Puzzling Permeabilities: In Situ Permeability Measurements of the Punchbowl Fault, California

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Abstract

Faults serve as permeable structures through the upper crust due to increased fracture densities within fault damage zones. While many studies have used measurements of fracture density to infer permeabilities of exhumed faults, measurements of in situ permeability are rare. Here, we use in situ measurements of permeability at the Punchbowl Fault to assess its permeability structure. The Punchbowl Fault is an inactive strand of the San Andreas located ~5km southwest of active strands. The fault is composed of a continuous ultracataclasite layer bounded by damaged host rock (Chester and Logan 1986). The damage zone is riddled with fractures whose densities decay logarithmically with distance from the fault core. Measurements were made using a TinyPerm3 on smooth outcrops at various distances from the fault. We made at least 10 measurements at every location for a total of 323 measurements from 17 locations. . Permeabilities do not decay logarithmically with distance from the fault core as expected from previous measurements on microfracture densities. We hypothesize that grain size variations may be more important in determining permeability than microfractures within the Punchbowl Formation or that microfractures could have sealed over time through mineral precipitation.

How does Permeability Vary Around Strike-Slip Faults?

A fault zone is composed of three components (1) a fault core where shear displacement is localized, (2) a damage zone with elevated fracture density, and (3) the host rock (where damage is negligible; Chester & Logan 1986).

In the damage zone, fracture density decreases logarithmically with distance from the fault core. The decay in fracture density can be quantified with a power law function: $d = cr^{-n}$
where d is number of fractures per meter, c is a fault-specific constant, r is distance, and n is the density decay exponent. For small, isolated faults the average n is about 0.8 (Savage & Brodsky 2011).
These fractures cause significant changes in permeability.

In this study we use in situ permeability measurements to assess variations in permeability surrounding the Punchbowl Fault, CA, USA

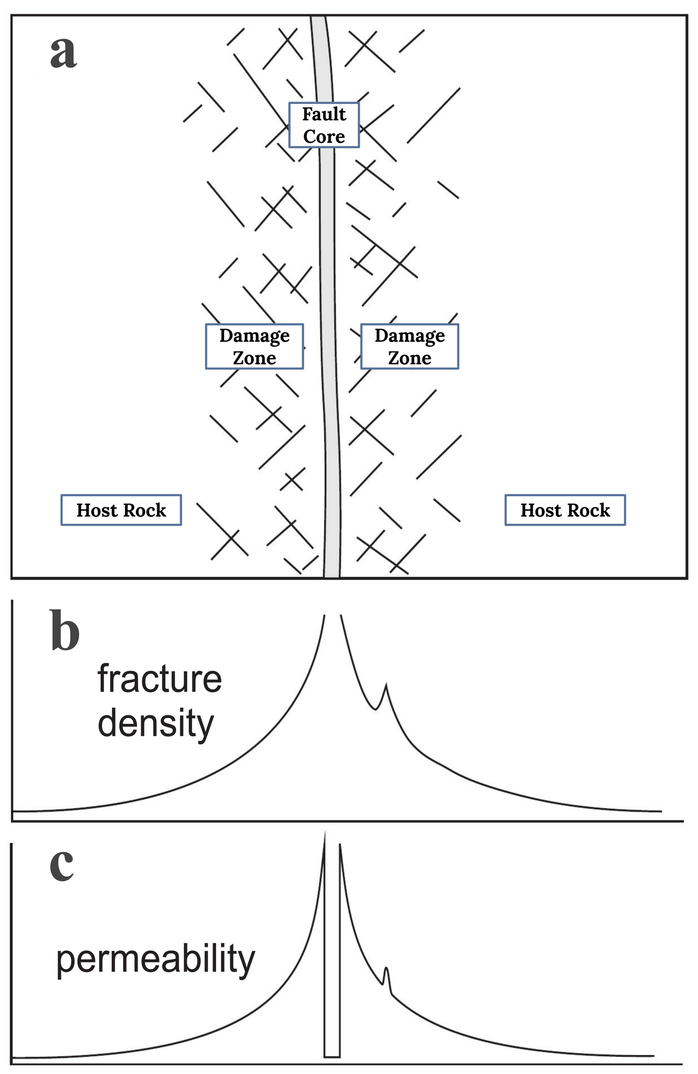

Figure 1:
Cartoon of typical fault structure. (a) Simple fault structure showing a single fault core, a damage zone, and the undamaged host rock. (b) Typical distribution of fractures. (c) Expected distribution of permeability (Faulkner 2010).

