Displaced rocks as an indicator of ground motion during the 4 July 2019 M6.4 Ridgecrest earthquake

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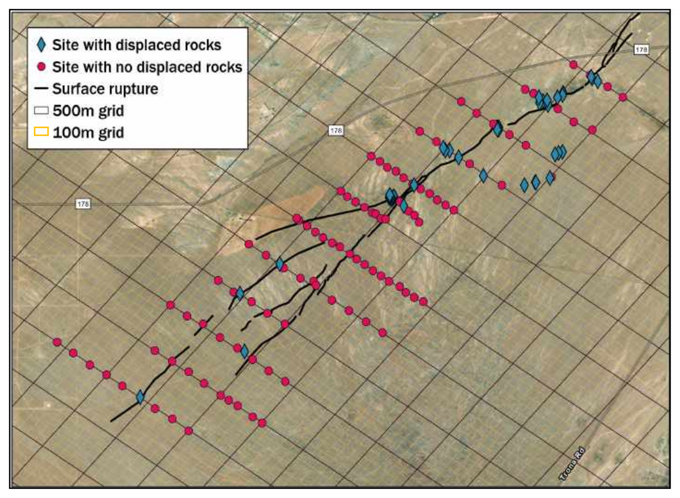
Abstract

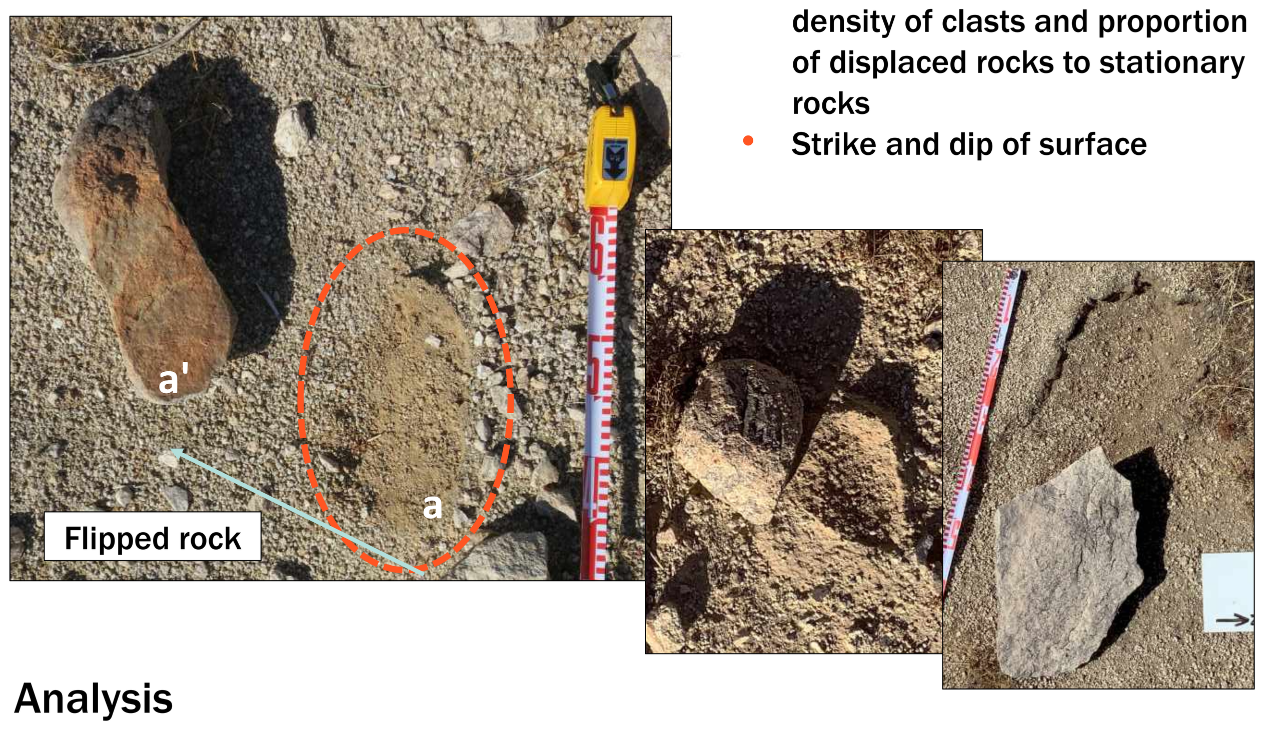
Fragile geologic features, including rocks or rock formations displaced or toppled during earthquakes, provide insight into spatial extent and intensity of strong ground shaking. This study focuses on individual pebble and cobble sized clasts displaced and disturbed during the July 4, 2019 M6.4 Ridgecrest, California earthquake. The goal of this study is to use these data as a primary input for models of near-fault strong ground motion.
In the fall of 2019, we collected measurements of displaced rocks at 170 sites in orthogonal transects along the southern 8 km portion of rupture. Displaced rocks were identified primarily based on the presence of empty soil sockets on the nearby ground surface. We developed a rubric and GIS routine to measure, locate, and describe displaced rock measurements in the field. At each measurement site, we recorded clast dimensions, displacement type, magnitude and azimuth, substrate type, slope gradient and aspect, and location relative to the surface rupture trace. Preliminary results suggest that the prevalence of displaced rocks strongly depends on substrate type, rock size and density, fault complexity, local topography, and proximity to the rupture. These results suggest ground motion attenuates on a meter scale moving away from the fault.

