

# Characterizing shallow slow slip with natural and experimental hematite fault surfaces

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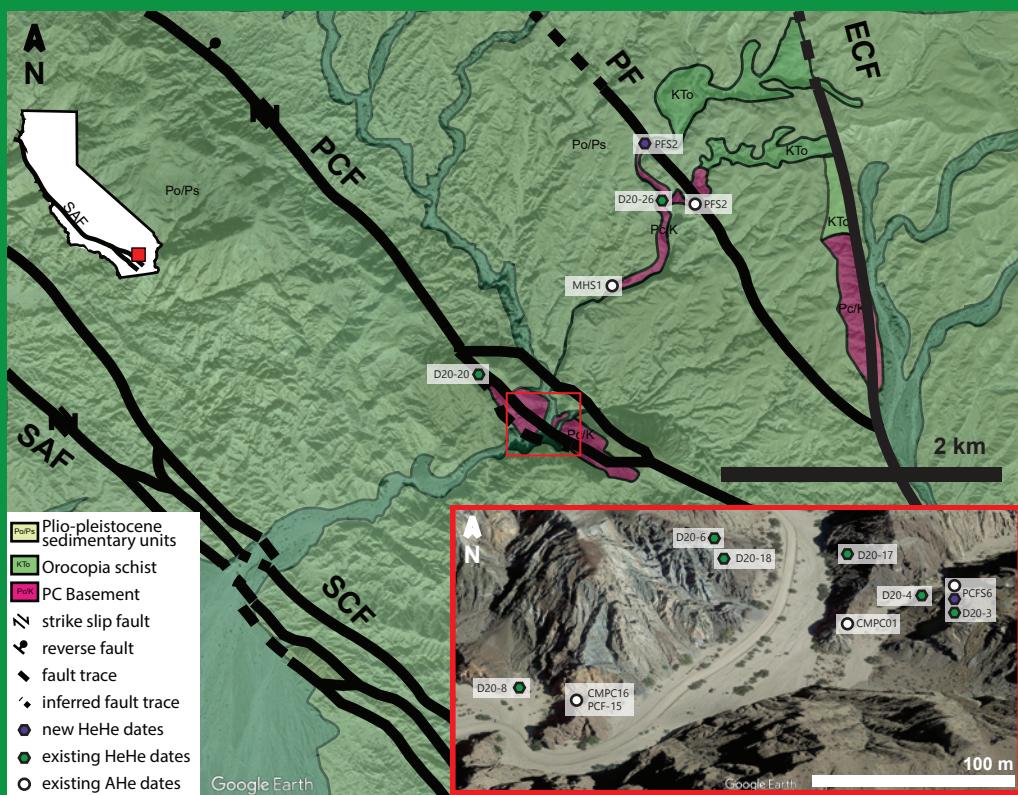


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## 1 Natural



### Background

Mecca Hills, CA - exhumed region NE of the southernmost segment of the San Andreas fault (SAF)

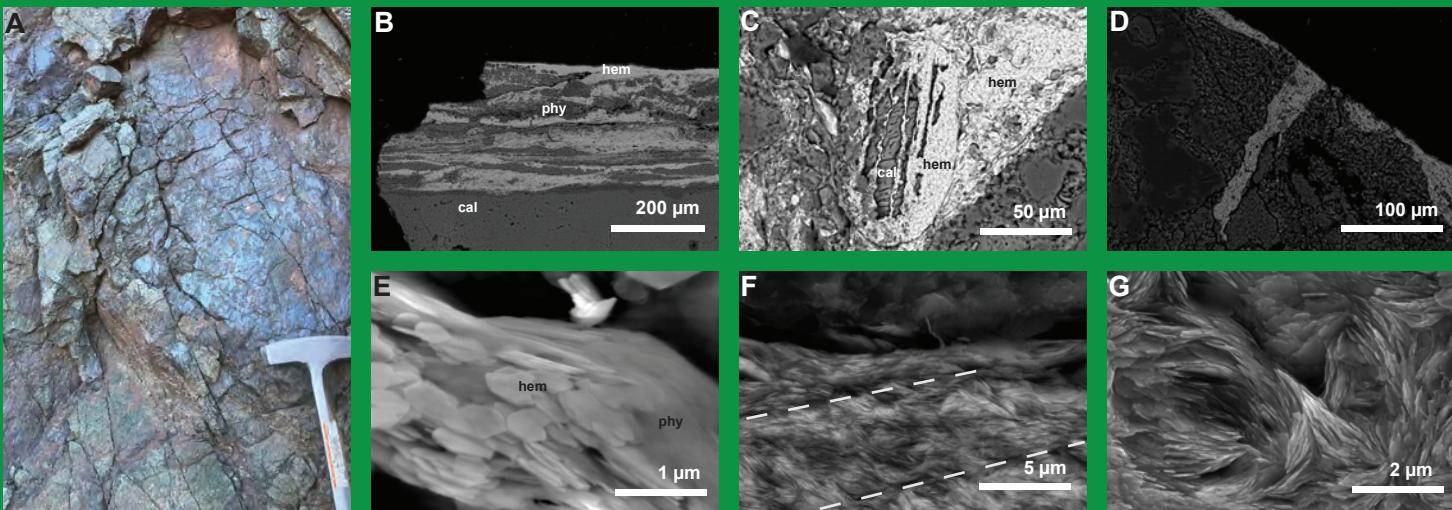
SAF through region experiences shallow slow slip events (e.g. Tymofeyeva et al., 2019)