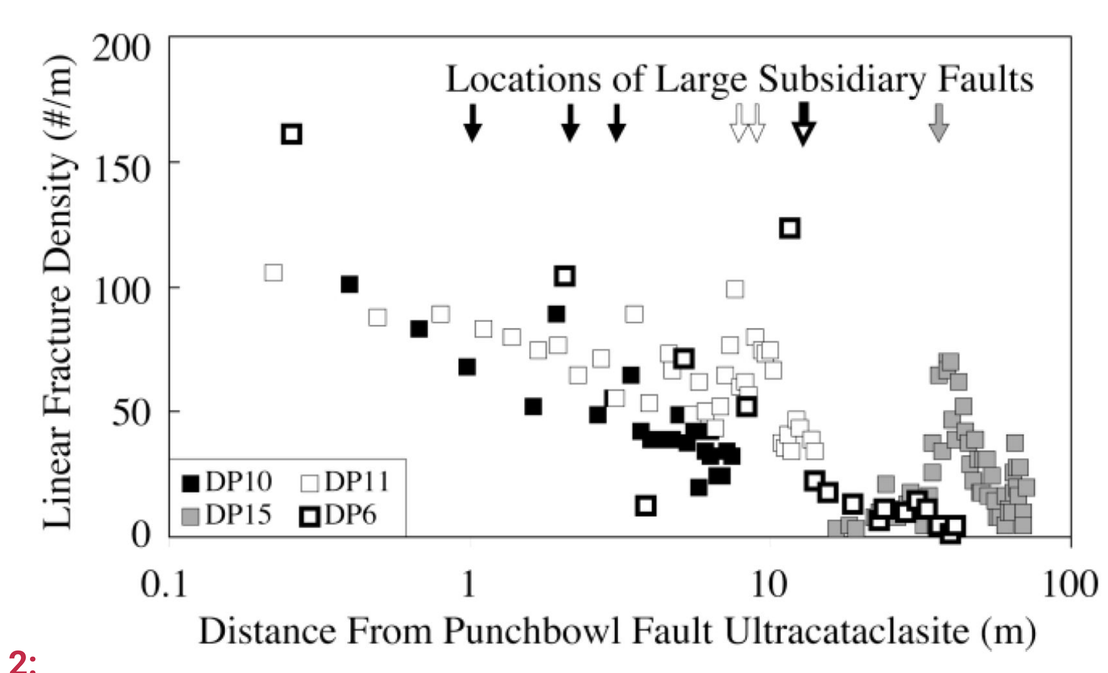

Figure 2:
Fracture density of the Punchbowl Fault with distance from the fault core (Wilson 2003).