Data Collection and Approach



Fieldwork

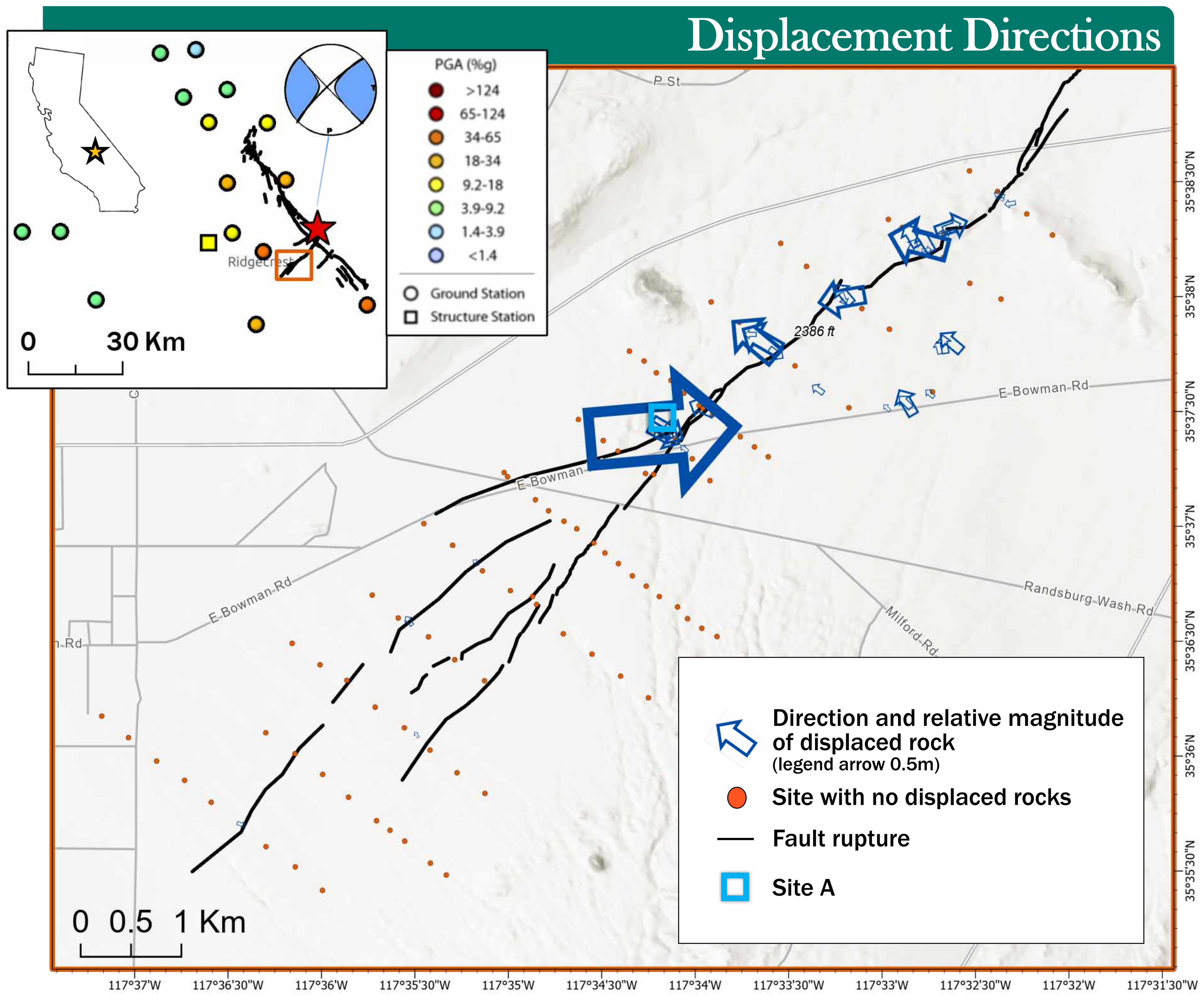
- Created 500m and 100m grids to follow using ArcGIS and Collector app on iPad
- Gathered measurements of one rock each at grid intersections
  - Magnitude, direction and type of displacement from socket to rock
  - Clast dimensions and degree of adhesion to substrate
  - Substrate type, estimated density of clasts and proportion of displaced rocks to stationary rocks
  - Strike and dip of surface



