FRACTURE ANALYSIS OF THE STEWART PEAK CULMINATION IN THE FOLD AND THRUST BELT OF WESTERN WYOMING: IMPLICATIONS FOR STRUCTURALLY CONTROLLED FLUID MIGRATION

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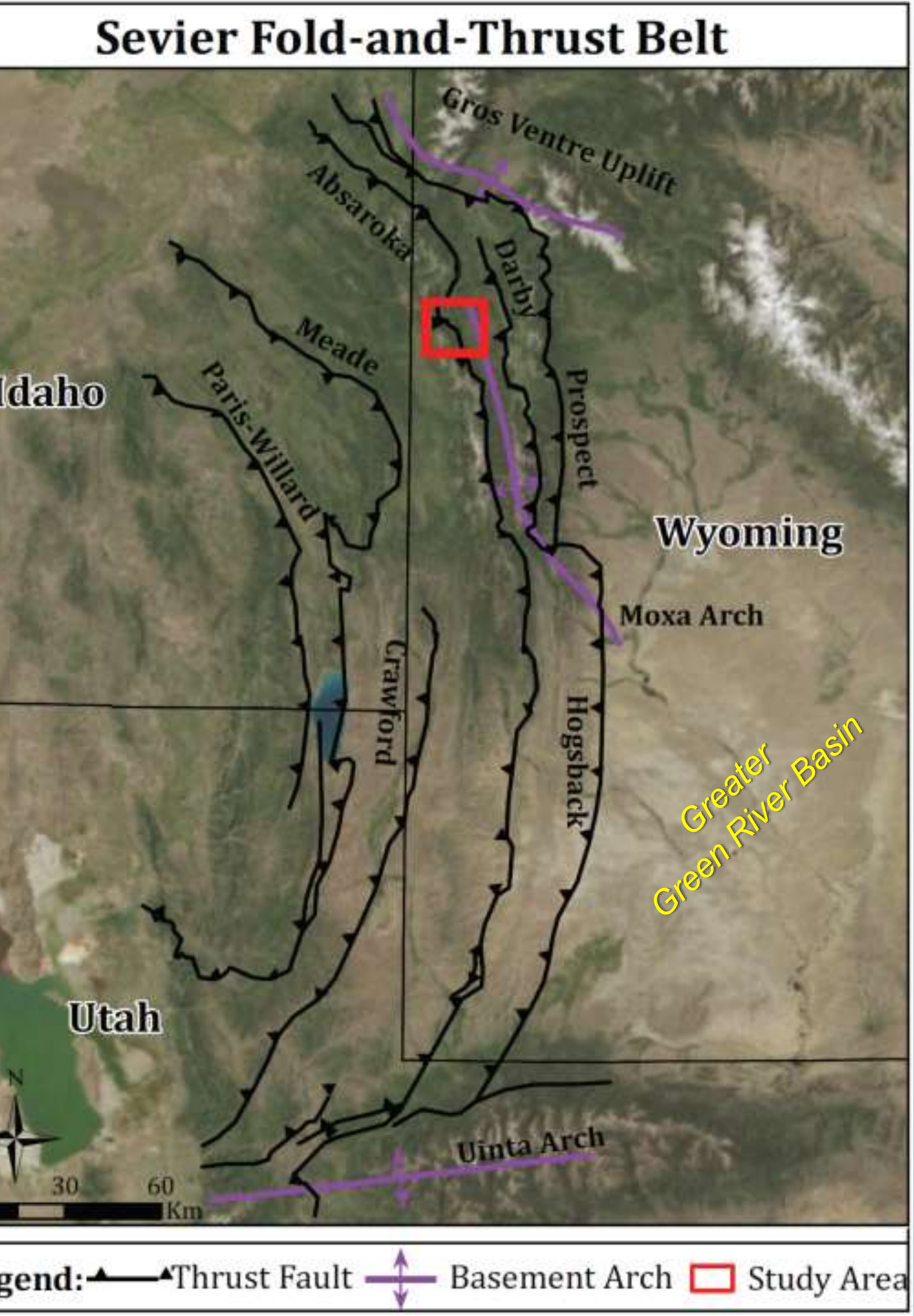
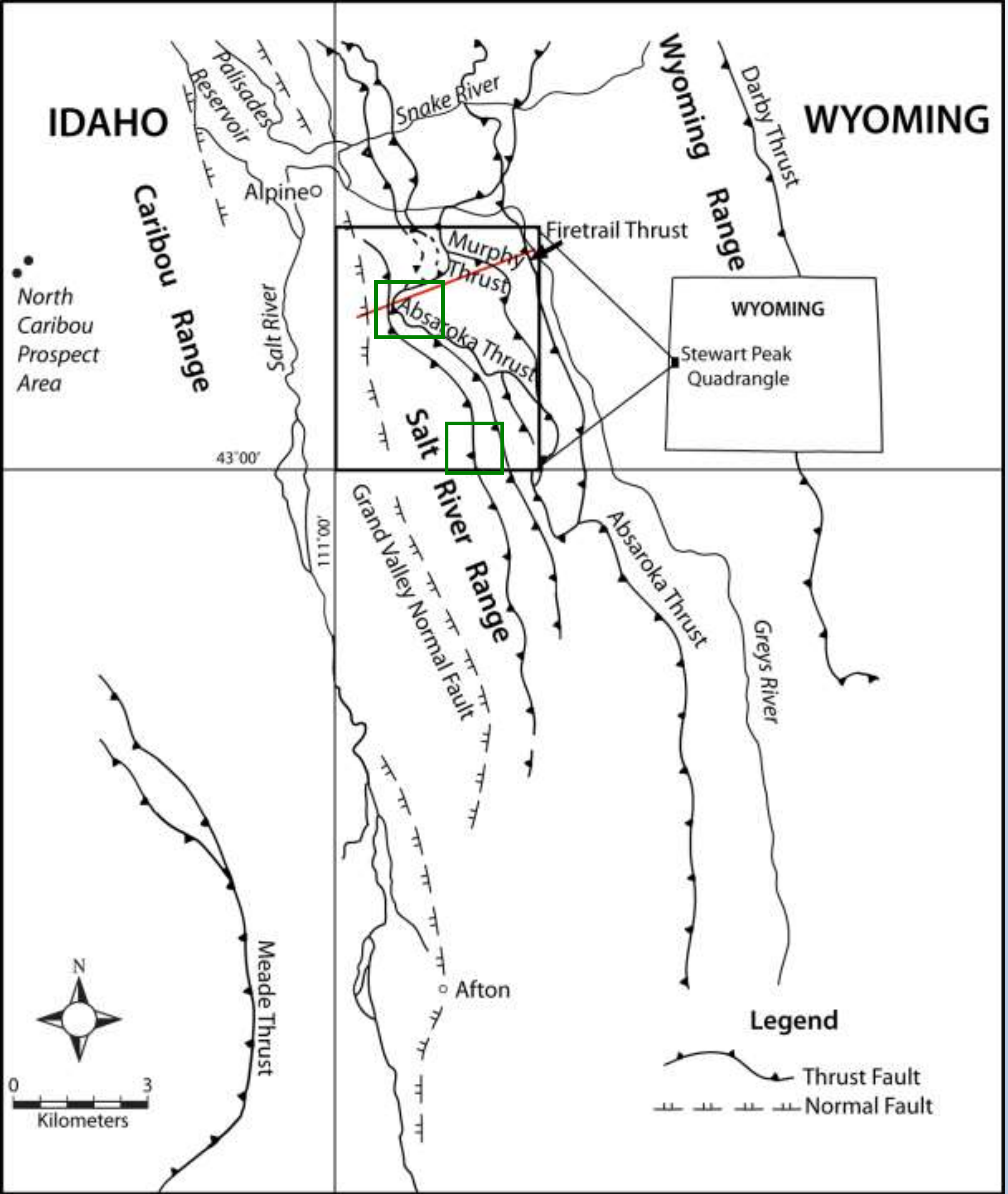
Introduction

