

Progress Report on Investigating Along-Fault Variation of Shallow Inelastic Damage of the San Andreas Fault

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Abstract

A recurring question in modern seismic hazards of active plate boundary systems is on the along-strike variability of long-term inelastic damage along their principal fault zones, and how this variability influences shallow fault zone rheology, yield strength of fault blocks, and near-field coseismic ground shaking. Along the San Andreas Fault (SAF), decades of field geological mapping and seismological characterization have advanced the understanding of many important segments of the plate boundary, yet there remains a knowledge gap on the detailed relative variation in the shallow rheology along-strike of the fault zone as viewed through the lens of coupled field geology and shallow geophysical imaging. Our proposed project aims to bridge this gap by leveraging on published field geological and/or geophysical characterization of exposures of the principal slip zone of the Mohave segment of the SAF (MSAF), by conducting shallow (<100-m deep) high resolution seismic survey experiments across sites that are yet to be seismically imaged but are geologically characterized and utilize both techniques in segments that lack both forms of characterization. We will estimate the on- and off-fault shear modulus of the slip zone at each site and eventually, compare how fault damage structure maps onto the shear rigidity estimates to assess the first-order along-fault variability in the rheology of the SAF. We anticipate that the results of this project will provide realistic fault zone rheology constraints that can improve SCEC's computational dynamic rupture simulations to accurately capture the expected near-fault coseismic ground shaking effects along the MSAF.

Status of Research Objectives:

1. Field-based geological characterization of brittle damage along the MSAF:

A key objective that was proposed in the funded grant was to characterize the damage zone of the MSAF in outcrops along the principal fault trace as documented in the Q-Fault database. Previous studies (e.g., Dor et al., 2006) have documented the broad groupings of bedrock damage character along the fault. The studies highlight the common presence of pulverized granites in the fault blocks as manifestations of compounding long-term coseismic fracturing of the surrounding rocks. We proposed to perform detailed damage zone characterization at already identified outcrops exposed in roadcuts and river channels along the fault trace. The characterization includes detailed structural and lithological (primary, and alterations) mapping and descriptions, fracture distribution mapping, rebound hammer measurements, and rock sampling for micro-structural analysis.

We successfully completed the tasks during a week of field work in the Lake Hughes-Lake Elizabeth section of the MSAF (Fig. 1). Due to limited period of funding (funding terminated in 2026 January ending), we were unable to stay longer in the field or return to the field to cover additional sections of the fault. However, we are convinced that the data collected are adequate for understanding the geology of the mapped section of the fault. We identified and mapped the detailed deformation patterns

in granitic country rocks proximal to- and distal to the modern SAF trace at Lake Elizabeth (Fig. 1). The results demonstrate that the pulverized nature of the granites proximal to the modern SAF trace becomes patchy with increasing distance from the fault trace. We find a well-developed but inactive SAF-parallel fault core at significant distance (~600 m) from the modern fault trace, representing the character of earlier deformation in the SAF wall rocks. In the many secondary faults mapped within the pulverized granite SAF wall rocks, we document the heterogeneity of fault rock lithologies and are evaluating their implications for the mechanical and seismic behaviors of the fault zone. Overall, the observations are relevant for advancing the understanding of compounding long-term off-fault deformation in granitic wall rocks of active continental transform faults such as the SAF.

2. Seismic Survey Using a Dense Seismic Array:

The second objective of the project is to perform along-fault and across-fault seismic imaging of the shallow subsurface along the Mohave SAF. We had planned across-fault 2-D seismic survey profiles for the Lake Hughes, Elizabeth Lake, Palmdale, Little Rock, and Jackson Lake sections of the fault. Based on discussions with USGS seismology collaborator Rufus Catchings who is helping with the survey, the team decided to revise the plan from a seismic refraction survey to seismic active source survey in order to optimize imaging resolution.

