jurassic Twin Creek
Missisipian Madison
Devonian Darby
Ordovician Bighorn
Cambrian Undivided


Fracture Intensity For Each Domain
Fractures per meter
0
5
10
15
HWST
FWST
HWAT
FWAT
Fracture Length For Each Domain
Length cm
0
20
60
100
140
HWST
FWST
HWAT
FWAT
Fracture Aperture For Each Domain
Aperture mm
0
5
10
15
HWST
FWST
HWAT
FWAT
Structural Domain
Hanging wall Absaroka Thrust
Footwall Absaroka Thrust
Hanging wall Stewart Thrust
Footwall Stewart Thrust
N
Total Data : 391


Fracture Intensity For Each Group
Fractures per meter
0
5
10
15
20
G1
G2
G3
G4
G5
Fracture Trace Length For Each Group
Length cm
0
20
40
60
80
100
G1
G2
G3
G4
G5
Fracture Aperture For Each Group
Aperture mm
1
2
3
4
5
G1
G2
G3
G4
G5
N
Fracture Sets
Group 1
Group 2
Group 3
Group 4
Group 5
Total Data : 287



Fracture Intensity Interpolation (IDW)
Murphy Thrust
Stewart Thrust
Stewart Peak Ramp
Absaroka Thrust
Grand Valley Normal Fault
Stewart Thrust
Star Thrust
0 0.5 1 2
Km
N
Group 1
Group 5
Group 2
Group 3
Group 4
Thrust Transport
Group 3
Group 4
Group 2
Group 1
Group 5
Hinge
Legend
GPS Points
Fracture Station
Breccia Pipe
Fault Contact
Fracture Swarm
Altered/Bleached Zone
Sample Station
Travertine Spring
Faults
Lineaments