- **<u>Purpose</u>:** Investigate the relationship between brittle deformation and subsurface paleo-fluid migration in the Stewart Peak Culmination in order to better understand factors controlling migration of fluids in complex fault zones
- The Stewart Peak Culmination (SPC) is a thrust-faulted duplex structure of the Absaroka thrust in western Wyoming
- Breached by erosion exposing the architecture of the duplex
- Exhumed nature allows for outcrop-scale investigation of fracture systems and analysis of the relative timing of faulting, fracturing, fluid migration and structurally controlled diagenesis
- Geometry, connectivity and extent of fracture systems can control fluid migration pathways in complex structural traps



Background

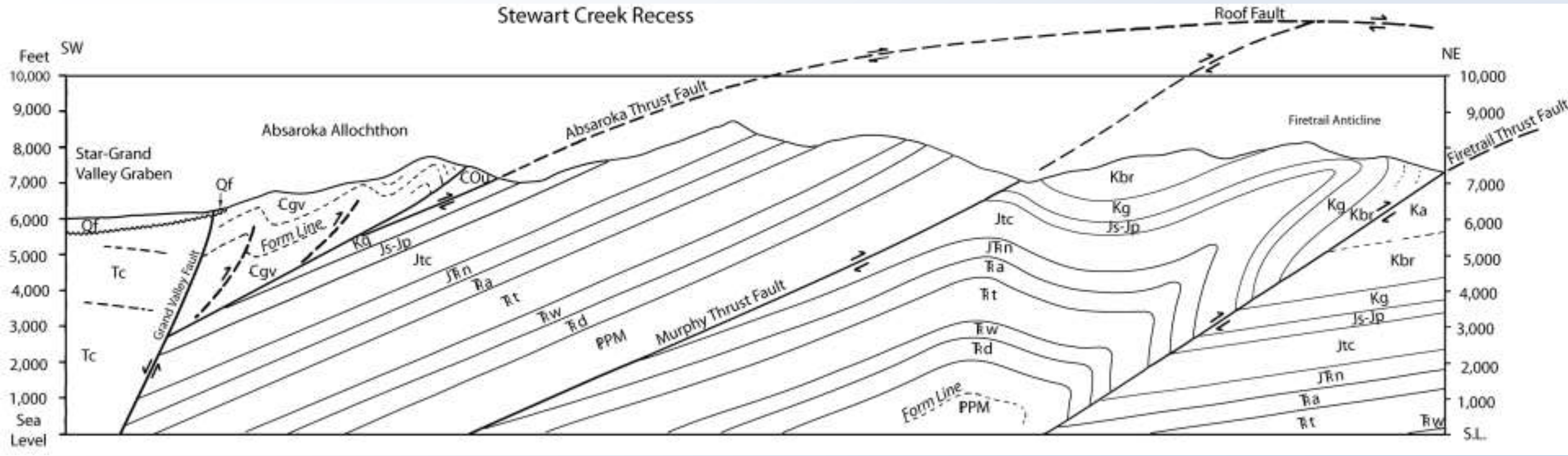
- The Absaroka Thrust is one of five major thrust sheets of the Sevier fold-and-thrust belt
- The culmination is a structural and topographic high-point of the Absaroka thrust sheet
- Structural relief is the result of thrusting up and over a major footwall ramp, footwall duplexing and the presence of a basement arch
- The culmination has been uplifted and eroded as a result of Neogene extension
- The culmination forms a re-entrant in the surface trace of the Absaroka Thrust



- Fracture studies were focused on the Absaroka thrust in the Stewart Creek recess and the Stewart thrust in the Prater Mountain area to the south (green boxes)

- The Stewart Creek recess marks the apex of the culmination

- This recess provides a window into the geometry of the culmination



Cross-section through the Stewart Creek Recess (from Lageson, 1980)

•Duplex traps are structurally complex, but can make excellent subsurface oil and gas traps