The Punchbowl Fault

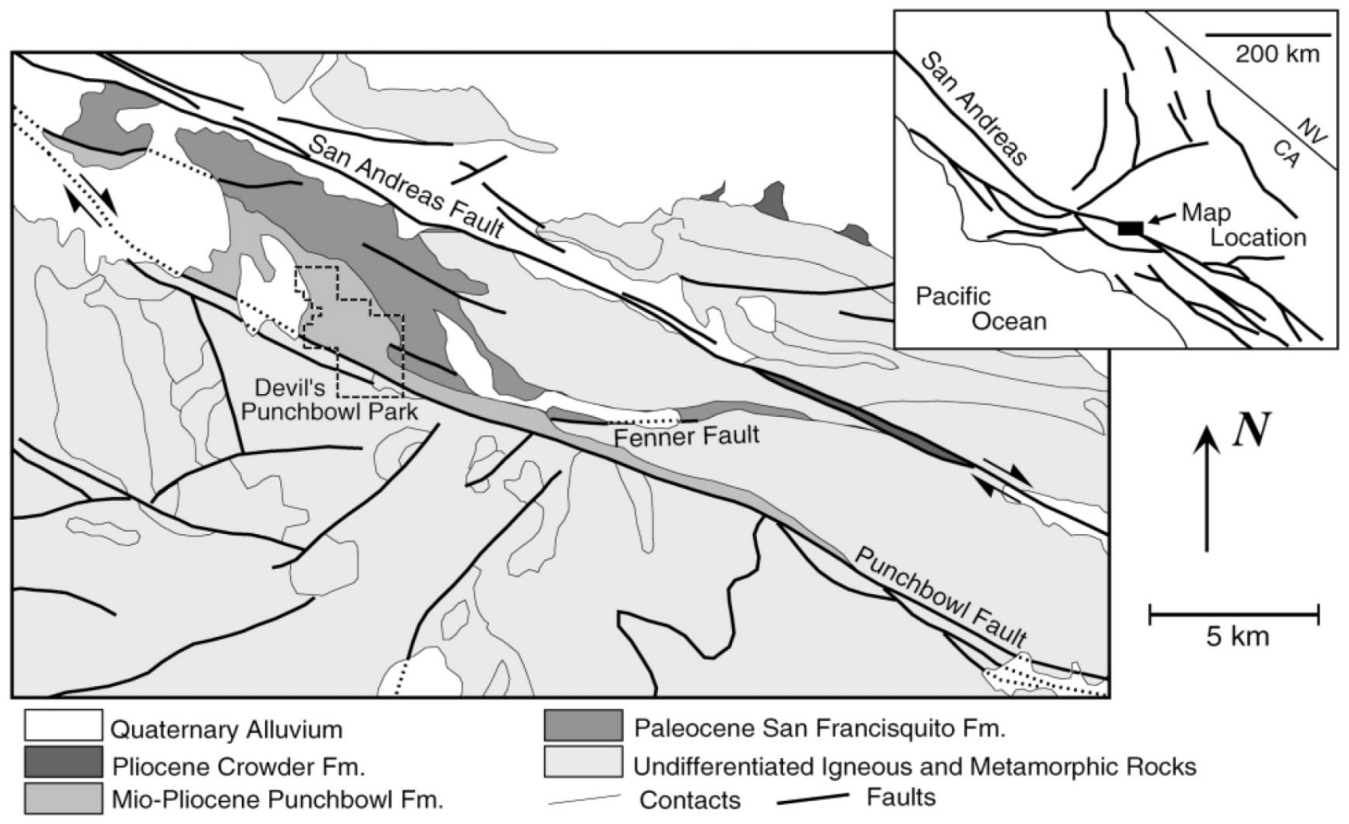

Figure 3: Geologic map of Punchbowl Fault area (Wilson 2003). The Punchbowl Formation is concentrated on the Northwest part of the fault while Basement rock makes up the South side.

The Punchbowl Fault is an ancient, inactive strand of the San Andreas Fault System. It was exhumed from a depth of 2-4 km. ~40 km of right lateral separation occurred during the Late Miocene and Pliocene. It is composed of a continuous fault core strand made of ultracataclasite. The south side of the fault is made of the San Gabriel Basement Complex while the north side is the Punchbowl Formation. The latter will be the focus of this study (Wilson 2003).

Methodology

We used a TinyPerm3 to make in situ measurements of permeability.
The TinyPerm3 is a handheld, air permeameter that creates a vacuum on a rock specimen and measures how long it takes for the vacuum to dissipate.