Average Intensity
All Fracture Groups
High : 13.8415
Low : 1.7424
By Helen Lynn June, 2011
DEM from <seamless.usgs.gov>


Fracture Intensity Interpolation (IDW)
Murphy Thrust
Stewart Thrust
Stewart Peak Ramp
Absaroka Thrust
Grand Valley Normal Fault
Star Thrust
0 0.5 1 2
Km
N
Group 1
Group 2
Group 3
Group 4
Group 5
Thrust Transport
Hinge
Legend
GPS Points
Fracture Station
Breccia Pipe
Fault Contact
Fracture Swarm
Altered/Bleached Zone
Sample Station
Travertine Spring
Faults
Lineaments
Average Intensity
Group 1 Fractures
High : 15.9519
Low : 0
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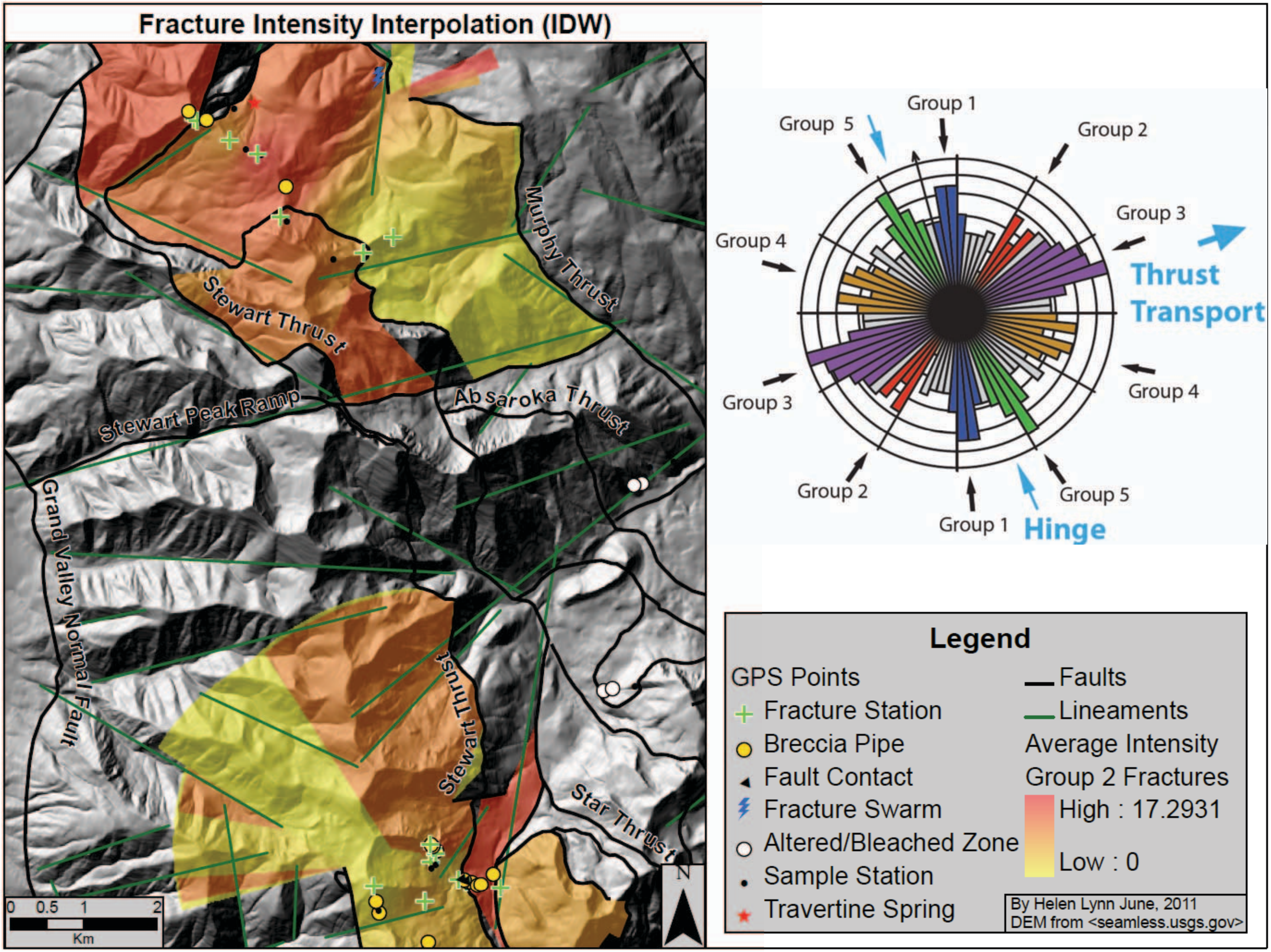
Fracture Intensity Interpolation (IDW)
Murphy Thrust
Stewart Thrust
Absaroka Thrust
Stewart Peak Ramp
Grand Valley Normal Fault
Stewart Thrust
Star Thrust
0 0.5 1 2
Km
N
Group 1
Group 2
Group 3
Group 4
Group 5
Group 1
Group 2
Group 3
Group 4
Group 5
Thrust Transport
Hinge
Legend
GPS Points
Fracture Station
Breccia Pipe
Fault Contact
Fracture Swarm
Altered/Bleached Zone
Sample Station
Travertine Spring
Faults
Lineaments
Average Intensity
Group 2 Fractures
High : 17.2931
Low : 0
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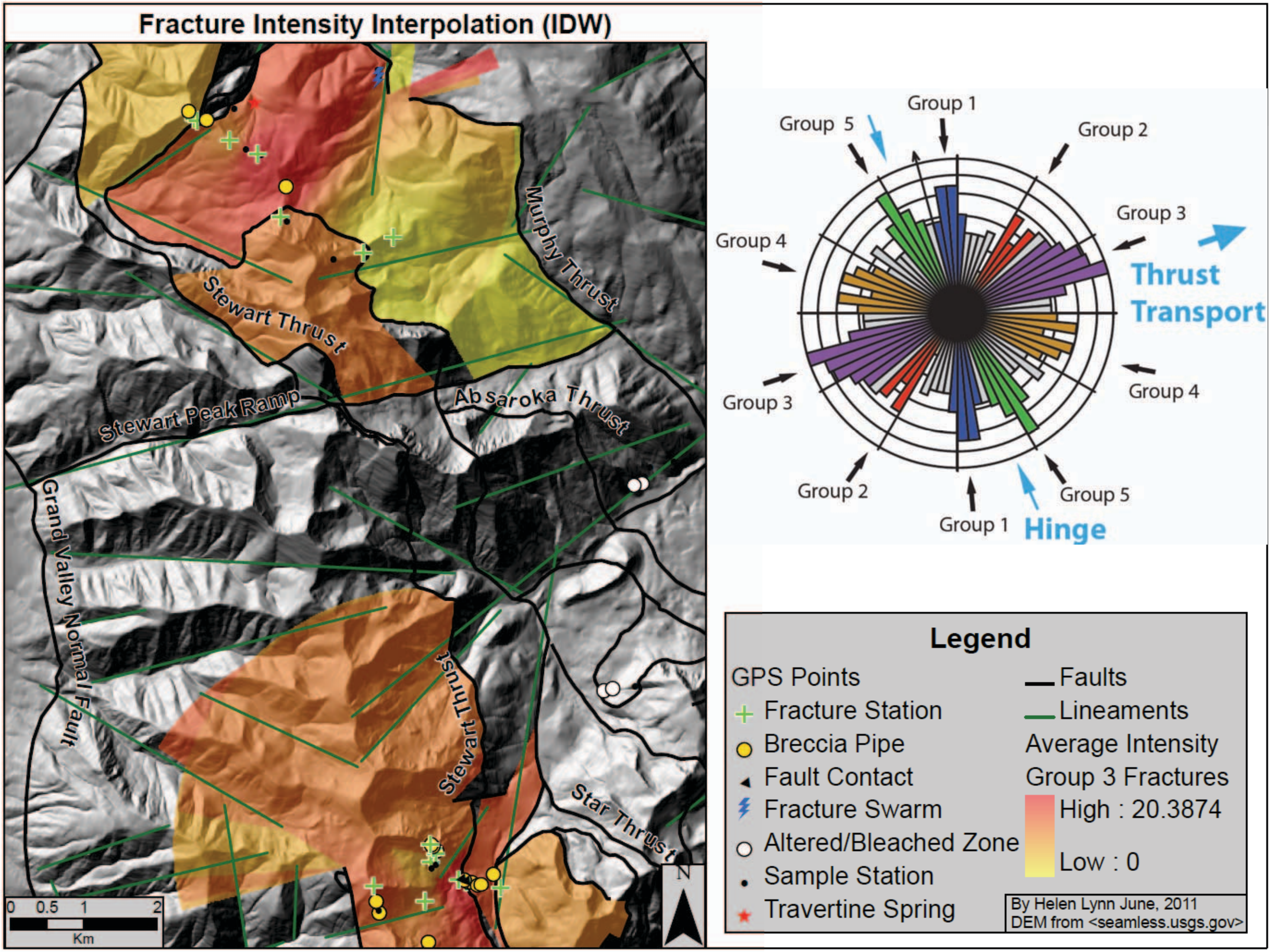