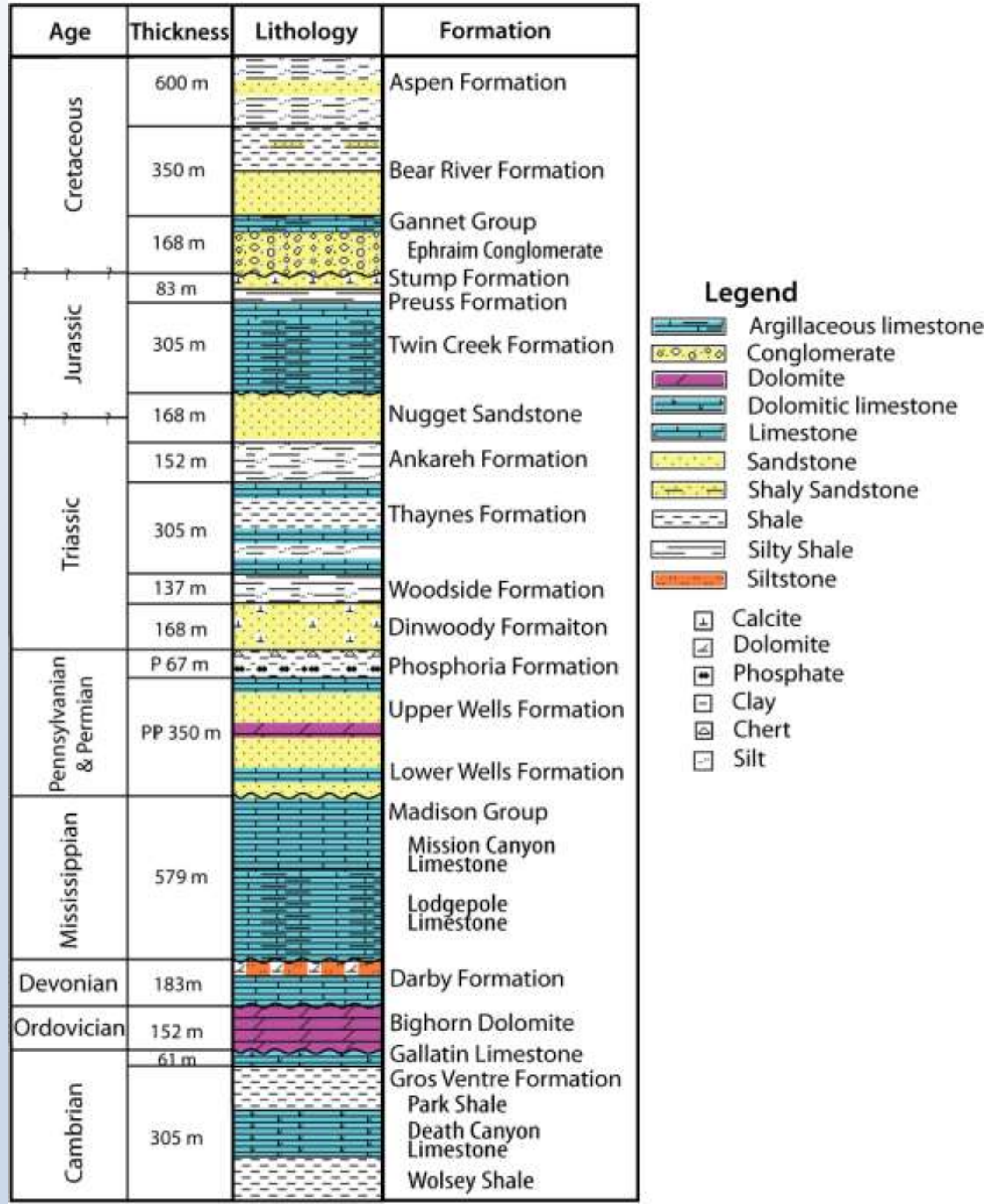
•Components of a duplex fault zone ➔ roof thrust, floor thrust and internal imbricate thrusts

•Stacked structural horses (Murphy and Firetrail thrusts sheets)

The culmination exposes structures and reservoir rocks analogous to those found in nearby subsurface hydrocarbon and CO_2 traps, such as the Moxa Arch as well as tightly folded anticlines and duplex structures found throughout the fold and thrust belt

Oil & gas reservoirs in the fold & thrust belt (Powers,1995)

Stratigraphic Section for the Stewart Peak Quadrangle



Methods

•Fractures were measured using the selection method (Davis and Reynolds, 2007) to visually pick out **dominant systematic** fractures

•Attributes of fractures recorded:

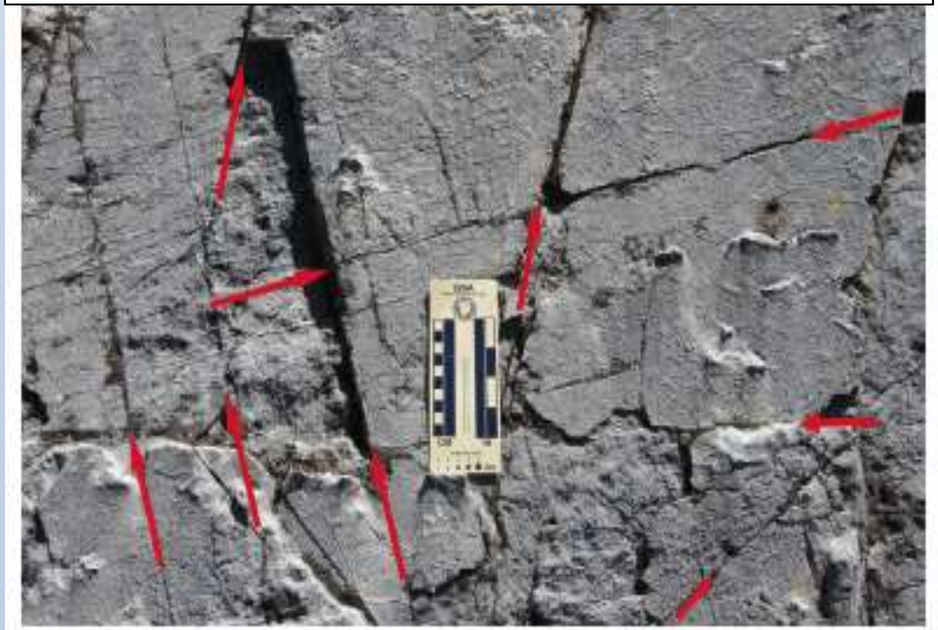
Station Name	Strike	Dip direction	Dip	Length cm	Aperture mm	Spacing cm	Vein Fill Index	Structural Domain	Lithology
710sta1 obfwst	44.3	134.3	36	500	3.5	122	2	FWST	OB

•Descriptive analysis of fault zones, breccia pipes, and fracture swarms.