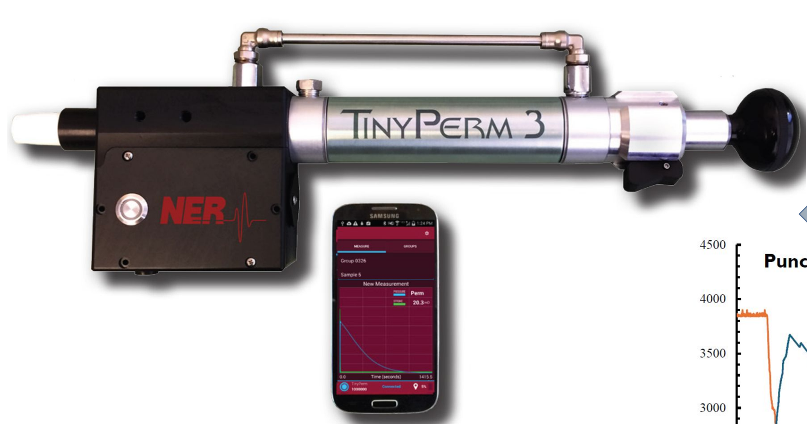

Figure 4:
TinyPerm3 + Android Phone that connects to the device and stores measurements. Picture from ner.com.

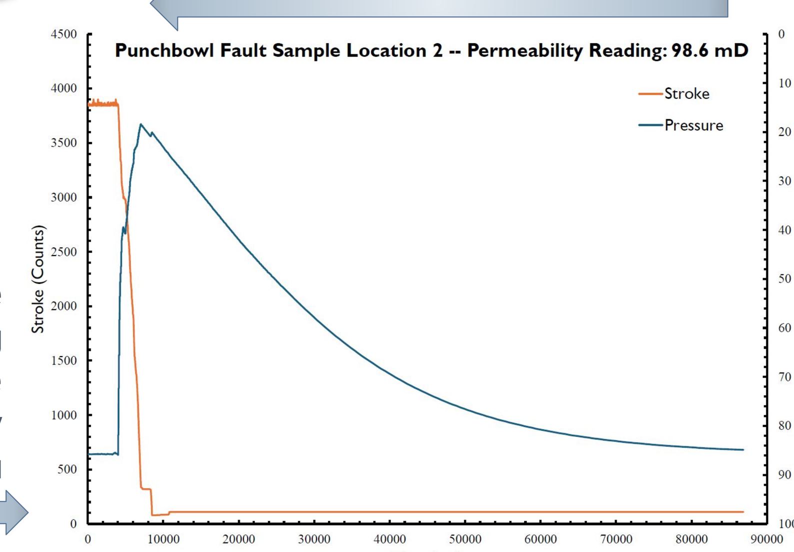

Figure 5:
Stroke and pressure graph made on the Android Phone as measurement is being taken. Evolution of stroke and pressure during a single measurement. The decay in pressure is used to calculate in situ permeability.

We tested permeability at 17 smooth outcrop locations on river washes and joint surfaces. At each outcrop we made 10 measurements parallel to bedding and 10 perpendicular to bedding (where possible). Extreme variations in grain size exists within the Punchbowl Formation Sandstone, so grain size was recorded with each measurement.

Figure 6: Pictures of the Punchbowl field site. Left image is approximately 15 m from fault. Right image, 9 m from fault.