Series of oblique strike-slip faults subparallel to and in flower structure with SAF; Skeleton Canyon fault (SCF), Painted Canyon fault (PCF), Platform fault (PF), Eagle Canyon fault (ECF), Hidden Springs fault (HSF, not shown on map) (Sylvester & Smith, 1976)

Basement rock exposed within PCF, PF, ECF. Damage zone of PCF contains hematite slip surfaces. This may represent modern SAF basement fault zone at depth where slow slip nucleates

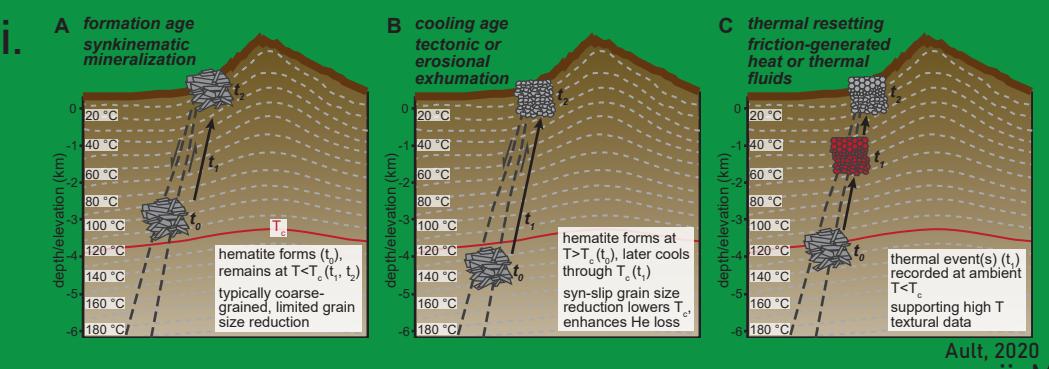
### Microstructures

A. Hematite-coated fault surface. B. Backscatter (BSE) image of interlayered hematite, phyllosilicates, and calcite. C. Reworked hematite clast within a hematite matrix (BSE). D. Hematite-filled injection vein (BSE). E. Secondary electron (SE) image of euhedral hematite crystals on a phyllosilicate surface. F. S-C fabric perpendicular to hematite fault surface (SE). G. Anastomosing hematite plates (SE).



Episodic hematite mineralization occurred via pore fluid overpressure, and faults were reactivated at subseismic slip rates