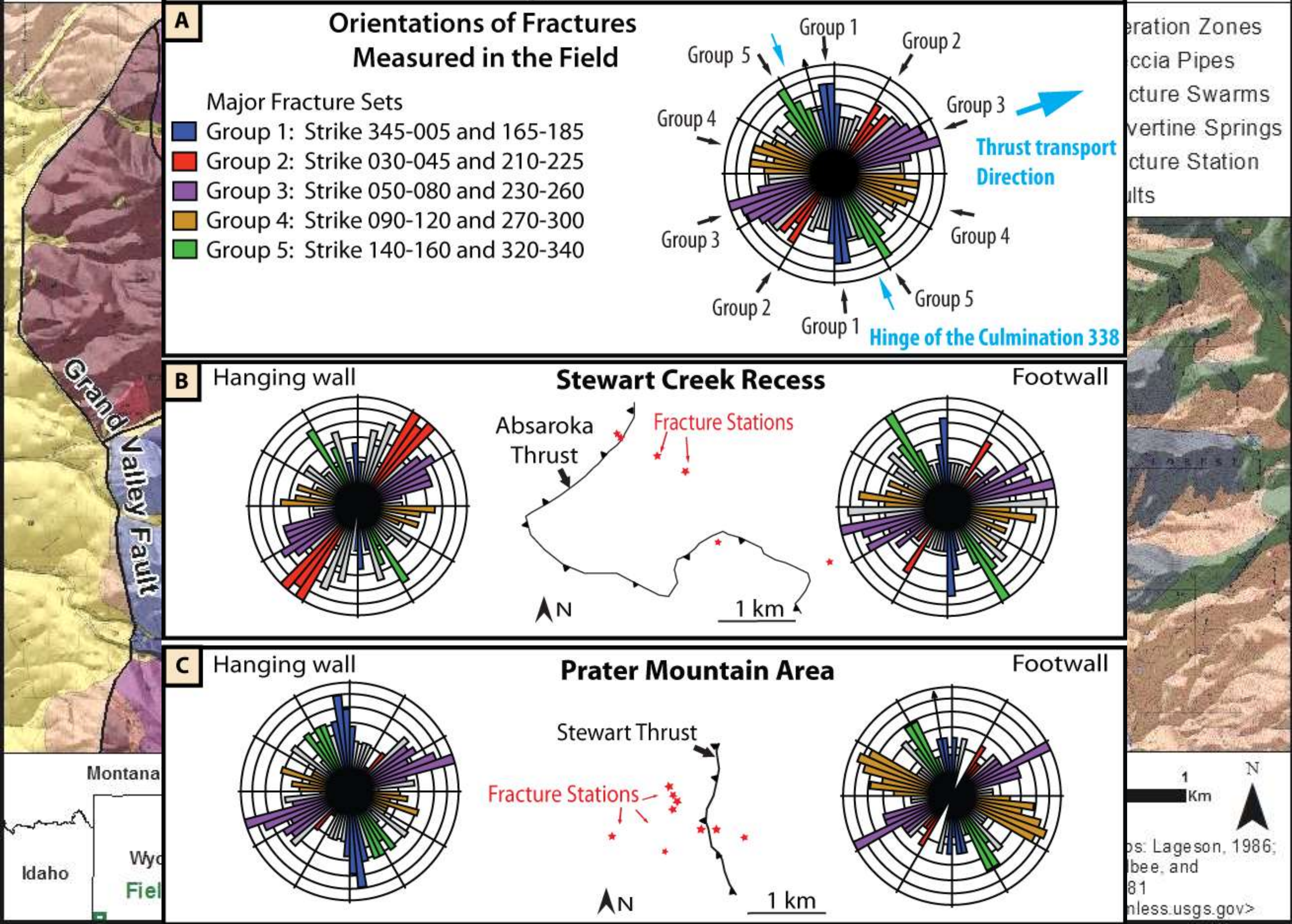
•Geometric, kinematic and statistical analyses of fracture data

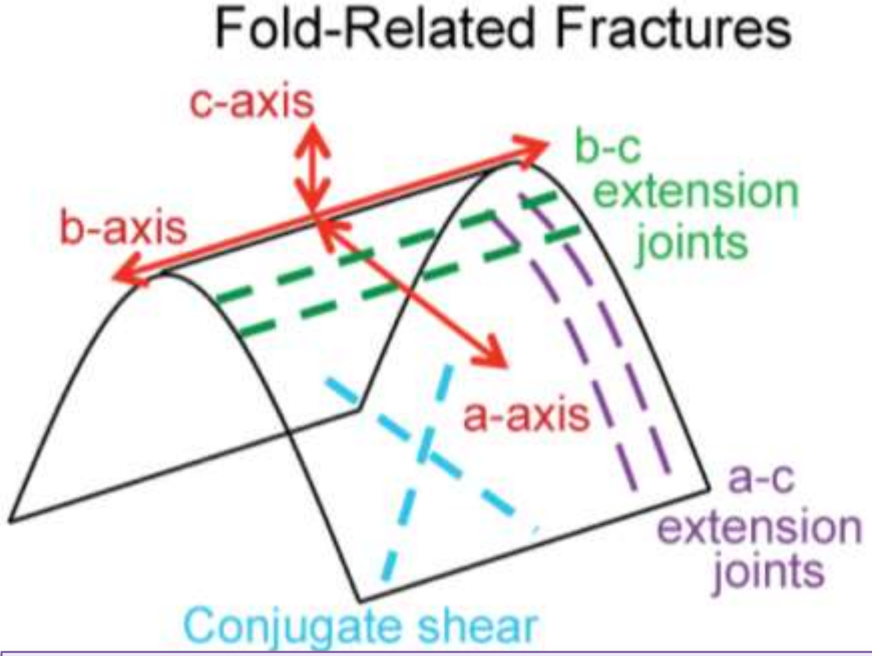
•Thin section petrography augmented with carbonate staining, **FEM and SEM** imaging ➔ structurally controlled late-stage diagenesis

Systematic fractures - Cambrian Gros Ventre Formation (footwall of the Stewart Thrust)



Rose Diagrams of Fracture Data





•Fracture sets in folded strata are generally systematically oriented about the fold

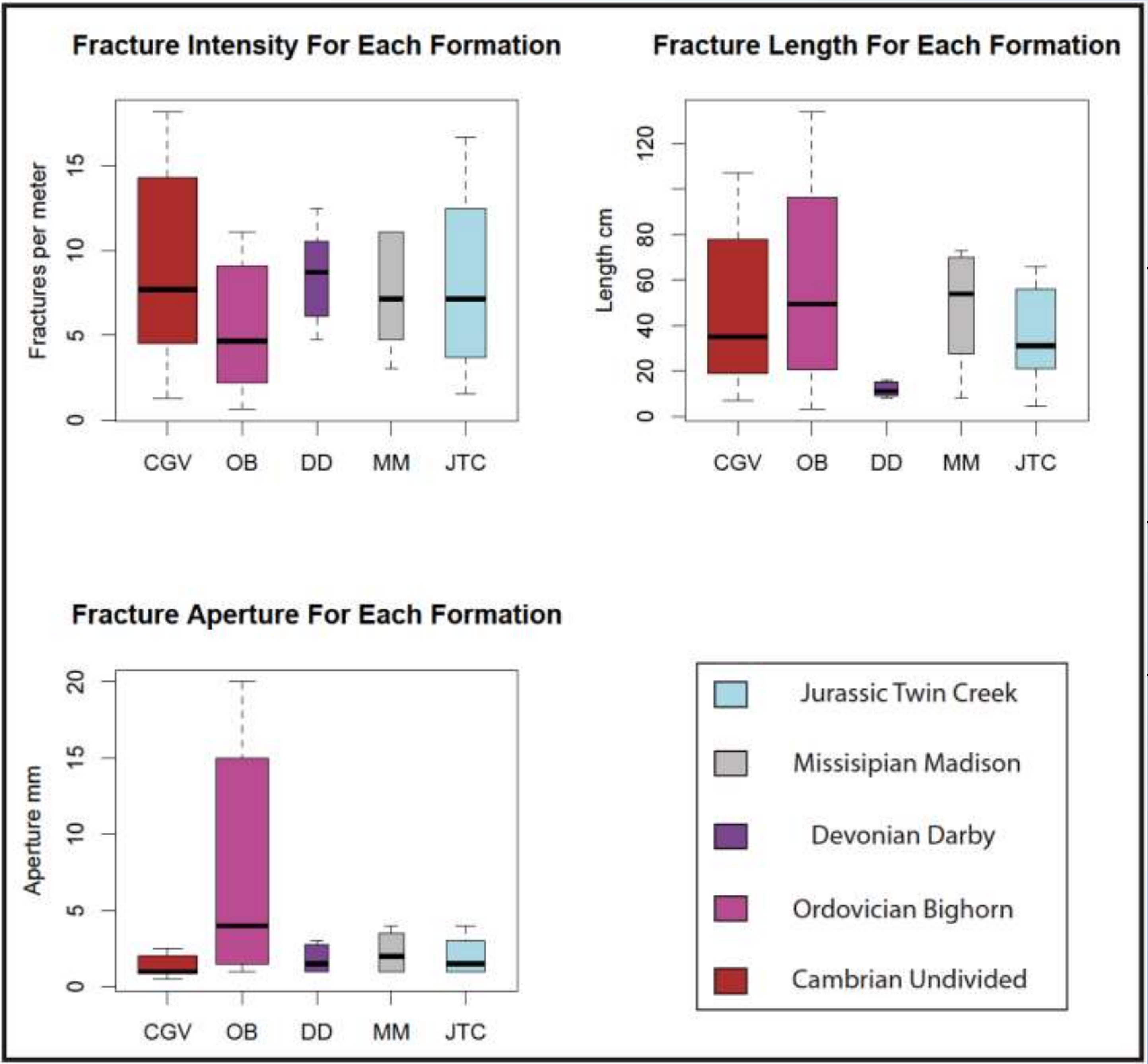
•**a-c joints**: Mode I tensile fractures parallel to the tectonic compression