Fracture Intensity Interpolation (IDW)
Murphy Thrust
Stewart Thrust
Absaroka Thrust
Stewart Peak Ramp
Grand Valley Normal Fault
Stewart Thrust
Star Thrust
0 0.5 1 2
Km
N
Group 1
Group 5
Group 2
Group 3
Group 4
Thrust Transport
Group 3
Group 4
Group 2
Group 5
Group 1
Hinge
Legend
GPS Points
Fracture Station
Breccia Pipe
Fault Contact
Fracture Swarm
Altered/Bleached Zone
Sample Station
Travertine Spring
Faults
Lineaments
Average Intensity
Group 3 Fractures
High : 20.3874
Low : 0
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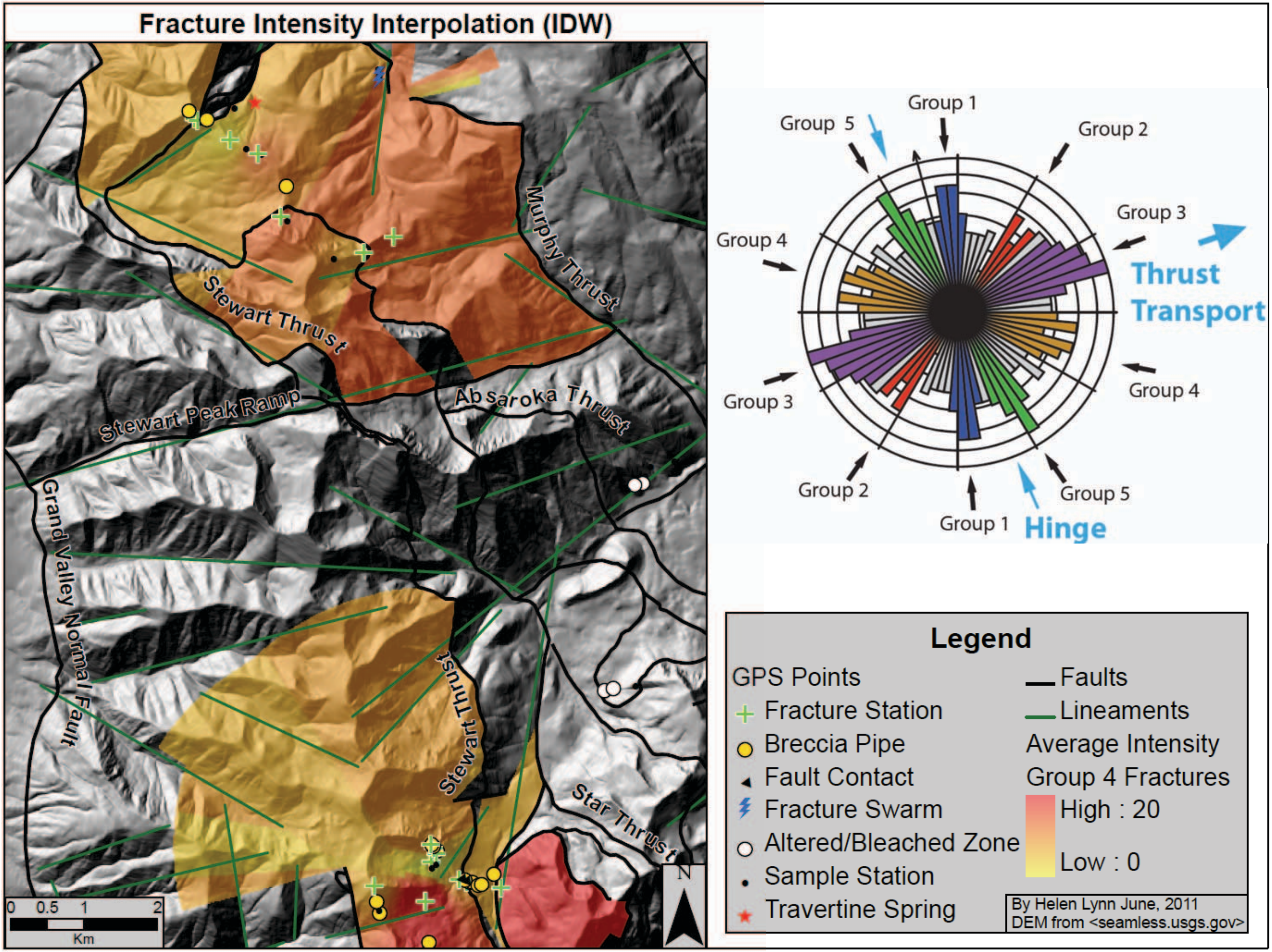
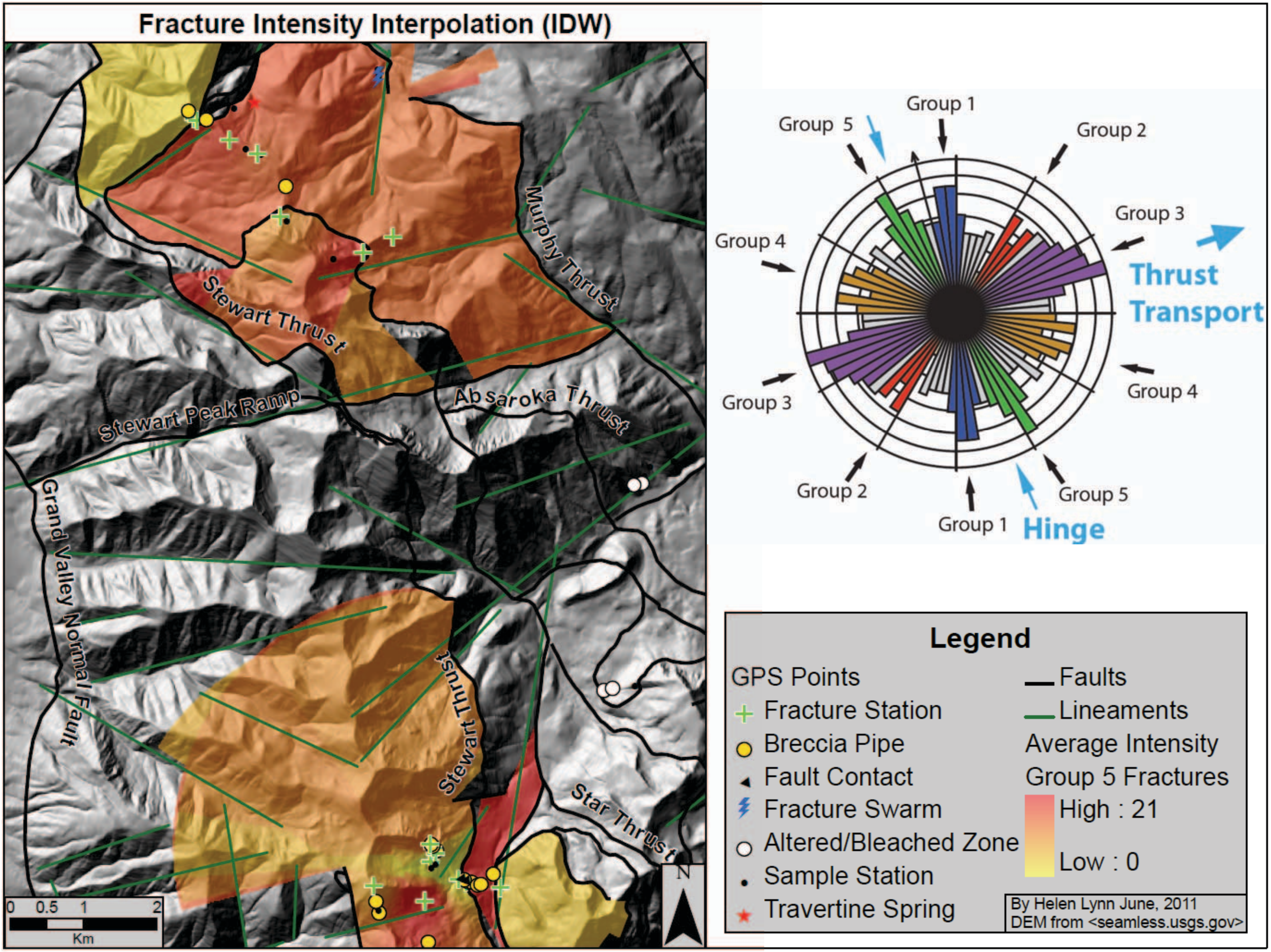
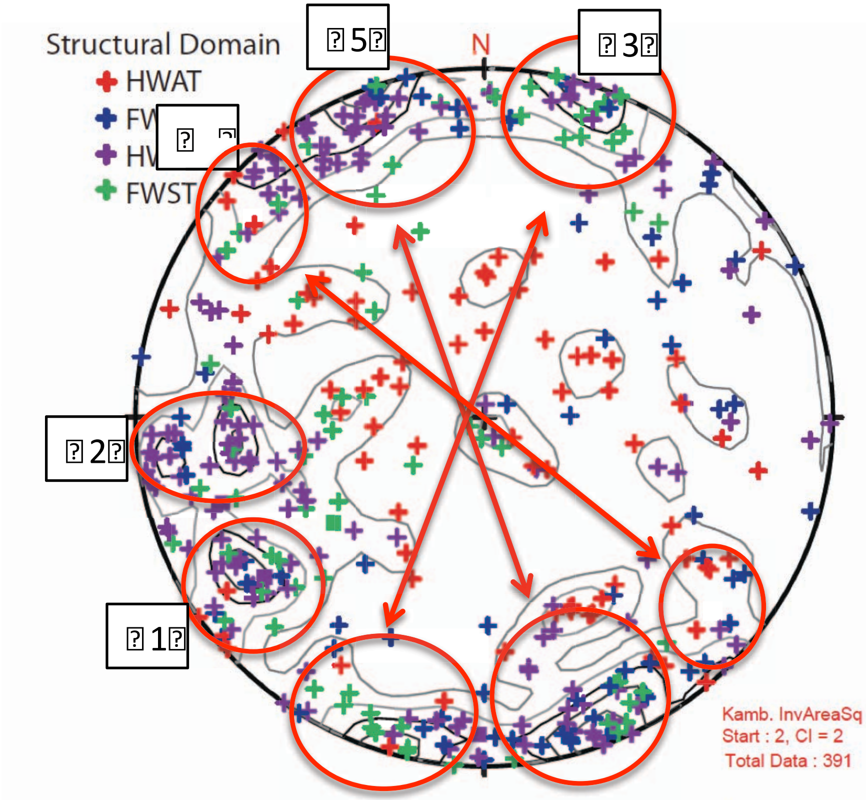