### (U-Th)/He Thermochronometry

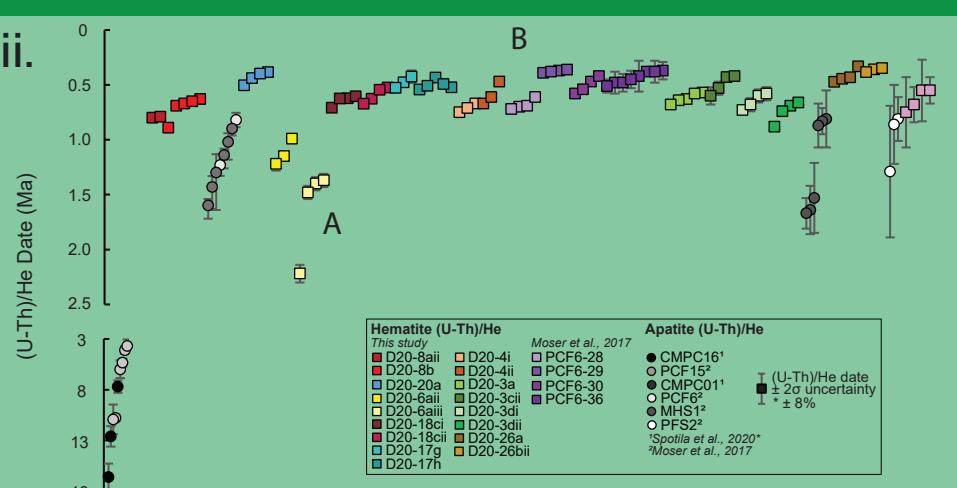


Apatite He (AHe) dates record basement exhumation.

He loss within hematite is a thermally-activated, grain-size dependent process.

i. Hematite (U-Th)/He dates record A. formation B. exhumation or C. resetting by friction-generated heat and/or hydrothermal fluids

Use textures, grain-size distribution, and comparison with AHe dates to interpret dates.



ii. Mecca Hills AHe dates record exhumation in the upper ~1.5 km

Mecca Hills hematite dates:

- A. overlap with AHe (hematite records mineralization or exhumation)
- B. are younger than AHe (hematite records mineralization)

Individual fault surfaces have reproducible dates

Fault surfaces within a few cm to m of one another sometimes yield overlapping dates and sometimes have different dates

Thermochronometry records at least two periods of Plio-Pleistocene hematite mineralization in the upper ~1.5 km of basement fault zones

iii. Mecca Hills hematite dates:

A. overlap with AHe (hematite records mineralization or exhumation)

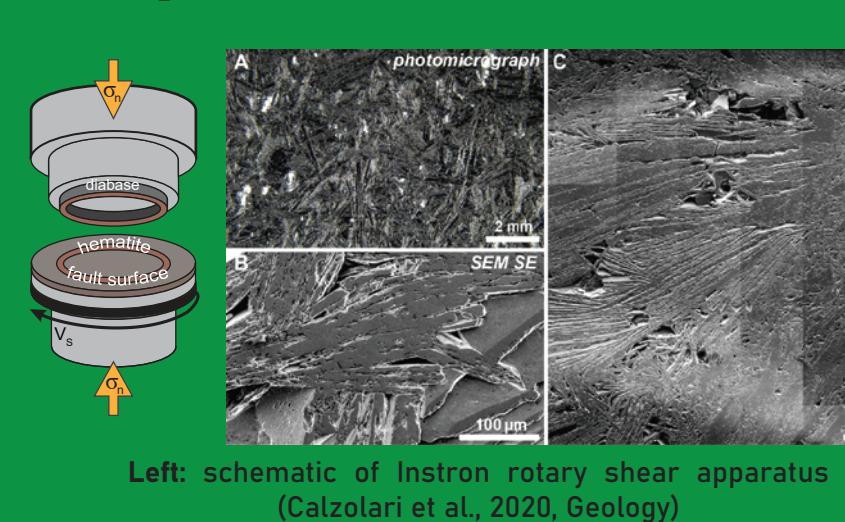
B. are younger than AHe (hematite records mineralization)

Individual fault surfaces have reproducible dates

Fault surfaces within a few cm to m of one another sometimes yield overlapping dates and sometimes have different dates

Hematite has a low coefficient of friction that is comparable to phyllosilicates and displays velocity strengthening and velocity neutral behavior that may promote slow slip events and arrest shallow earthquake propagation and nucleation.