Analysis

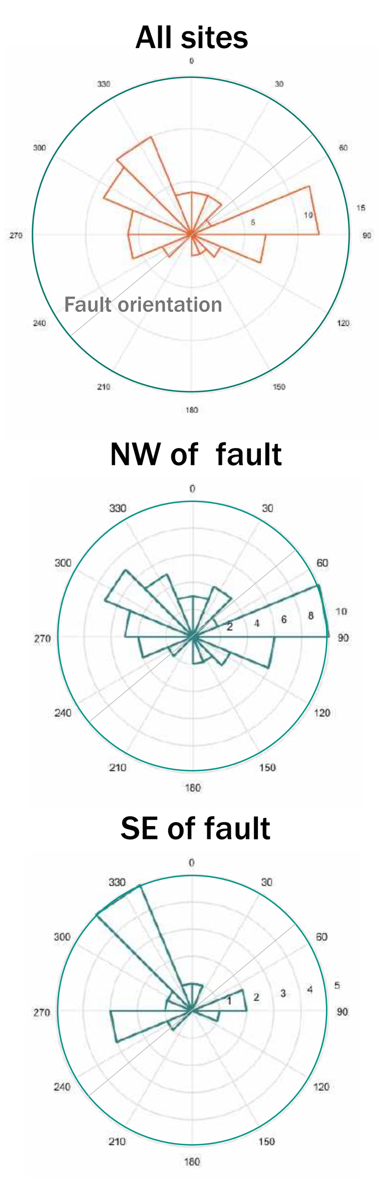
- Evaluate correlation between rock parameters, distance moved and proximity to rupture and epicenter
- Interpret field data using digital mapping
- Explore relationship between directivity and moment tensor
- Compare data with accelerations recorded by strong motion stations

