FRACTURE PATTERN VARIABILITY IN THE ENTRADA FORMATION IN THE MOAB AREA, UTAH

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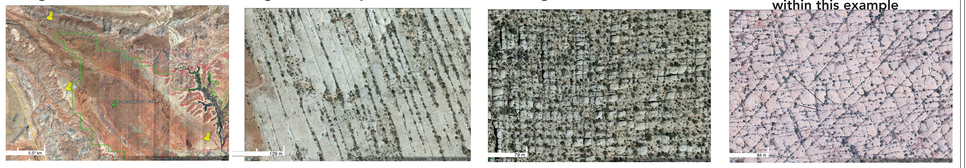
Abstract: Analysis of fracture traces in Google Earth led to field work concentrated in the Castle Mesa area and the NW end of the Arches anticline. Extensive bedding plane exposures of the Moab Tongue Member (MTM) presents an opportunity to see variation of within unit fracture patterns. Multiple episodes of mainly Cenozoic age salt tectonics and related faulting contributed to fracturing. Overall variation in the MTM of joint patterns a spans area dominated by one joint preferred orientation versus those with up to 3. In contrast, the underlying Slickrock can be devoid of joints, or has a much lower overall joint density, often in one dominant direction. Facies variations within the MTM influence fracture development, with 3 discernable sub-units. Stereoplots from field work show three distinct joint sets which include a dominant subvertical set running ≈E-W with an antithetic orthogonal set, and a more locally developed additional NE-SW joint set. Deformation bands formed first, followed by the E-W joints, and lastly the N-S set. A singular-appearing fracture in Google Earth was often a cluster of joints and deformation bands in the field. Deformation bands influenced later joint formation, with joints running parallel or perpendicular to the bands. In the Castle Mesa area, normal faults of varying sizes indicate overall N-S extension, with a dominant N-dipping set and a subordinate S-dipping set. Distributed deformation band bundles, some of which evolved into small faults with less than a meter of offset, occurred in the Castle Mesa area at distances greater than 700 m from the nearest substantial fault, but not in the immediate underlying Slickrock. From the cliff sides, joints appear to be locally conjugate. Maps of measures of the degree of strike organization in the MTM show an increase in complexity with an approach to the major fault. Weathering related jointing is common in the MTM, with sub-horizontal fractures, often along bedding. Exfoliation-like layers contain subvertical shallow joints that truncate against the sub-horizontal ones. These “slab break-up” joints often parallel deformation bands and older joints. Variation in fracture pattern is influenced by a combination of localized faulting and salt tectonics, the distribution of earlier structural elements, and facies changes (mechanical stratigraphy).

Large scale variation in MoabTongue fracture patterns as seen in Google Earth



note significant variation within this example

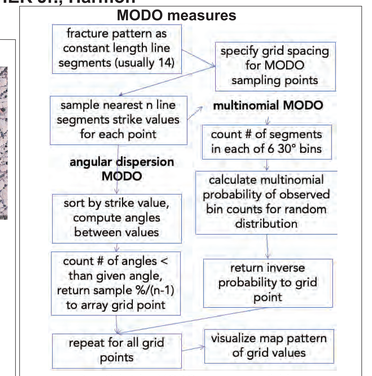
Map of Examples:
- All images oriented with North up
- Images taken from Google Earth from various areas indicated on the map
- Pattern increases in complexity with each example

Example 1:
- One preferred orientation at ~165°
- Apparent to the eye regular spacing
- No truncations
- Simplest pattern

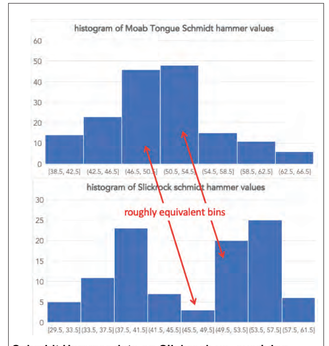
Example 2:
- Two preferred orientations at ~90°, and 5°
- Inconsistent truncations and cross pattern
- 5° fractures closer spaced than 90° which creates rectangular space between fractures
- Apparent even spacing

Example 3:
- Three preferred orientations at ~90°, 55°, and 165°
- 90° fractures clustered in groups
- 165° fractures fairly consistently truncate against 55° fractures
- Polygonal jointing between fractures
- Uneven spacing