fractures parallel to the fold

Group 3: formed early ➔other fractures terminate against these or offset them (if sealed)
Groups 2 & 4: formed synchronously-possibly postdating Group 3
Groups 1 & 5: formed late, sometimes reactivate tectonic stylolites

- Group 3: a-c extension joints parallel to tectonic transport
- Groups 2 and 4: conjugate or oblique fractures
- Group 5: b-c extension joints parallel the hinge of the culmination
- Group 1: b-c extension joints parallel the hinge of the Prater Mountain anticline; may also be associated with recent, east-west extension -they parallel the Grand Valley normal fault and are favorably oriented for reactivation

Fracture Attributes



Statistically, **lithologic unit** is the most important controlling factor on fracture attributes, and **best explains the variability** of those attributes based on analysis of variance (ANOVA) F-tests of multiple linear regression models

Fault Zones

•Planar faults ➔ Localized deformation characterized by grain-size reduction, which can hinder fluid flow

•Anastomosing faults ➔ Distributed deformation with well-developed damage zones, which can create complex permeability networks that facilitate fluid flow

•Episodic deformation ➔ Fault zone permeability was maintained with limited cementation and sealing due to repeated fault rupture

Small-Scale Imbricate thrust in the Prater Mountain area places Gros Ventre over Bighorn.

Anastomosing slip surfaces make up this small fault zone in the Cambrian Gros Ventre in the hanging wall of the Absaroka Thrust

Brittle Fault Zone Components

- **Core zone ➔** intense cataclastic deformation
- **Damage zone ➔** surrounds the core zone, less intense deformation characterized by fracture networks
- **Process zone ➔** zone of microfractures ahead of the fracture tip (frictional breakdown zone)

- Ratio of the **damage zone width to the total fault zone** width (F_a) provides an estimate of the amount of strain localization versus distribution within a fault zone (Caine et al., 1996):

  F_a= damage zone width/total fault zone width
  - **Near zero ➔ fault damage zone is absent**
  - **Near one ➔ fault core is largely absent**

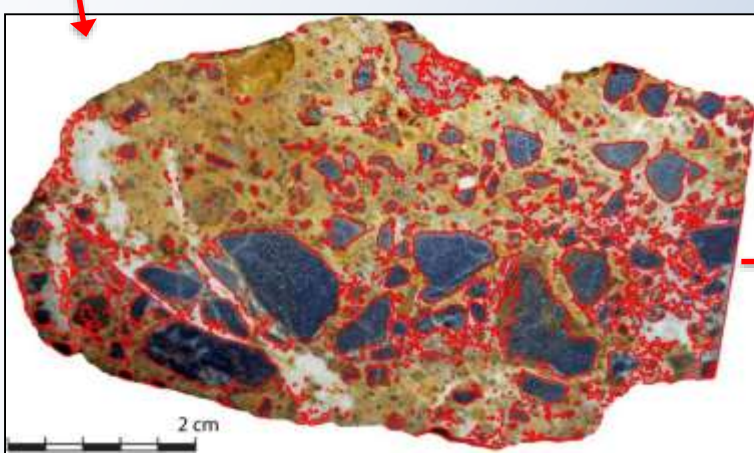
- Fault zones dominated by the fault core ➔ likely fluid flow barriers due to the lower permeability
- Fault zones dominated by distributed damage zones ➔ likely fluid conduits due to the higher permeability of the damage zone

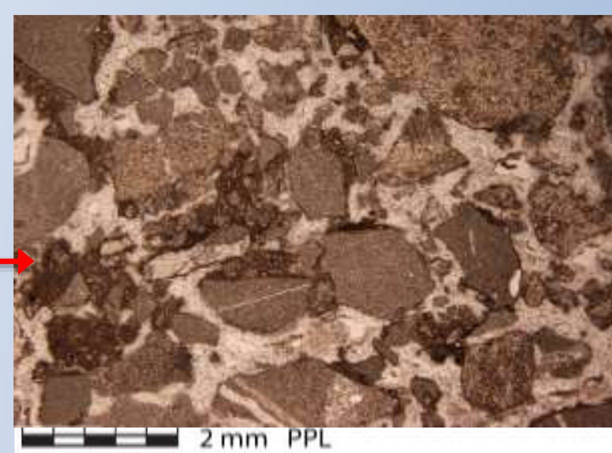
Absaroka Thrust - Stewart Creek Recess

- The damage zone ➔ Network of fractures, slip surfaces and veins
- Extends 25 m into the hanging wall
- Absaroka fault core ➔poorly consolidated fault breccia
- Core extends 4 m into hanging wall
- Fault zone ratio ➔ 0.84
- Likely a fluid conduit

Faults in the culmination are still active fluid conduits➔ springs located along faults precipitate travertine from CO_2-rich fluids

(After Lageson, 1980)