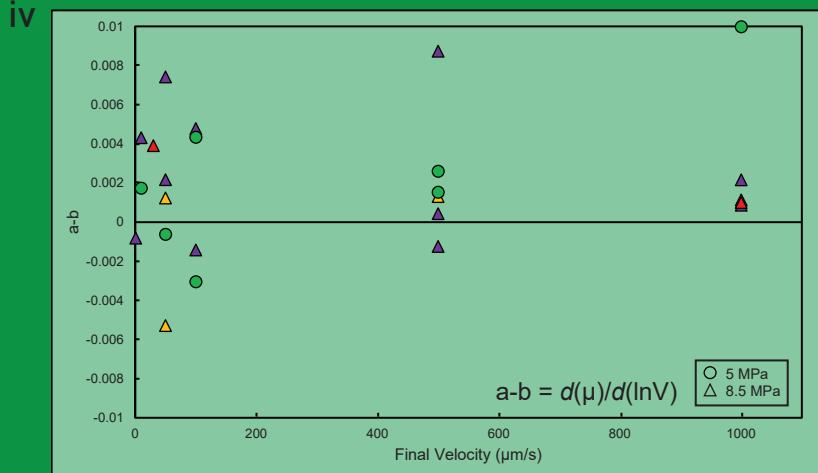
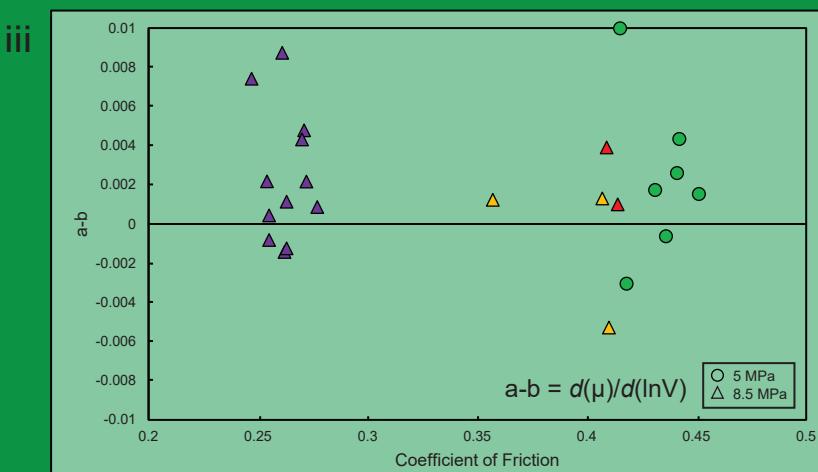
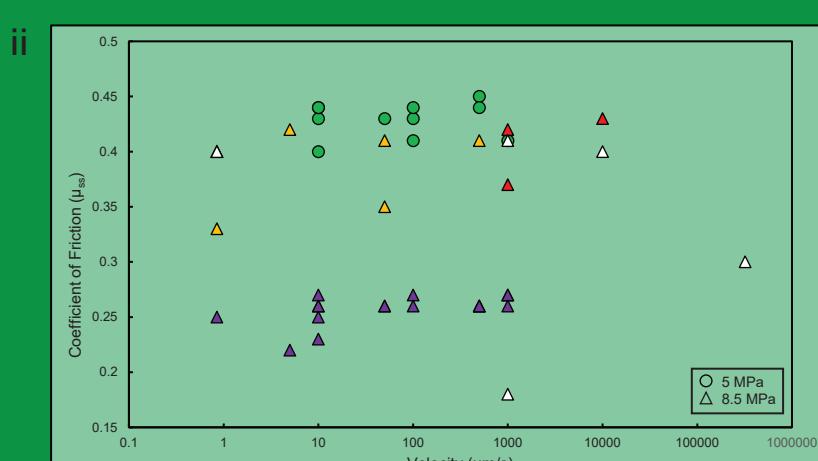
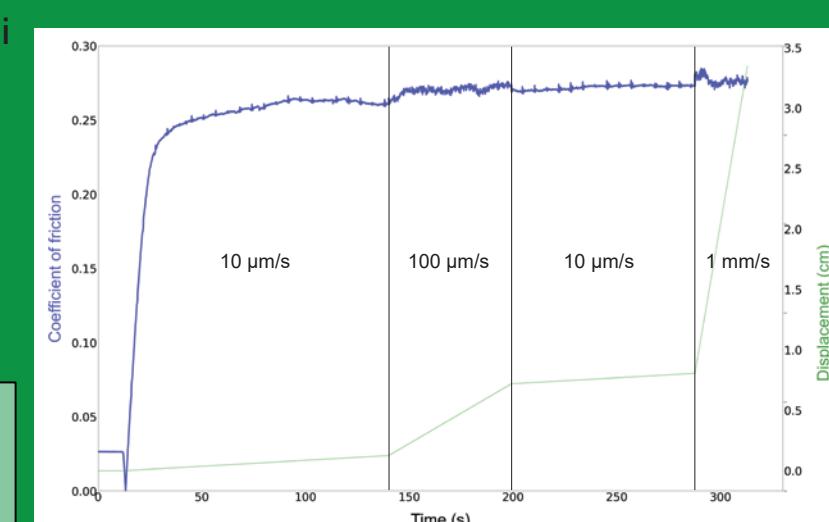
## 2 Experimental