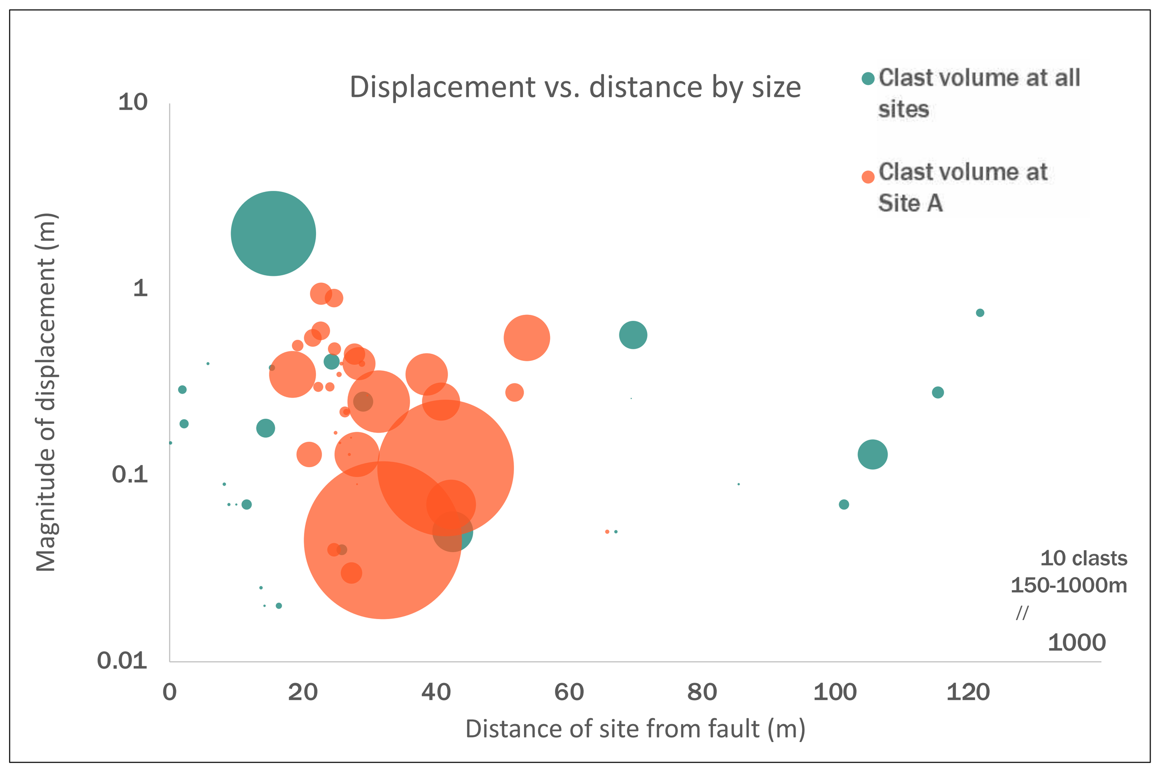
Displacement Directions



All sites including those with no displaced rocks and sites with at least one displaced rock. Rocks exhibited less offset SW of fault splay and more offset directly near divergence point. Map at top left shows the paucity of regional seismic instrumentation in stark contrast to the density of collection sites below (CESMD, 2019; USGS, 2019). Light blue square corresponds to site study area, Site A, with more closely spaced sites in right panel.