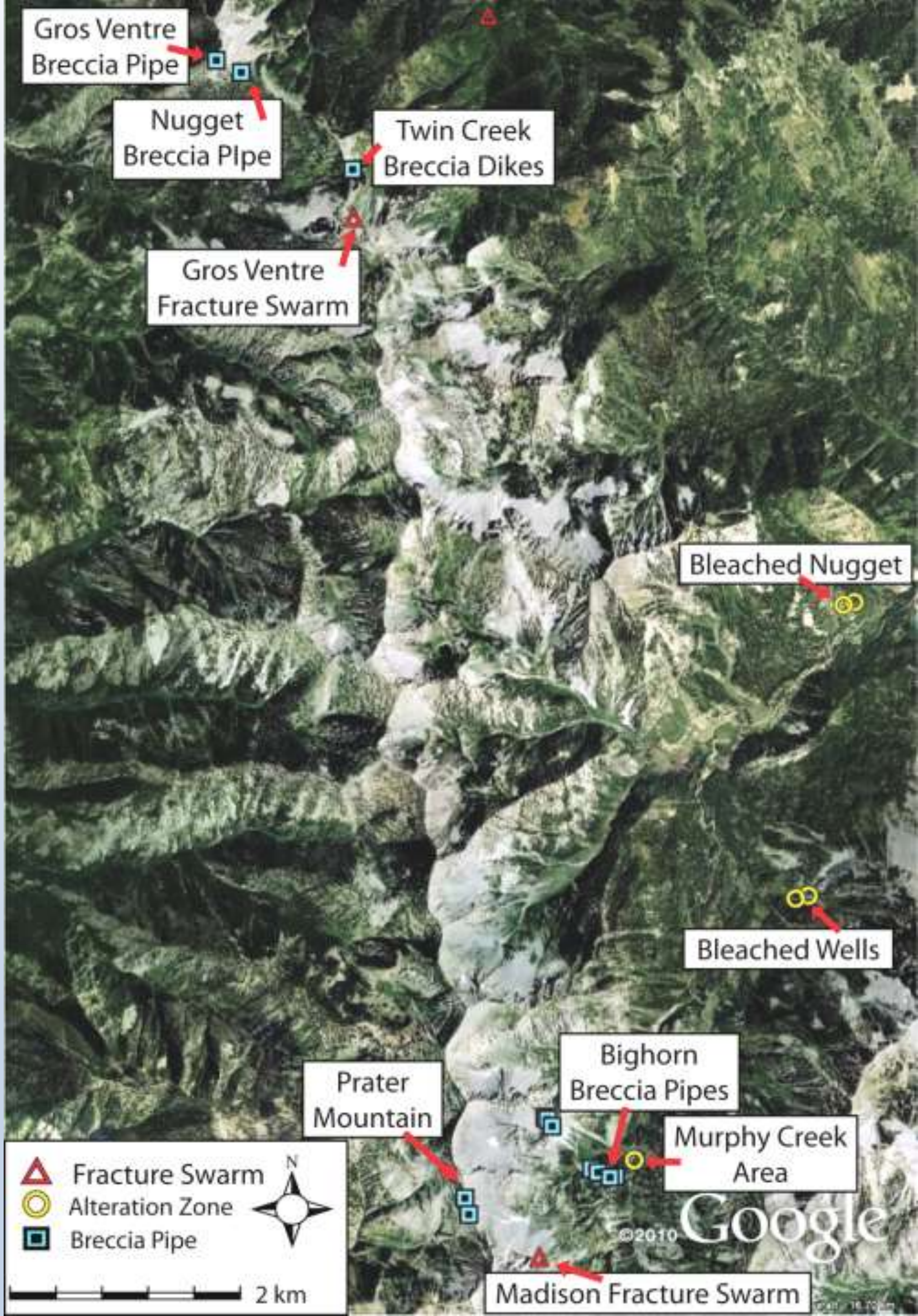




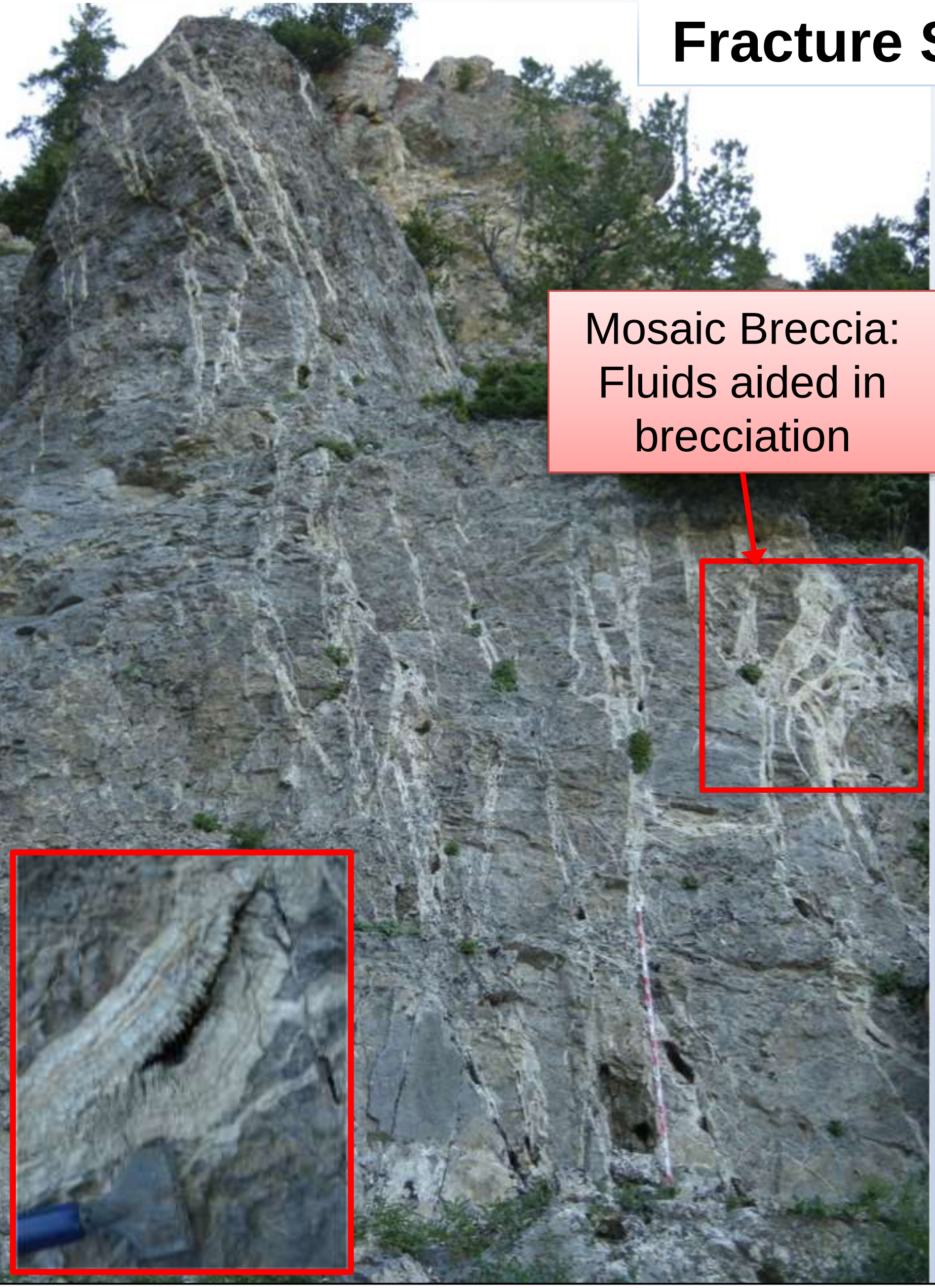
- Carbonate cements and recrystallization textures ➔ faults with well-developed damage zones facilitated multiple episodes of fluid migration