MODO measures



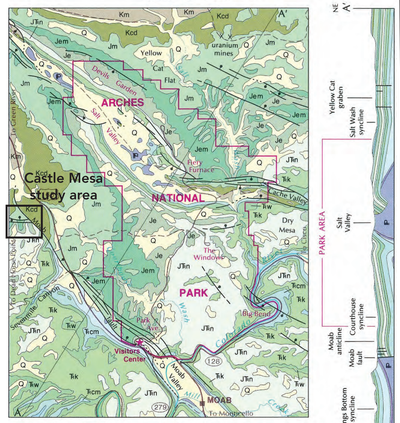
Bart Cubrich’s MODO program available at https://github.com/Bcubrich



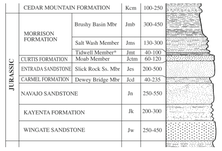
Schmidt Hammer data on Slickrock vs. overlying Moab Tongue. Portions of the Slickrock have higher uniaxial strength levels than the Moab Tongue. This difference could contribute to the difference in fracture density and pattern.

GEOLOGIC MAP OF THE ARCHES NATIONAL PARK AREA

GRAND COUNTY, UTAH

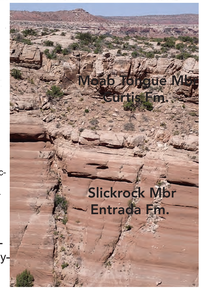


Q Surficial deposits; Jem Moab Tongue; Jtw Wingate Sandstone; Km Mancos Shale; Je Entrada Sandstone; Tkm Chinle-Moenkopi Formations; Kcd Dakota-Cedar Mtn. Fms.; JTrn Navajo Sandstone; Pc Cutler Formation; Jm Morrison Formation; Trk Kayenta Formation; IP Hermosa-Paradox Formations; Contact; Fault; Dashed where approximate, dotted where covered; bar and ball on downthrown side.



Above Strat column from: Swanson, B. A., Santucci, V. L., Madsen, S. K., Elder, A. S., Kenworthy, J. P. (2005). Arches National Park paleontological survey. National Park Service, Geologic Resources Division, 1-8. http://npshistory.com/publications/arch/grdtr-05-1.pdf

Right: Concentration of fractures in Moab Tongue. Normal fault has a corridor of conjugate fractures that extend into the underlying Slickrock member.

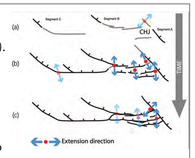


Structural history of area

-fracture patterns & local stresses related to polyphase salt mobility in underlying Paradox Formation (Lorenz & Cooper 2001) shortly after deposition and during several periods in the Mesozoic and Cenozoic (Cruikshank & Aydin 1995).
- two sets of deformation bands, N55°-10°E, then joints striking N5°-10°E. As stress field rotated counterclockwise, joints at N15°-22°W and then at N20°-25°W (Cruikshank & Aydin 1995)

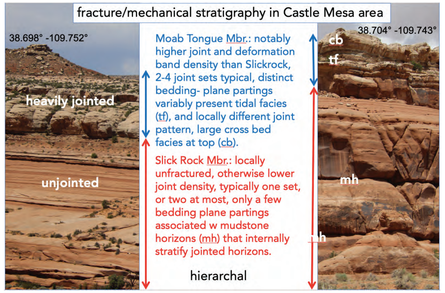
-Moab Fault was active from the Triassic to mid-Jurassic as well as from the mid-Cretaceous to early Tertiary (van Gent & Urai 2020)

-Cu and Mn mineralization along Moab Fault occured at about 25-20 Ma (Chan et al. 2001)



stress evolution, figure from van Gent & Urai, 2020

fracture/mechanical stratigraphy in Castle Mesa area



Moab Tongue Mbr.: notably higher joint and deformation band density than Slickrock, 2-4 joint sets typical, distinct bedding- plane partings variably present tidal facies (tf), and locally different joint pattern, large cross bed facies at top (cb).

Slick Rock Mbr.: locally unfractured, otherwise lower joint density, typically one set, or two at most, only a few bedding plane partings associated w mudstone horizons (mh) that internally stratify jointed horizons.