Fracture Intensity Interpolation (IDW)
Murphy Thrust
Stewart Thrust
Stewart Peak Ramp
Absaroka Thrust
Grand Valley Normal Fault
Stewart Thrust
Star Thrust
0 0.5 1 2
Km
N
Group 1
Group 2
Group 3
Group 4
Group 5
Group 1
Group 2
Group 3
Group 4
Group 5
Thrust Transport
Hinge
Legend
GPS Points
Fracture Station
Breccia Pipe
Fault Contact
Fracture Swarm
Altered/Bleached Zone
Sample Station
Travertine Spring
Faults
Lineaments
Average Intensity
Group 4 Fractures
High : 20
Low : 0
By Helen Lynn June, 2011
DEM from <seamless.usgs.gov>

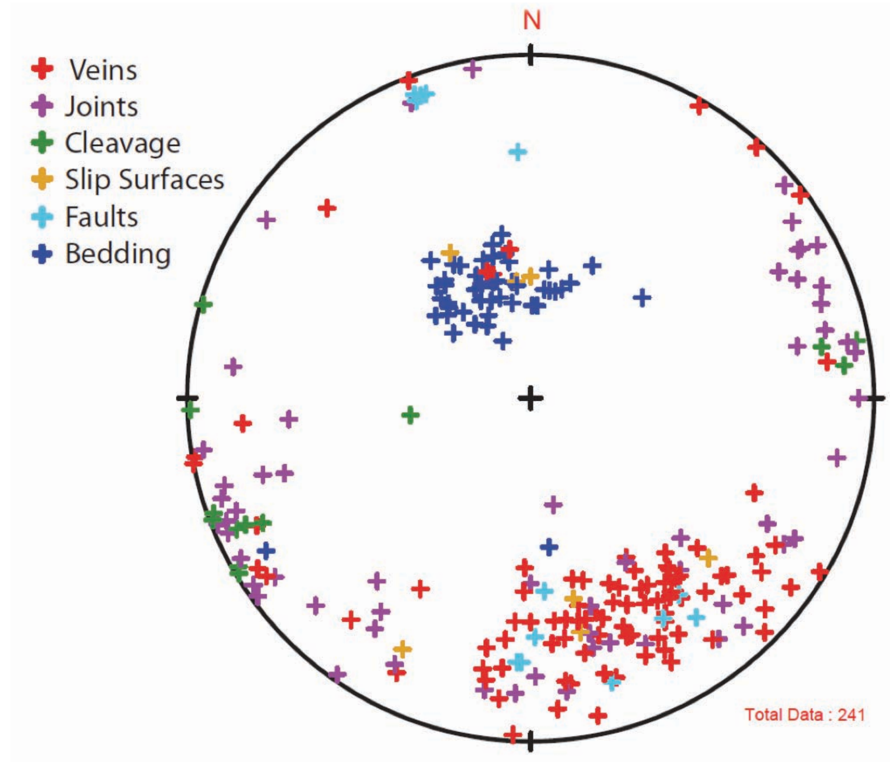

Fracture Intensity Interpolation (IDW)
Murphy Thrust
Stewart Thrust
Stewart Peak Ramp
Absaroka Thrust
Grand Valley Normal Fault
Stewart Thrust
Star Thrust
0 0.5 1 2
Km
N
Group 1
Group 5
Group 2
Group 3
Group 4
Thrust Transport
Group 3
Group 4
Group 2
Group 1
Group 5
Hinge
Legend
GPS Points
Fracture Station
Breccia Pipe
Fault Contact
Fracture Swarm
Altered/Bleached Zone
Sample Station
Travertine Spring
Faults
Lineaments
Average Intensity
Group 5 Fractures
High : 21
Low : 0
By Helen Lynn June, 2011
DEM from <seamless.usgs.gov>

Stewart Peak Culmination



Stereonet projection of poles to fracture surfaces from the Stewart Peak Quadrangle

Haystack Peak Region

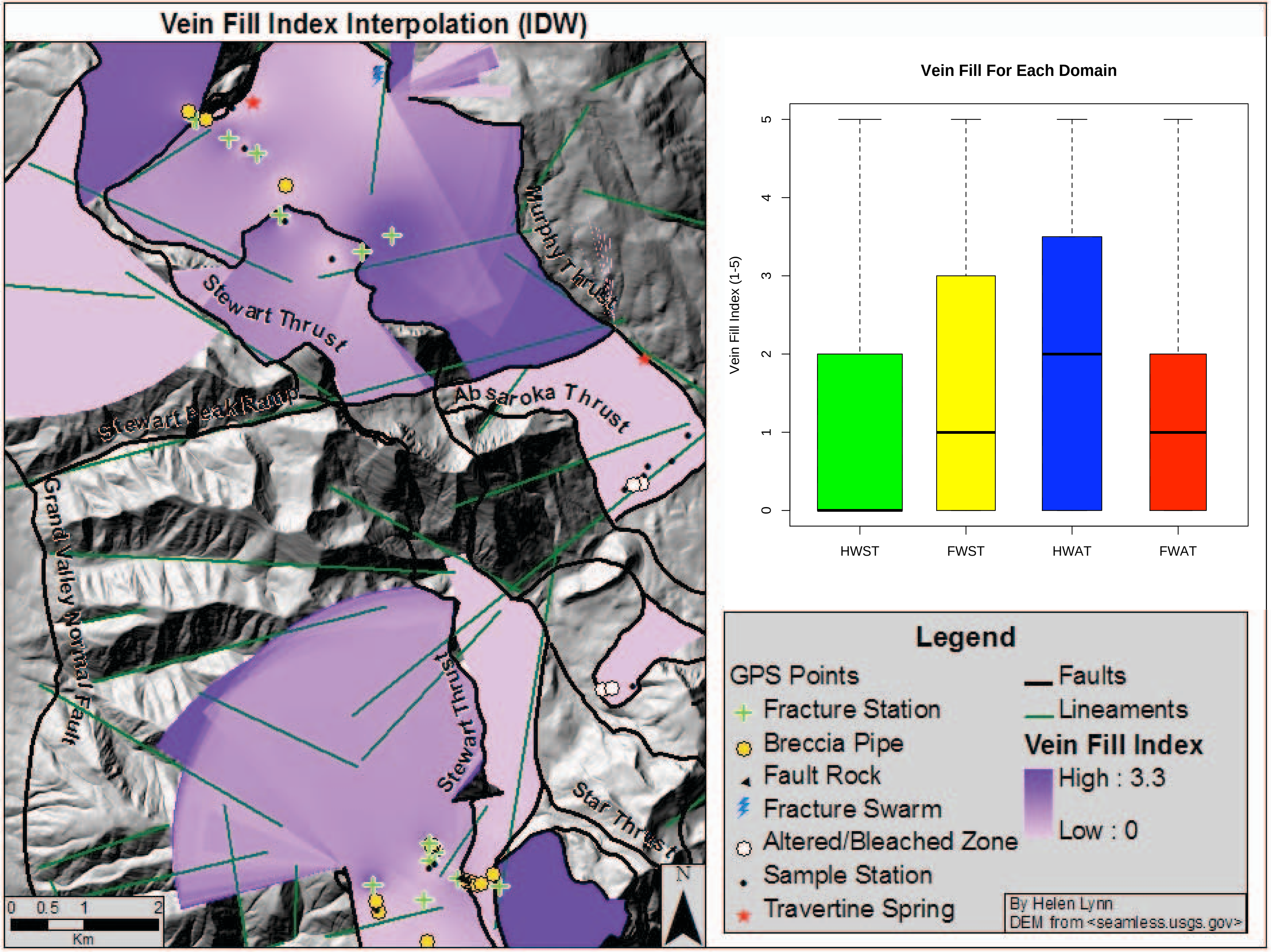


Stereonet projection of poles to tectonic surfaces from the Haystack Peak region (modified from Budai and Wiltschko,1987)

Fractures geometrically fit with Sevier deformation and are consistent with the regional tectonic fabric

What is the relationship between deformation, and fluid migration in the Culmination?