Left: schematic of Instron rotary shear apparatus (Calzolari et al., 2020, Geology)

### Mechanical data

- i. Velocity step tests ("D20\_s") at slow slip rates and cm-scale displacements comparable to offset seen in Mecca Hills

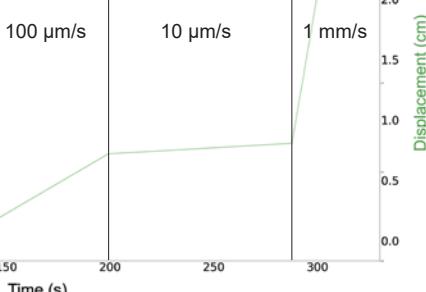


### Background

A-C: Starting material: coarse-grained specularite boulder from Wellsville Mts, UT (Calzolari et al., 2020)

### New experiments

-Instron rotary-shear apparatus  
-5 & 8.5 MPa  
-room-temperature  
-diabase, SiC, and granite upper annuli  
-velocity-steps and interrupted slip  
-~0.85 4m/s to ~320 mm/s



### Experiments

- Purple - "D20\_S" - diabase annulus - 8.5 MPa
- Yellow - "D20\_P" - granite annulus - 8.5 MPa
- Red - "D20\_M" - diabase annulus - 8.5 MPa
- Green - "D20\_PVI" - diabase annulus - 5 MPa
- White - "D20\_PHe" - 6 separate surfaces conducted to evaluate He loss - diabase and SiC annuli - 8.5 MPa

ii. Hematite coefficient of friction ranges from ~0.25-0.45 at slow slip rates (comparable to 0.16-0.40 range observed at ~320 mm/s rate, Calzolari et al., 2020)

iii. Hematite is velocity strengthening to roughly velocity neutral

iv. Velocity strengthening and velocity neutral behavior observed over the range of slow slip rates

Hematite has a low coefficient of friction that is comparable to phyllosilicates and displays velocity strengthening and velocity neutral behavior that may promote slow slip events and arrest shallow earthquake propagation and nucleation.

## 3 Integration

Mecca Hills microstructures and thermochronometry provide a record of slow slip events in shallow PCF zone hematite slip surfaces.

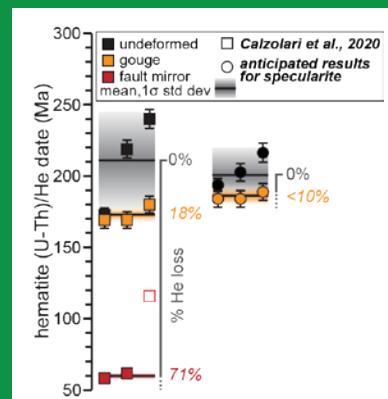
Preliminary experimental results support potential of hematite to propagate slow slip in the shallow crust.

## Future Work

Acquisition of hematite He dates from experimental slow-slip surfaces. We do not anticipate He loss associated with slow slip (see image at right)

SEM images - comparison of experimental and natural slow slip textures to investigate how texture affects hematite mechanics

Calzolari et al., 2020:  
-71% He loss within FM w/ sintered nanoparticles



## 4 References & Acknowledgements

- Tymofeyeva et al., 2019, JGR: Solid Earth v. 124
- Sylvester & Smith, 1976, AAPG Bulletin v. 60
- Ault, 2020, JSG v. 133
- Moser et al., 2017, EPSL v. 476
- Spotila et al., 2020, Geosphere v. 16
- Calzolari et al., 2020, Geology v. 48

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