Role of confinement in coseismic pulverization of sediments: testing the rock record of rupture directivity on the San Jacinto fault

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Objectives

1. Determine stress states and strain rates necessary to pulverize poorly consolidated sediments
2. Test hypothesis of preferred directivity along San Jacinto Fault

Field Site: Rockhouse Canyon – Anza Borrego State Park

- Clark fault of the San Jacinto fault zone juxtaposes Cretaceous tonalite (Kton) against weakly to unconsolidated sediments of Pleistocene Bautista Formation (Qb) (Fig. 1)
- Whearty et al. (2017) analyzed damage zone samples from two fault transects:
  - *i.* *Upper Transect*: exhumation depths of Qb and Kton are ~70 m and ~600 m, and
  - *ii.* *Lower Transect*: exhumation depths ~120 m and ~900 m

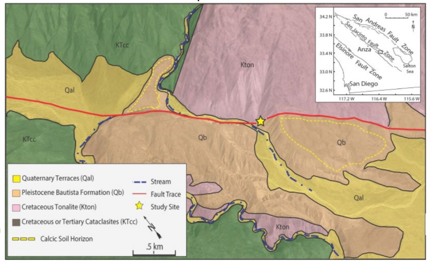
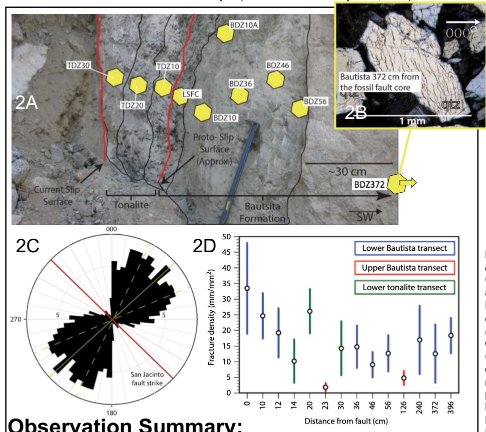


Figure 1. Geology of field area. Inset provides location relative to other significant faults in Southern California. (Geologic boundaries adapted from Sharp [1967], image from Whearty et al. [2017])

Figure 2. (A) Lower transect of the Clark fault at Rockhouse Canyon. Yellow polygons represent sampling locations of Whearty et al. (2017), where nomenclature represents damage zone lithology (TDZ – tonalite; BDZ – Bautista; LSFC – lower transect fault core) and distance from the fault core (BDZ36 was sampled 36 cm from the fault core). (B) Photomicrograph of incipient pulverization in sample BDZ372. (C) Mean orientation of microfractures in the lower transect Bautista sediments is roughly orthogonal to the fault trace. (D) Distribution of fracture density in tonalite and Bautista Fm. at Rockhouse Canyon (modified from Whearty et al., 2017)



Observation Summary:

Distance from fault core:

- Microcrack density of Bautista Fm. decreases with distance from fault core along *Lower Transect* (Fig. 2D)

Role of confinement:

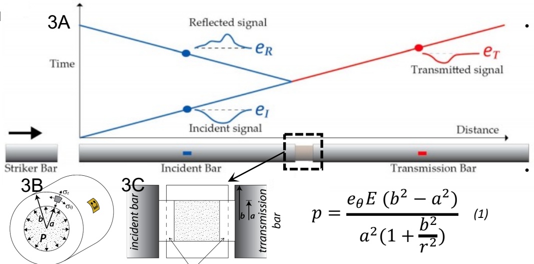
- In *Upper Transect* Bautista sediments display minimal damage while *Lower Transect* Bautista sediments show evidence of "incipient pulverization," (Fig. 2B). ***Whearty et al. (2017) proposed a minimum confining pressure required to initiate sediment pulverization between 1.4 and 2.4 MPa***

Damage asymmetry across SJF:

- Jigsaw texture in tonalite (e.g., Griffith et al., 2018), suggests pulverization in tension - asymmetric damage pattern across fault plane and potential evidence of preferred rupture directivity preserved in rock record

Method: Split-Hopkinson Pressure Bar (SHPB) Apparatus

- We replace the traditional specimen with a sediment-filled cylindrical confining cell plugged on both ends (Fig 4BC)
- Axial stress, strain, and strain-rate histories are calculated using traditional SHPB methods
- A strain gauge mounted circumferentially on the outer confining cell wall records the experimental circumferential strain (e_θ), which is used in eq. *(1)* to calculate the internal dynamic confining pressure (p) as a function of the confining cell dimensions (a, b, r) and sediment sample material properties (E, v)



$$p = \frac{e_\theta E\,(b^2 - a^2)}{a^2(1 + \frac{b^2}{r^2})} \quad (1)$$

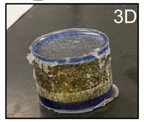


Figure 3. (A) Traditional Split-Hopkinson Pressure Bar assemblage and wave behavior. Dynamic force balance across the specimen is represented by $e_T = e_I + e_R$. (B) Circumferentially mounted strain gauge on the outer confining cell wall records circumferential strain data to calculate the dynamic confining pressure throughout an experiment by *eq. (1)*. (C) Schematic drawing of cross-sectional view of SHPB-mounted confining cell configuration. (D) Post-experimental sample preserved in epoxy resin for thin section preparation. (Image 4A from Griffith et al., 2018)