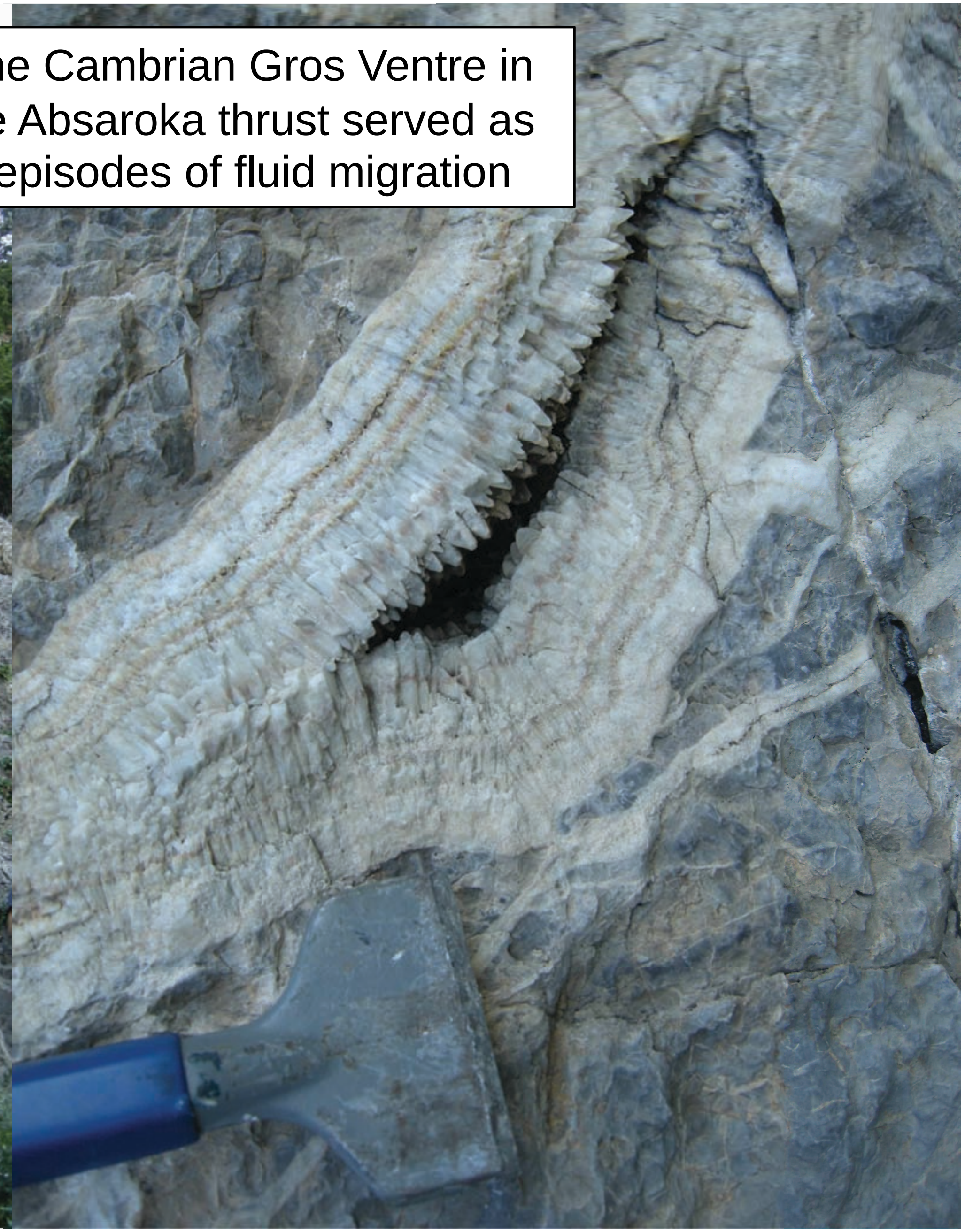
Structural Controls, Timing, Diagenesis

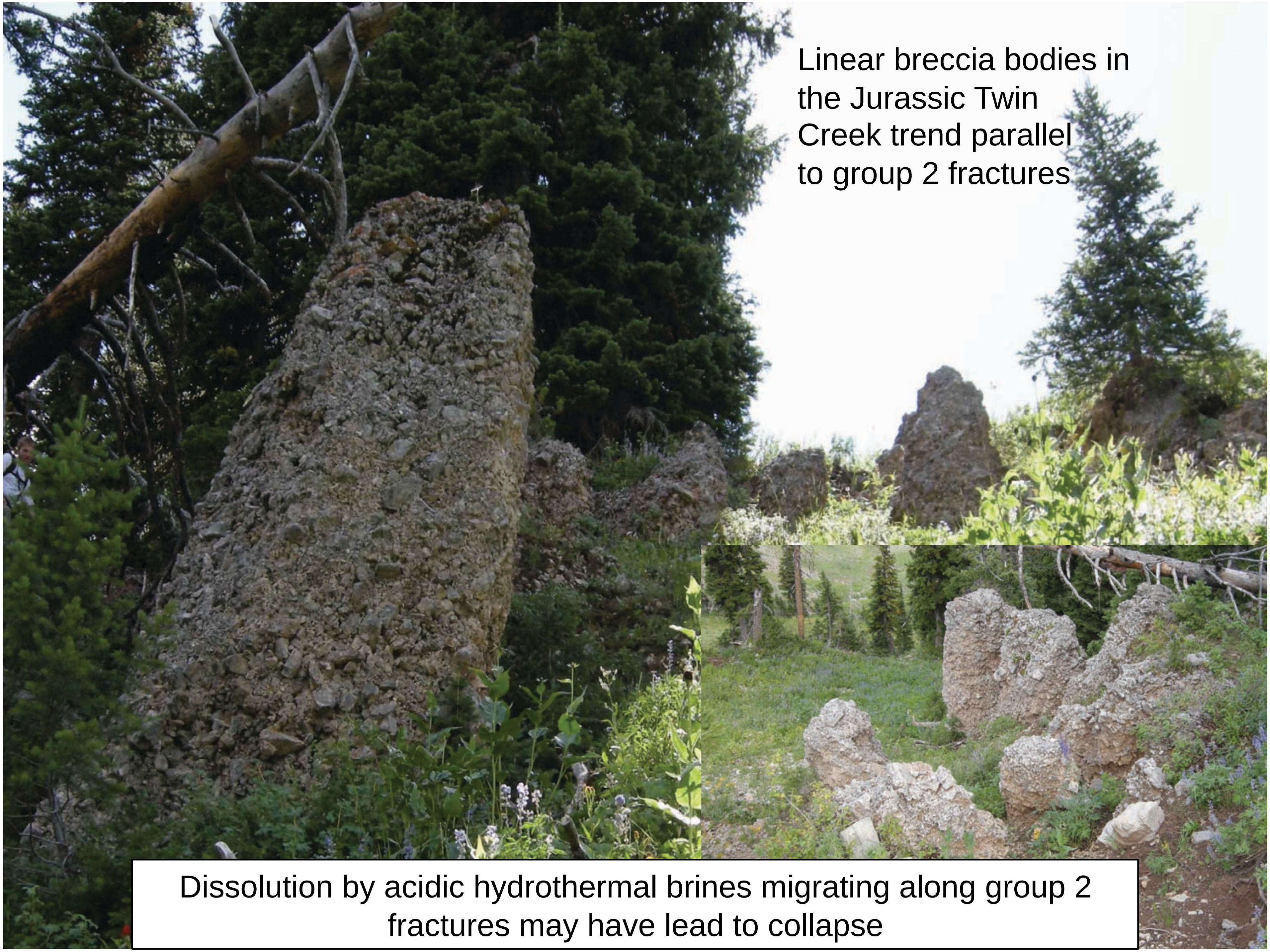


Vein Fill Index Interpolation (IDW)
Murphy Thrust
Stewart Thrust
Stewart Peak Ramp
Absaroka Thrust
Grand Valley Normal Fault
Stewart Thrust
Star Thrust
0 0.5 1 2
Km
N
Vein Fill For Each Domain
Vein Fill Index (1-5)
0
1
2
3
4
5
HWST
FWST
HWAT
FWAT
Legend
GPS Points
Fracture Station
Breccia Pipe
Fault Rock
Fracture Swarm
Altered/Bleached Zone
Sample Station
Travertine Spring
Faults
Lineaments
Vein Fill Index
High : 3.3
Low : 0
By Helen Lynn
DEM from <seamless.usgs.gov>