Focused fluid conduits identified in the culmination

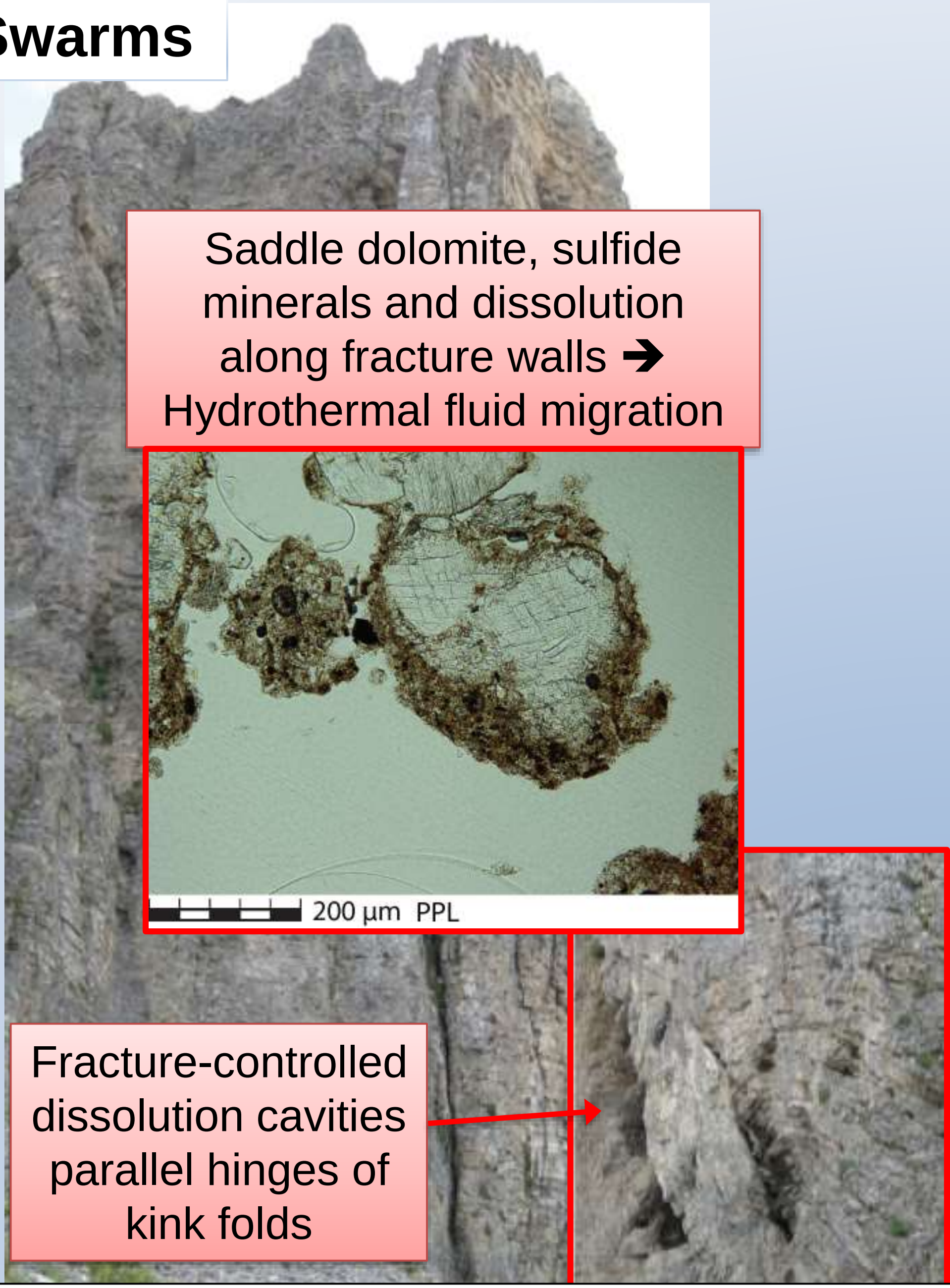
- Discrete breccia bodies are scattered throughout the culmination and include breccia pipes, breccia dikes and fracture swarms
- Breccia bodies served as focused fluid conduits and their formation was likely structurally controlled



Fracture Swarms



G3 fractures in the hanging wall, Absaroka thrust facilitated episodic fluid migration



G1 fractures in the hanging wall of the Stewart thrust served as fluid conduits

Breccia dikes in the Jurassic Twin Creek trend parallel group 2 fractures

Dissolution by acidic fluids migrating along group 2 fractures may have lead to collapse

Breccia Pipes

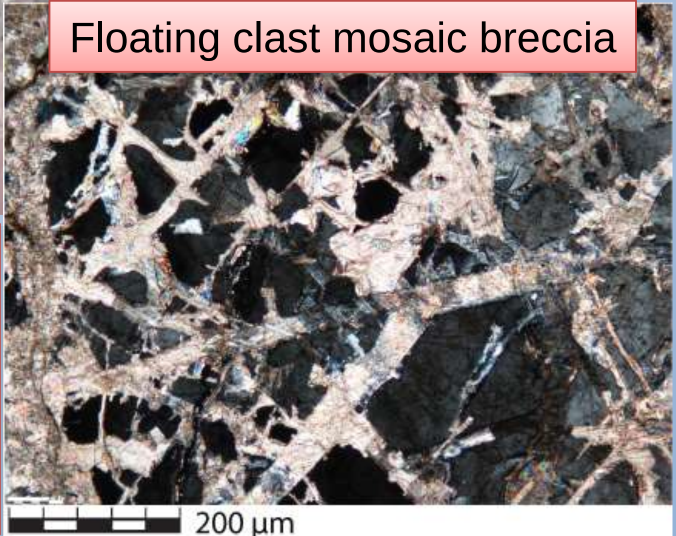
Gros Ventre Breccia Pipe

Funnel-shaped pipe ➔upward transport (Laznicka, 1988)