Results

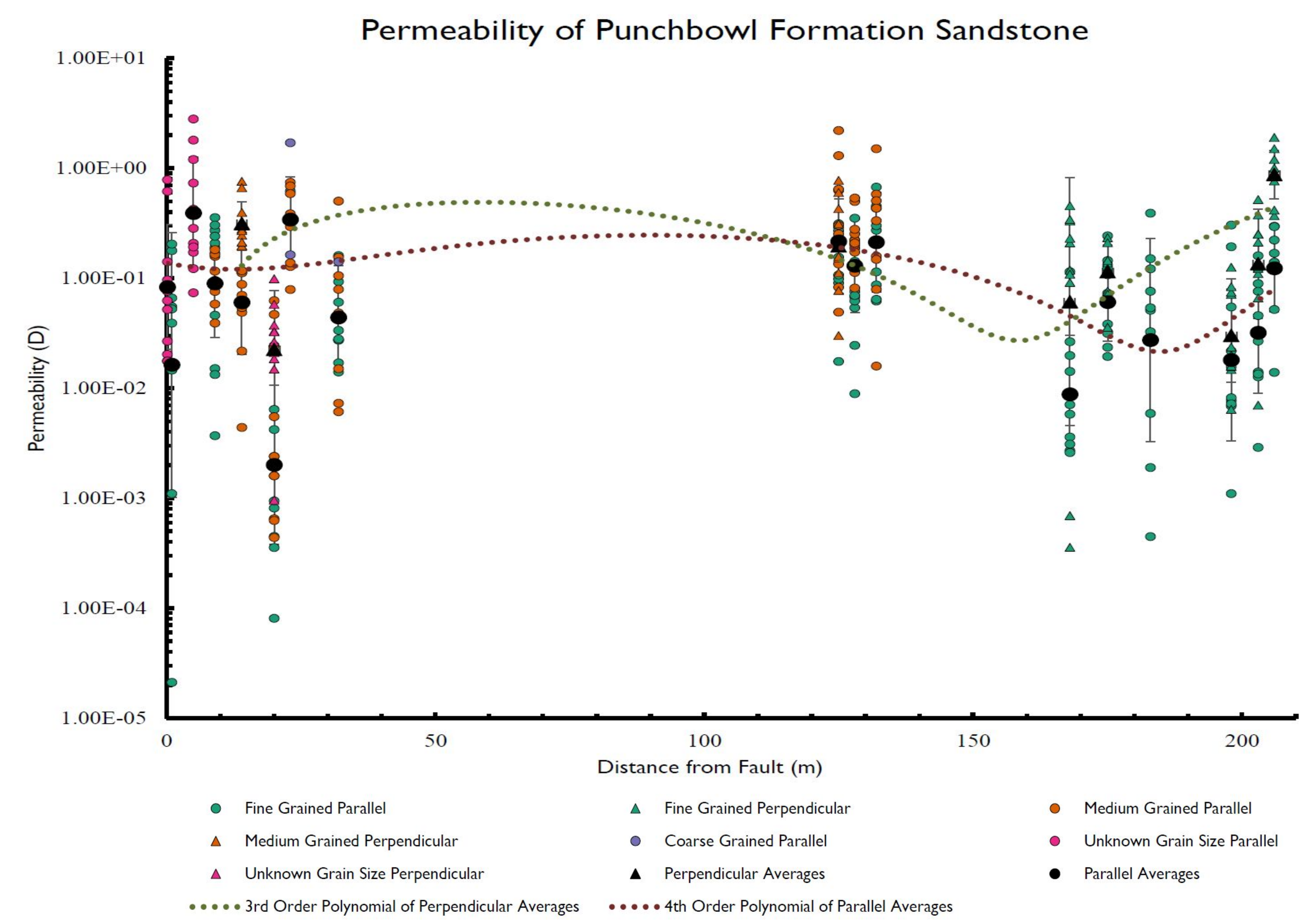

Figure 7:
Permeability measurements from 17 outcrops with distances ranging from 15 cm to 206 m from the fault. Grain sizes are represented with different colors. Measurements made parallel to bedding are represented as circles. Perpendicular measurements are represented as triangles. Averages at each location are shown with black symbols. Trend lines are made from the perpendicular and parallel averages and are 3rd and 4th order polynomials respectively.

Discussion

The results of this study deviate quite a bit from what was hypothesized. There is no clear trend like that of Figure 1. There are a couple of possibilities as to why this is the case.

- Over 150 m from the fault, the outcrops are exclusively fine grained and all have similar measurements. Outcrops closer to the fault have more variation in grain size and permeability. It could be that grain size variation plays a more important role in determining permeability than microfractures do.
- The Punchbowl Fault is an ancient fault that has been inactive for over 2.5 million years. It is possible that the microfractures have been sealed through mineral precipitation, altering the permeability structure.

Future Work:

A future study could collect samples from the Punchbowl Fault and make cores out of them. Using a lab permeameter on these cores will help validify the measurements made here.

Figure 8: Sandstone cores made from a sample collected at Muddy Mountains, Nevada, USA. Approximately two inches tall.

References

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