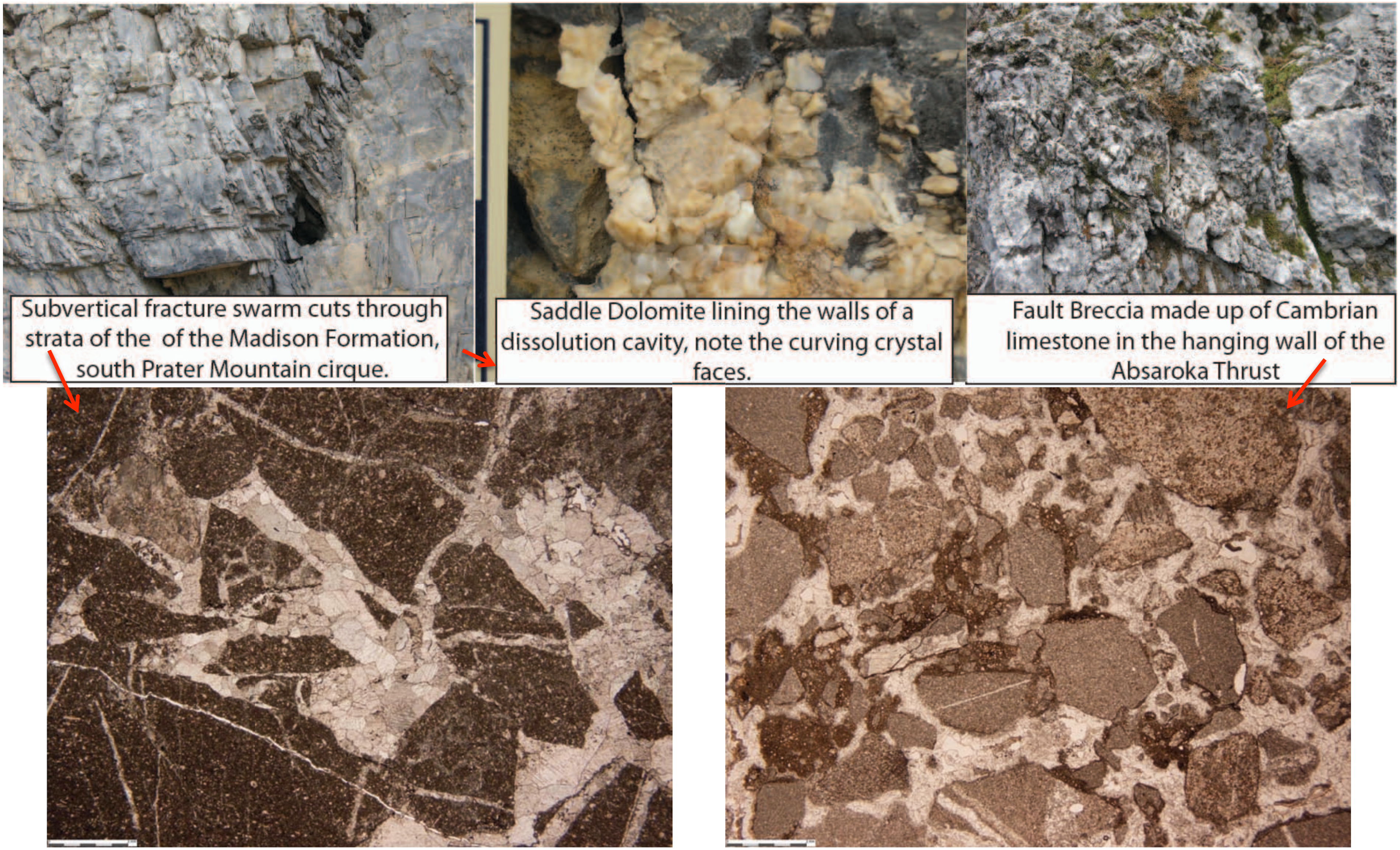
Major Fluid Conduits

Group 3 fractures in the Cambrian Gros Ventre in the hanging wall of the Absaroka thrust served as conduits for multiple episodes of fluid migration



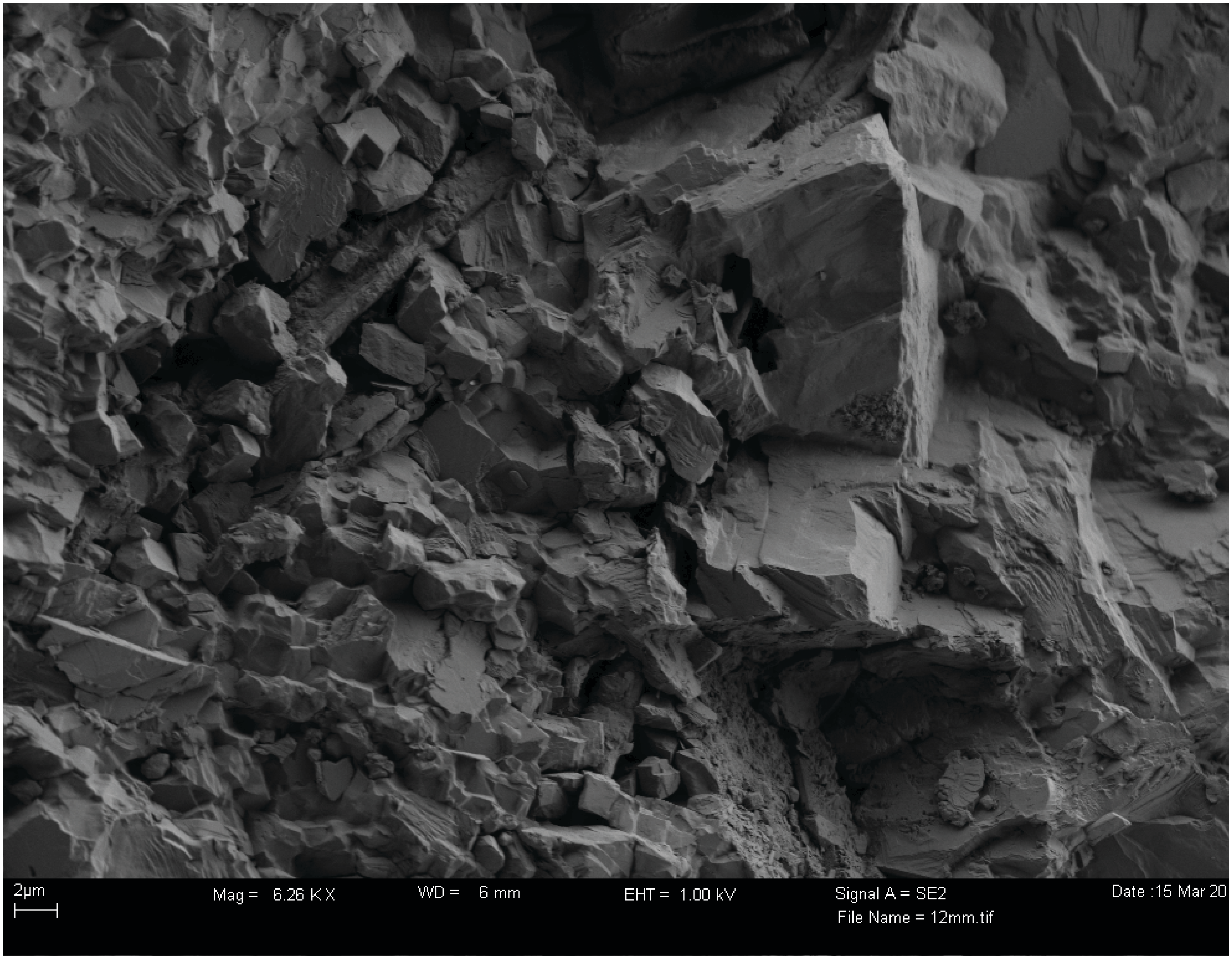

Linear breccia bodies in the Jurassic Twin Creek trend parallel to group 2 fractures
Dissolution by acidic hydrothermal brines migrating along group 2 fractures may have lead to collapse