Bighorn Breccia Pipe

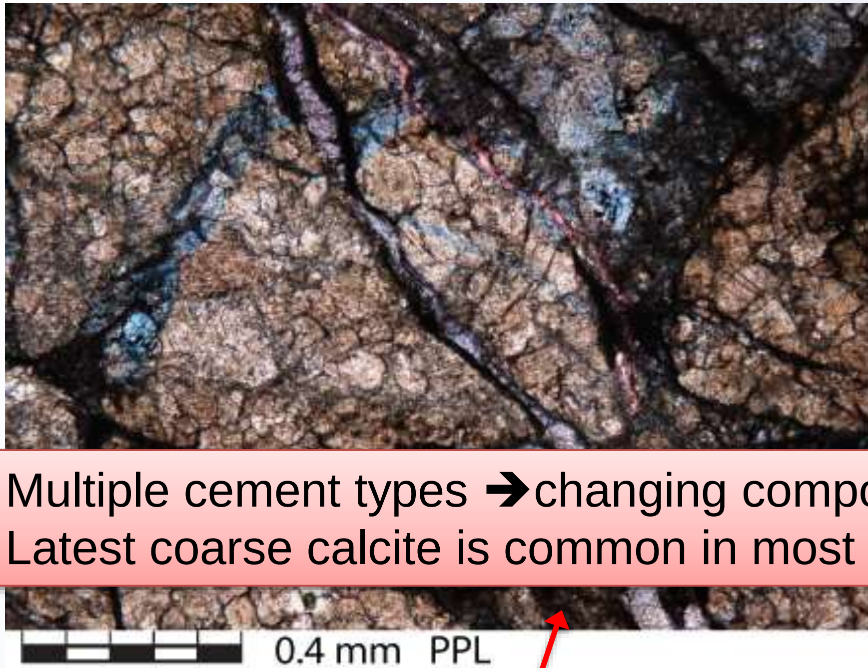
Nugget Breccia Pipe

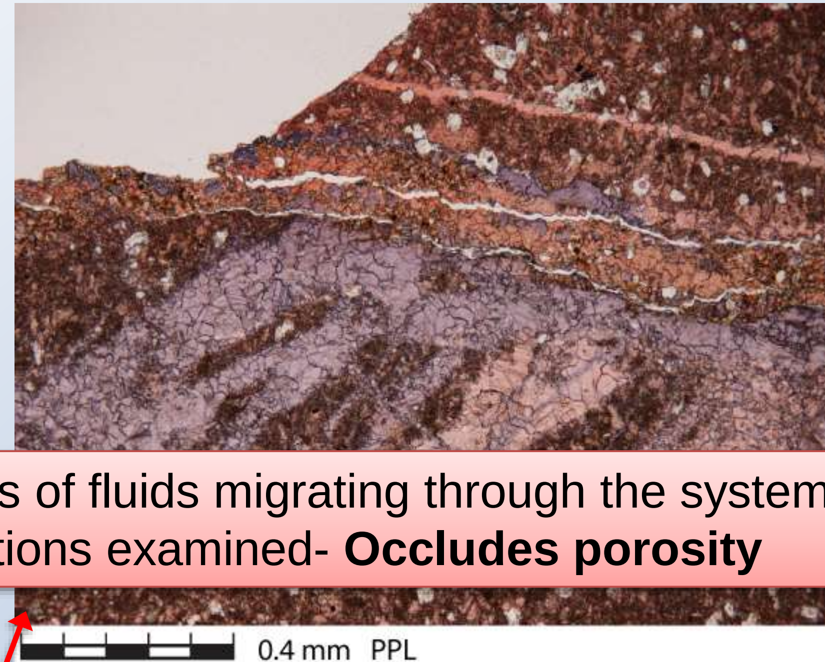
Boxwork fabric



The proximity of the Nugget breccia pipe in the footwall of the Absaroka thrust and the Gros Ventre pipe directly in the hanging wall, suggests that they are genetically related ➔ breccia pipes developed after final movement of the Absaroka thrust

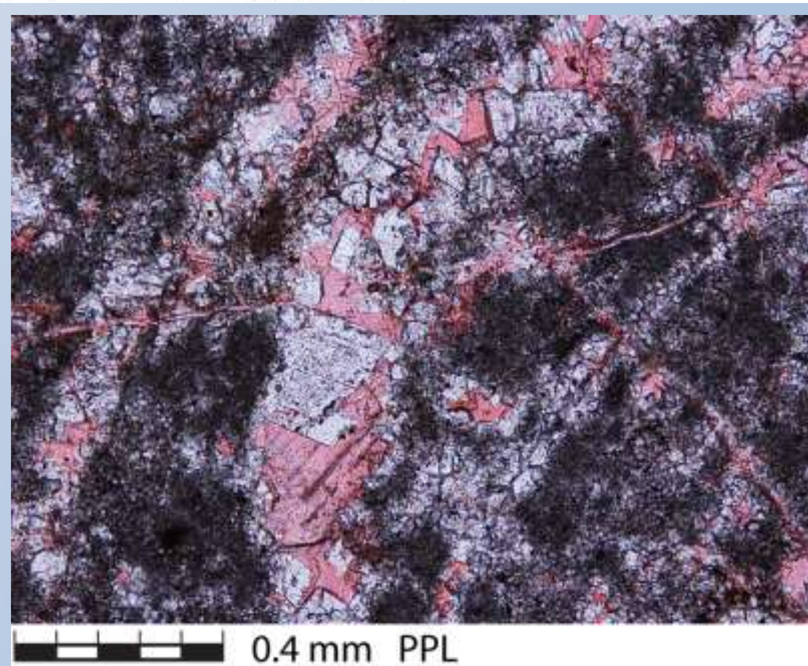
Structurally Controlled Fluid Migration





Multiple cement types ➔changing compositions of fluids migrating through the system
Latest coarse calcite is common in most formations examined- **Occludes porosity**

Gros Ventre Formation
Early Fe dolomite (teal), fracturing and shearing, Fe calcite (purple), latest coarse calcite (pink)
Madison Group: Fe calcite, later non-Fe calcite (pink)
Twin Creek Limestone: Dolomite precipitation, dissolution, cementation by late coarse calcite occludes porosity



Conclusions

- **Geometry of fractures fit with Sevier tectonic deformation**
- **Fracturing enhanced the secondary porosity and permeability of reservoir units, reducing vertical compartmentalization caused by lithologic changes**
- **Episodic faulting helped maintain fluid flow conduits and enhanced fault fracture permeability**
- **Fractures served as pathways for many fluid migration events including hydrocarbons, hydrothermal and CO_2 -rich fluids**
- **Hydrothermal and CO_2 -rich fluids can enhance permeability via the processes of dolomitization, dissolution and fluid-assisted brecciation.**
- **Fluids can decrease structural permeability and degrade reservoir quality by rapid cementation**
- **Fluid-assisted brecciation aided in formation of breccia bodies that appear to be associated with systematic fracture sets**
- **Favorably oriented Sevier Faults/Fractures have been reactivated by Basin and Range Extension and continue to control fluid migration pathways as evidenced by active travertine springs.**

Questions?