Initial Results





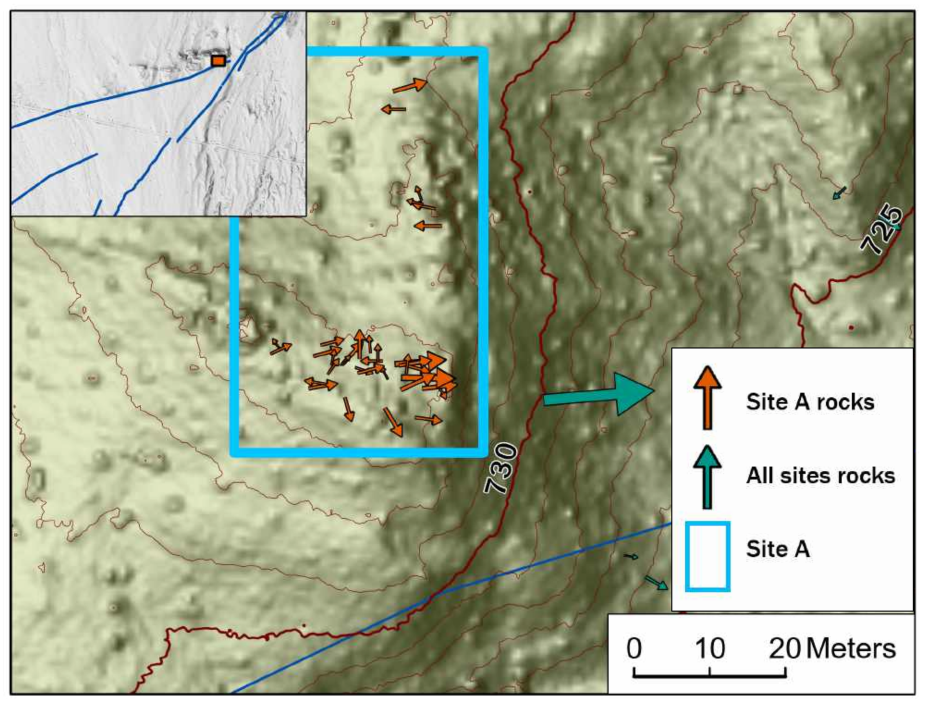
Displacement direction

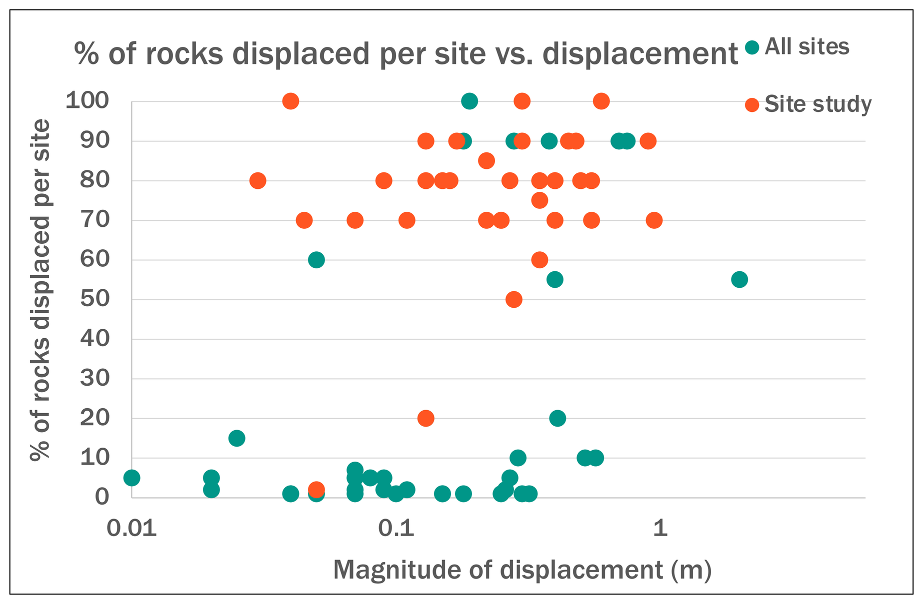
- Rock motion is roughly 30° and 90° from fault orientation (gray line)
- Subtle directivity outward from epicenter, but stronger signal perpendicular to fault
- Strong northwestward signal on both sides

Size and displacement

- No strong relationship between clast size and displacement
- No strong relationship between distance from fault and rock displacement at the scale of this project

Site Study





Site study (Site A)

- More densely spaced measurements on flat top of pressure ridge at point of splay. Area of interest with an anomalously large number of displaced rocks.
- As with the rest of the field area there is little observed impact of distance from fault.
- Rocks measured on slopes were displaced relatively farther down dip.
- Counter to our expectations, our data do not support evidence of seismic amplification from topography. Clasts did not have a larger displacement at higher elevation, but, not insignificantly, collection sites atop the ridge contained a consistently higher percentage of displaced rocks than the rest of the field area.

Discussion

Displaced rocks technique

- Low cost, low technology. Easy and quick data collection and evaluation
- Data are fragile and ephemeral. Must collect quickly after events
- Location
  - Mojave desert: Ideal opportunity to test this technique (substrate, climate)
  - May not be viable in other climates with more precipitation, vegetation
- Can be used to test ground motion models

Next steps

- Determine the validity of the method by comparing rock data to accelerometer data
- Quantify ground acceleration with displaced rocks based on Clark (1972) Michael et al. (2002) studies of displaced rocks after the Borrego Mountain and Hector Mine earthquakes
- Augment accelerometer data to give a more refined view of ground motion between strong motion seismic stations
- Illustrate the influence of substrate on ground motion
- Examine relationships between rock motion and fault parameters (e.g. proximity to epicenter, footwall/hanging wall, fault complexity)
- Explain why ground acceleration caused some rocks to move but not others in the same site
- Reassess rock movement with topographic effects removed

References

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