Fracture Swarms and Fault Damage Zones



Dilational strain creates fluid migration pathways

FEM image of saddle dolomite from the Madison fracture swarm

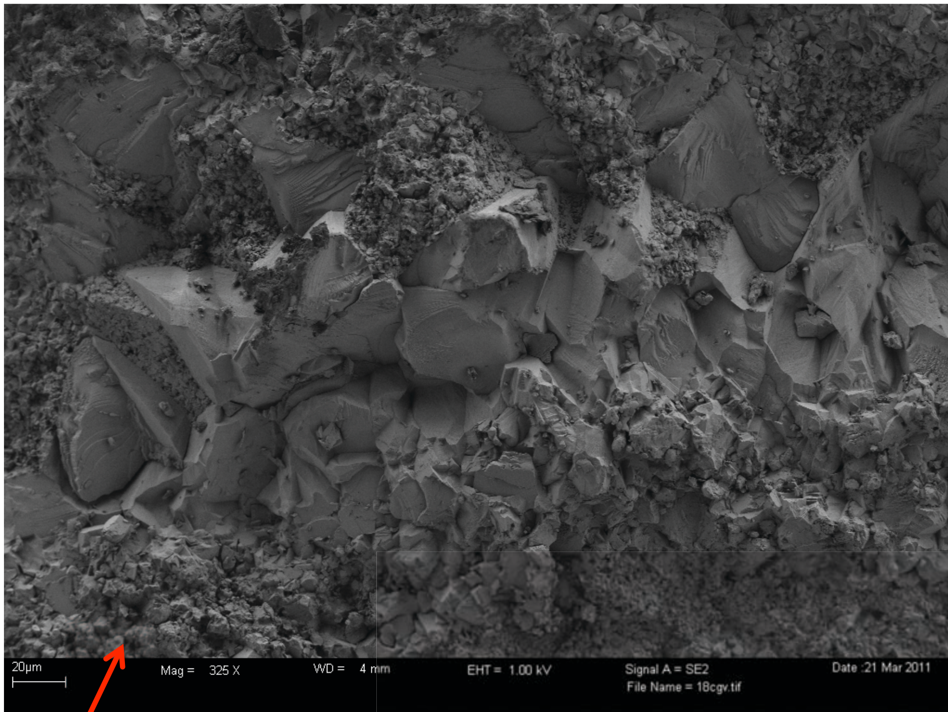


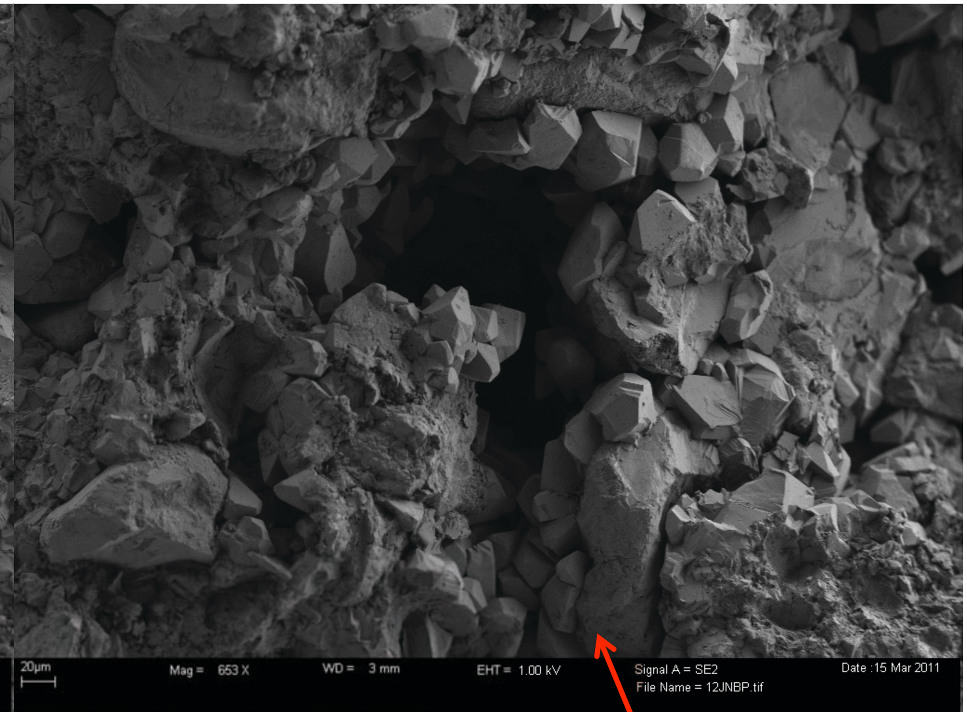
[illegible]

- [illegible]
- [illegible]

Funnel shaped Breccia Pipe in the Cambrian Gros Ventre formation, the Hanging Wall of the Absaroka Thrust, Stewart Creek Recess.

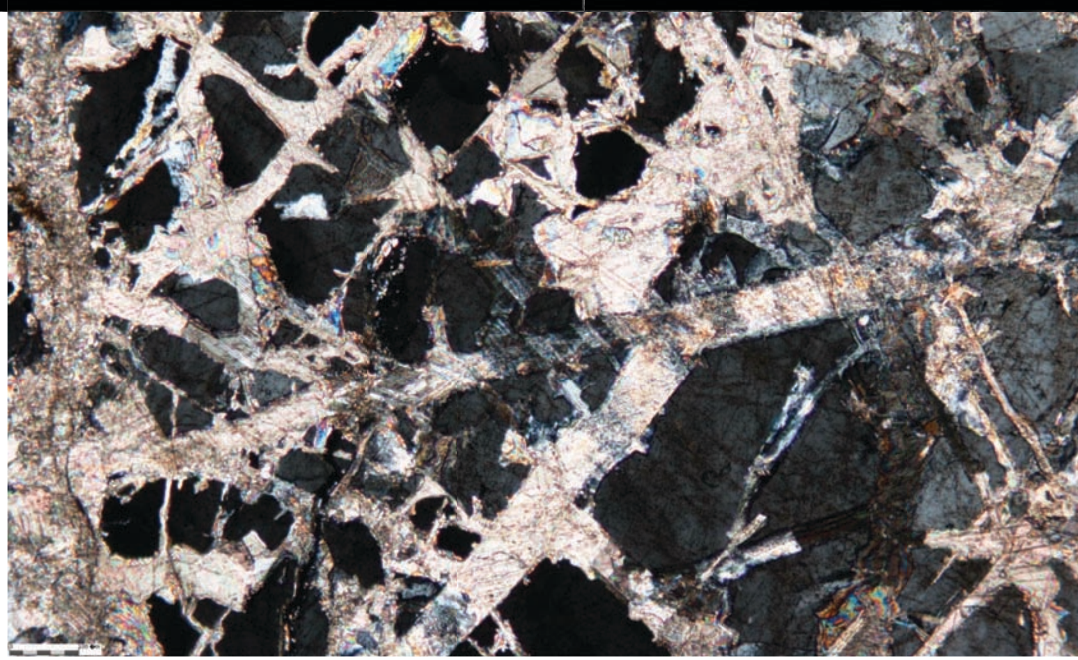
Breccia pipe in the Jurassic Nugget formation, footwall of the Absaroka Thrust





Vein filled with course saddle dolomite from the Gros Ventre breccia pipe in the Hanging wall of the Absaroka Thrust

Herkimer Quartz crystals in the Nugget breccia pipe



Floating-clast breccia fabric indicative of CO_2 boiling

Outcrop-Scale Alteration of Siliciclastic Rocks

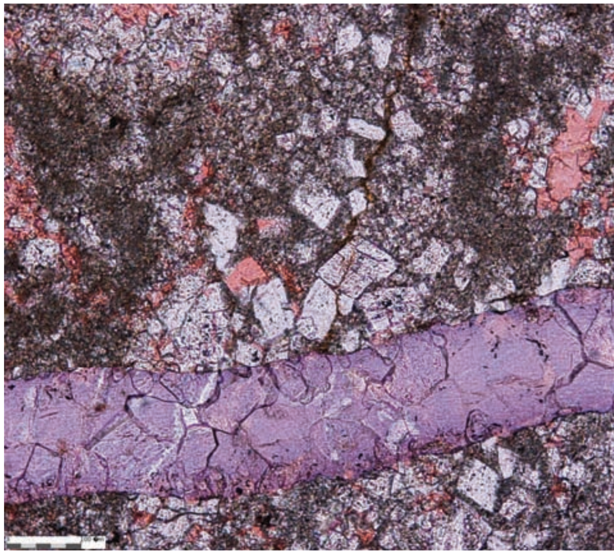
Bleached Nugget Formation with spotty hydrocarbon staining and bitumen residue