Exemplary photos of fracture types in Castle Mesa area

Above: deformation band bundle (shear/compaction)

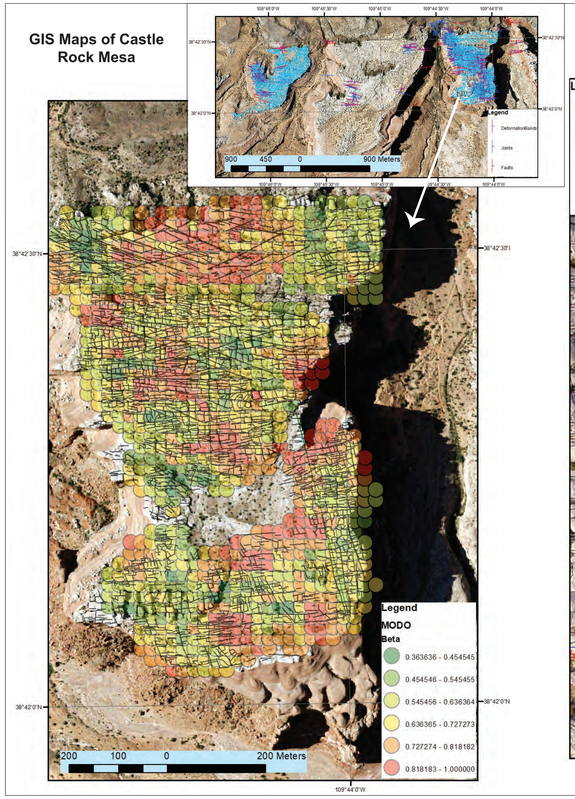
w strain evolves to

Above: small scale fault with striae & dbb with adjacent short joints

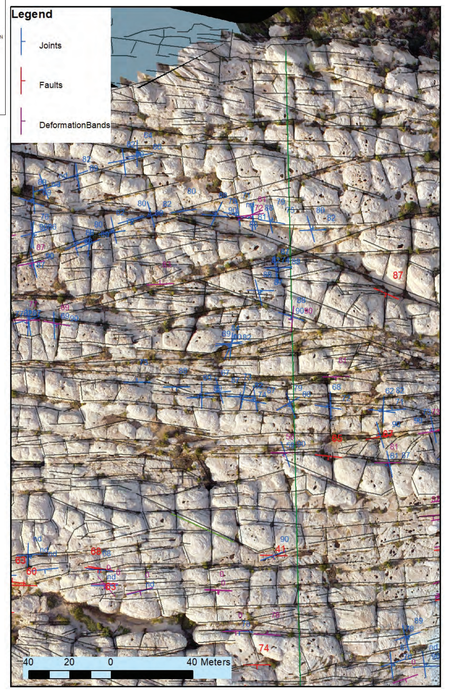
Left: combo def band w Mn-oxide mineralization and simple sub-parallel joints.

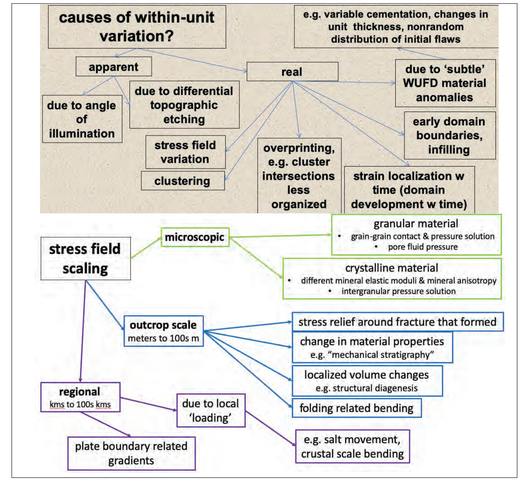
Right: outcrop showing dominant joint set ≈ EW joint set

GIS Maps of Castle Rock Mesa



Higher resolution drone imagery geotiff Jeff Moore, Paul Geimer and Erin Bessette-Kirton. Base for future work.





Conclusions:

- Significant within-unit fracture orientation variability in the Moab Tongue occurs at scales of kms to tens of meters.
- Locally the Moab Tongue can be subdivided into different fracture subunits (Curtis tidal facies as different), raising the question of what is “within unit”.
- Deformation bands significantly influenced subsequent fracture development.
- Fracture differences in the Slickrock vs. Moab Tongue may reflect sandstone strength and degree of layering.

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