Rufus took deliberate steps to seek permits at a target field site at Elizabeth Lake and the plausible dates for acquisition were set. Our project funding from SCEC would be complemented by field data acquisition/processing support from USGS given that the survey overlaps with other USGS-funded ongoing seismic surveys in the area. Unfortunately, government disruptions to USGS funding in the 2025/2026 fiscal year made it impossible to carry out the surveys. As a result of this, this part of our project objectives could not be met.

Ongoing/future work:

- We are currently analyzing the field datasets including structural modelling and microstructural analysis of thin sections. Undergraduate student Maya Madejewicz intends to prepare a manuscript on the field geological mapping results.
- We are still in conversation with Rufus Catchings at USGS to complete some of the seismological survey profiles that we had planned for the project, at least at the Lake Hughes-Elizabeth Lake section of the SAF so as to collocate the seismological data with our geological mapping. All collaborators are still interested, so there is a high chance that the surveys will be completed by USGS.

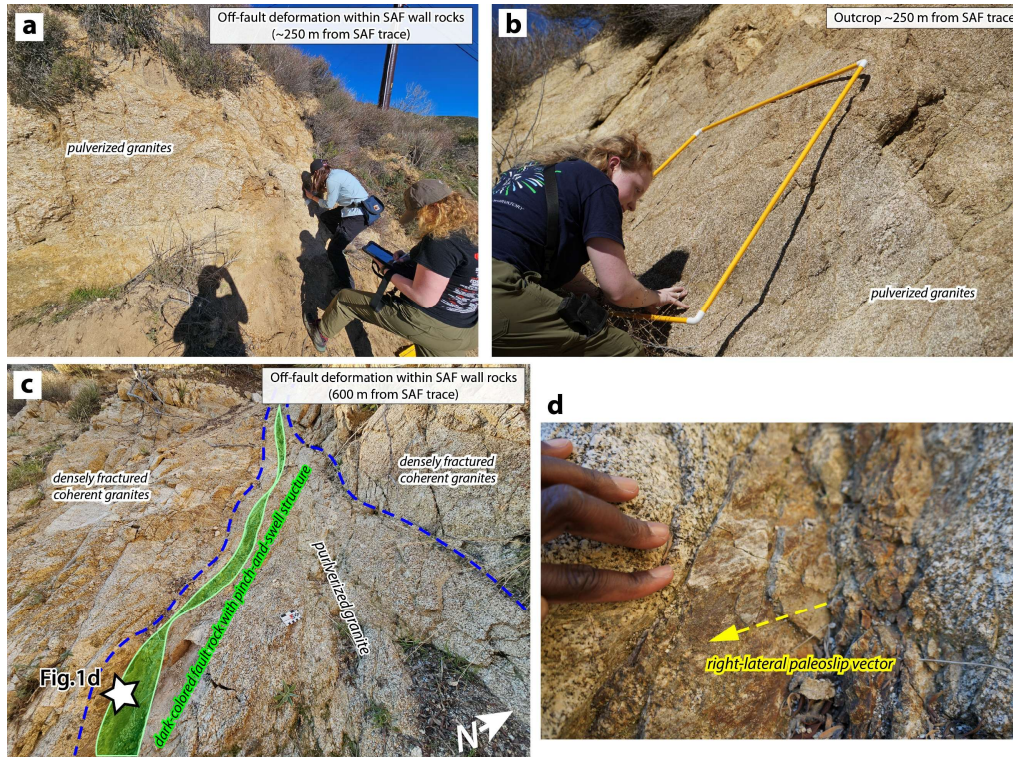


Figure 1. Field photograph taken during the geological field mapping work along the Lake Hughes - Elizabeth Lake sections of the MSAF. **(a – b)** Maya Madajewicz (undergraduate student) and Meritxell Colet (PhD student) mapping the deformation of the SAF wall rocks. **(c - d)** Exposure of a 1-1.5 m wide SAF-parallel fault core at ~600 m NW of the Q-Fault surface trace of the SAF.