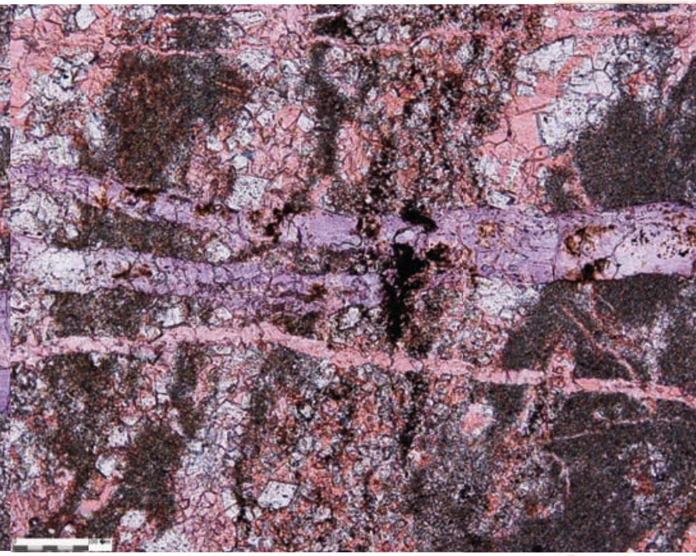
Footwall of the Absaroka Thrust

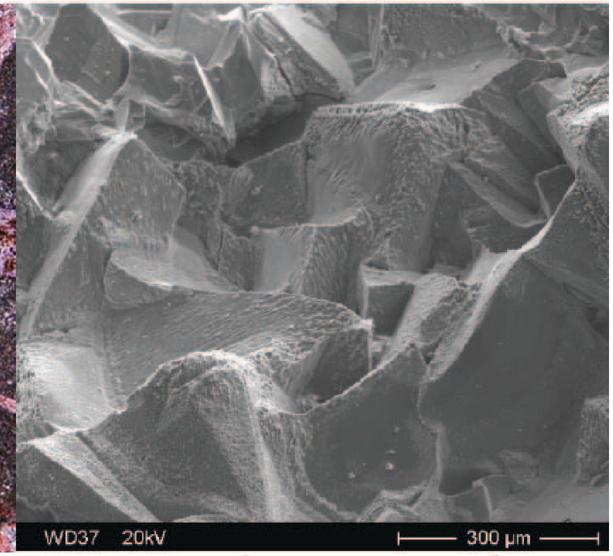
Bleached Wells Formation with extensive alteration and recrystallization of host rock and numerous herkimer quartz crystals

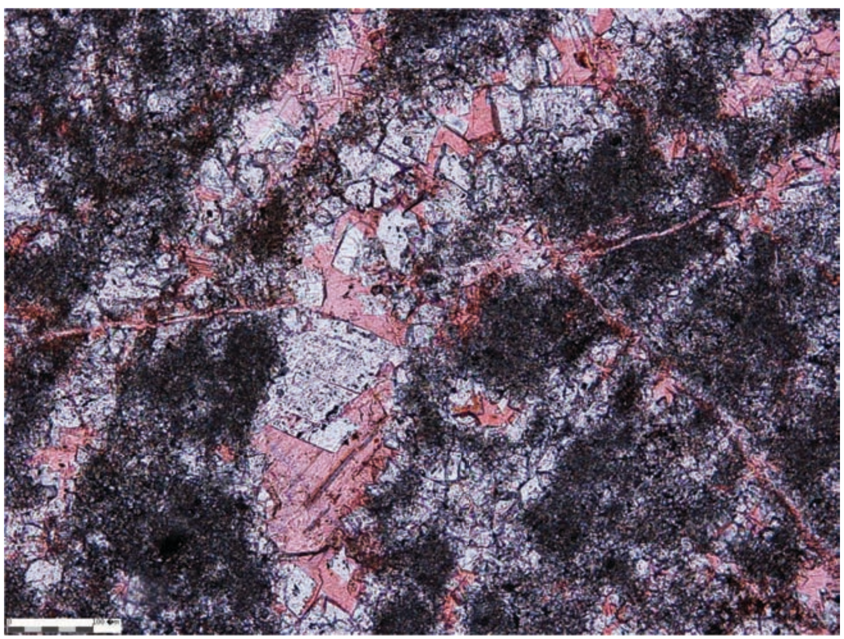
Footwall of a major hanging wall imbricate of the Absaroka Thrust

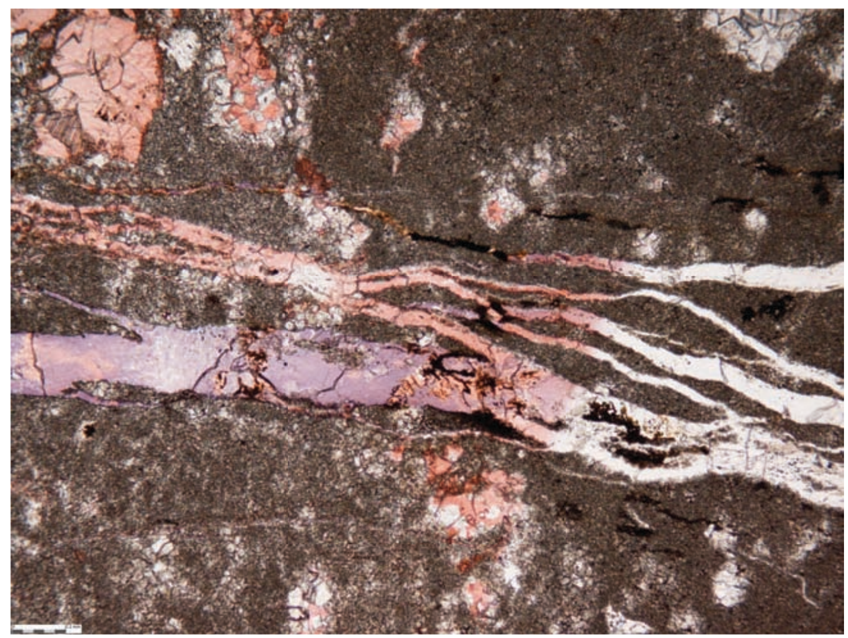
Petrography – Jurassic Twin Creek











Conclusions

- **Geometry of most fractures fit with Sevier tectonic deformation:**
  - **Group 3 ⇨ mode I extension fractures parallel to thrust tectonic transport**
  - **Group 3 ⇨ parallels the SE Idaho Lineament and Stewart Peak Ramp**
  - **Groups 2 and 4 ⇨ conjugate shear set (mode II)**
  - **Group 5 ⇨ parallel to the hinge of the culmination**
  - **Group 1 ⇨ youngest, related to regional extension & unloading**
- **Groups 2, 3, and 4 ⇨ Linked, open fractures with crack-seal textures, and multiple generations of cement were likely the best fracture controlled fluid conduits.**
- **Displacement transfer zones also made good fluid conduits**
- **Episodic faulting maintained fluid flow conduits and enhanced fault fracture permeability**
- **Multiple episodes of fluid flow via fractures (mostly vertical) and breccia zones (including breccia pipes and fault damage zones)**
- **Late dolomitization hydrothermal fluids ⇨ saddle dolomite, sulfide minerals, herkimer quartz**
- **Hydrothermal breccia pipes cut through the Absaroka thrust**
- **Fracturing and brecciation were likely driven by the ascent of hydrothermal brine+CO_2+hydrocarbon solutions through the thrust sheets**
- **Active travertine springs ⇨ still an active fracture controlled CO_2 system!**


Questions?