Bautista Fm. vs Silica Sand

Stress and strain under dynamic loading:

- Equivalent impact velocity (e.g., energy input) causes smaller peak axial & confining stress conditions in Bautista Fm. despite similar peak strains (Fig. 5AB)
- Likely result of: (1) increased compressibility due to concentration of soft minerals (i.e., phyllosilicates) and (2) enhanced grain reorganization relative to Ottawa Sand due to lower contact stresses (i.e., poor sorting increases number of contact points per grain)

Brittle deformation manifestation:

- Ottawa Sand dominated by Hertzian fractures clustered in zones interpreted as "locked" (Fig. 5E)
- Bautista Fm. fractures are dominantly intragranular and do not necessarily originate from grain boundaries (5CD)

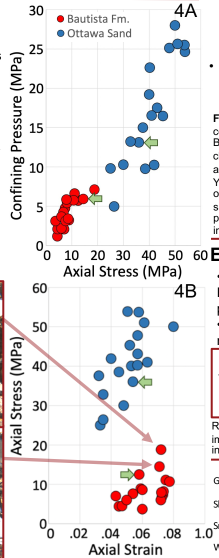
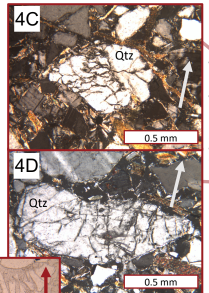
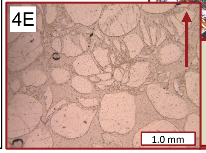


Figure 4. (A) Peak dynamic confining pressure (MPa) in relation to peak axial stress (MPa). (B) Peak axial stress and strain conditions. Green arrows (5AB) mark experiments of equivalent impact velocity. (CD) Photomicrographs of experimentally produced microfractures in relatively large quartz grains of Bautista Fm. (E) Photomicrograph of Hertzian fracture cluster in Ottawa Sand. All grains are quartz. Scarlet (4E) and gray (4CD) arrows indicate axial direction during experimental loading.

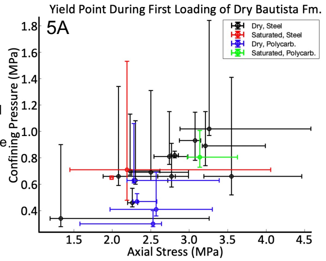


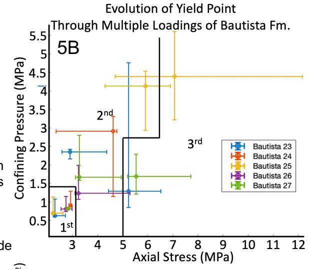


Results: Inelastic Deformation

Yield Point (YP):

- YP, or preconsolidation stress, of granular materials is estimated by point of maximum curvature along a plot of void ratio vs. ln(σ_{axial}) and understood as onset of pervasive inelastic damage
- Whearty et al., (2017) concluded a confining pressure between 1.4 and 2.4 MPa is required to initiate "incipient pulverization" in Bautista Fm. – here, **we report a range of ~0.6-1.3 MPa for damage onset (Fig. 5A)**
- YP is tied to void ratio – thus density – resulting in an **elevated preconsolidation stress over multiple loadings of Bautista Fm.** (Fig. 5B)





Fracture Density (FD):

- FD generally increases with increasing stress conditions (Fig. 5C)
- FD produced by single experimental loading is:
  - Equal order of magnitude to upper transect
  - An order of magnitude below lower transect (Fig.2D,5C)
- **How will FD evolve through multiple experimental loadings?**

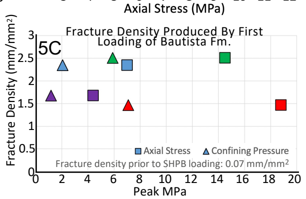


Figure 5. (A) Yield point stress conditions of first loading in Bautista Fm. Confining pressure clusters ~0.6-1.2 MPa where axial stress is ~2-3.5 MPa. (B) Yield point stress conditions over multiple experimental loadings to simulate seismic cycles. An apparent increase with each successive rupture is due to elevated sample strength in response to increased density/reduced porosity. (C) Experimental fracture density produced by first loading of Bautista Fm. generally increases with peak stress conditions.

Earthquake Rupture Directivity

- 'Jigsaw' texture of tonalite (Fig. 6A) at Rockhouse Canyon suggests tensile pulverization while…
- Bautista Fm. damage (Fig. 2B,4CD) is likely result of compressive loading, therefore…

Present damage asymmetry supports the hypothesis of a preferred SE→NW rupture direction along the Clark strand of the San Jacinto fault zone

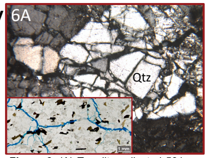


Figure 6. (A) Tonalite collected 501 cm from the upper transect fault core at Rockhouse Canyon shows clear 'jigsaw' fragmentation suggestive of tensile pulverization. Inset image shows experimentally produced 'jigsaw' texture via a modified SHPB apparatus designed to induce dynamic radial tension (Inset image modified from Smith, 2021)

References

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