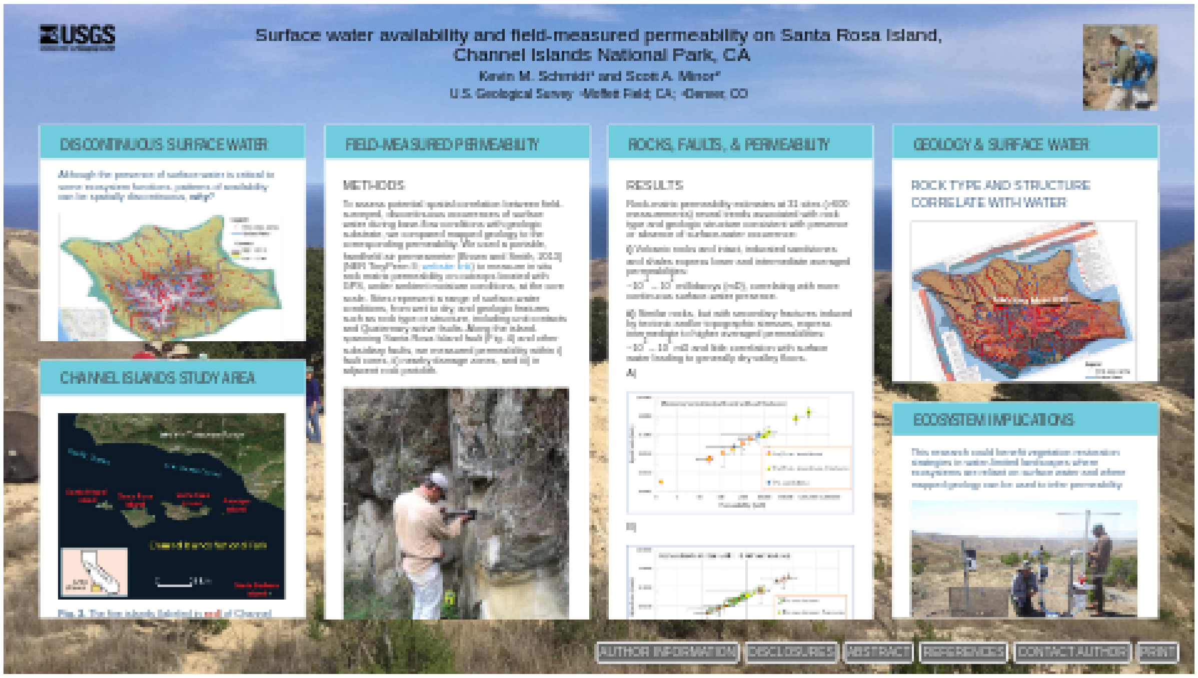
Surface water availability and field-measured permeability on Santa Rosa Island, Channel Islands National Park, California



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AGU FALL MEETING
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DISCONTINUOUS SURFACE WATER

Although the presence of surface water is critical to some ecosystem functions, patterns of availability can be spatially discontinuous, ***why***?

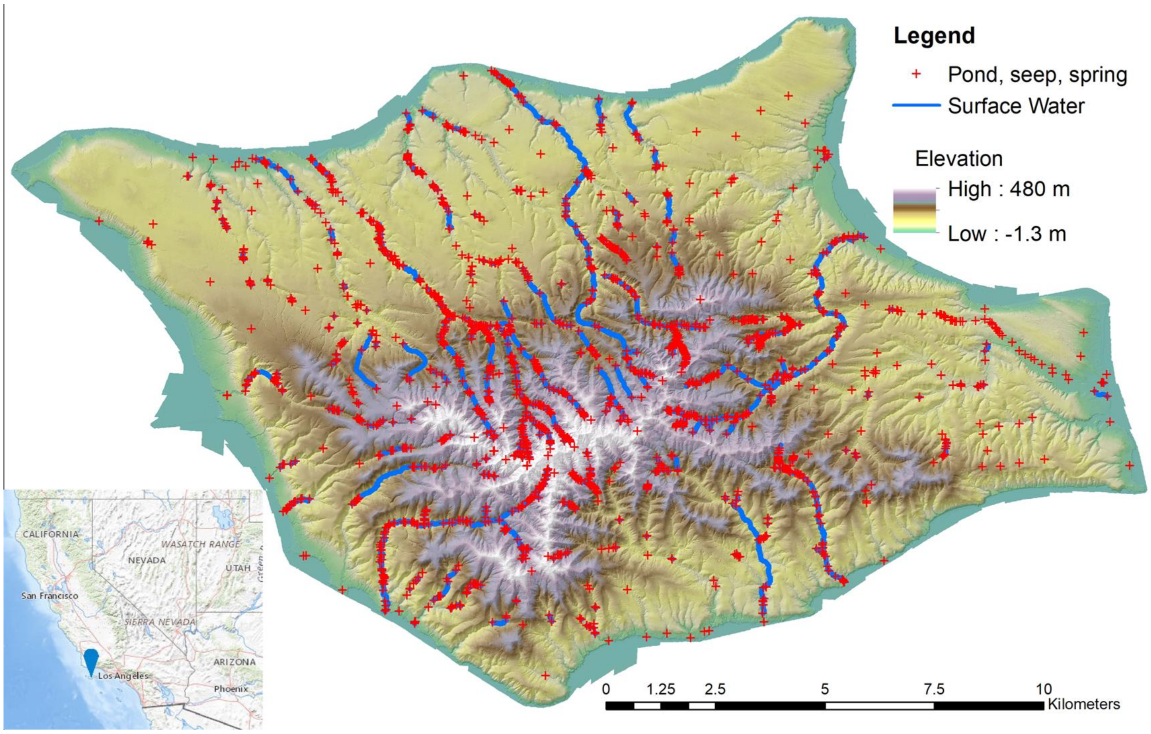


Fig. 1. Color shaded-relief topography of Santa Rosa Island, Channel Islands National Park, California with surface water presence from Power and Rudolph (2018). **Red** crosses denote start/stop points. **Blue** lines denote continuous surface water. Note that largest drainages do not have uninterupted flow from first emergence to outlet.

Power and Rudolph (2018) generated a unique suite of surface-water observations by walking all drainages (2nd order and higher) on Santa Rosa Island and recording locations of upslope starting and downslope ending points with GPS. These measurements followed a major five-year drought, from 2012 to 2017, and are thought to represent low, base-flow conditions. They covered 335 km of stream channel with over 1100 geo-tagged observations. Surface-water features identified include pools (standing water generally >1 m in length), springs (water emerging from ground with flow on surface for < 3 m in length), and surface water in trunk drainage continuously present for >3 m in length.

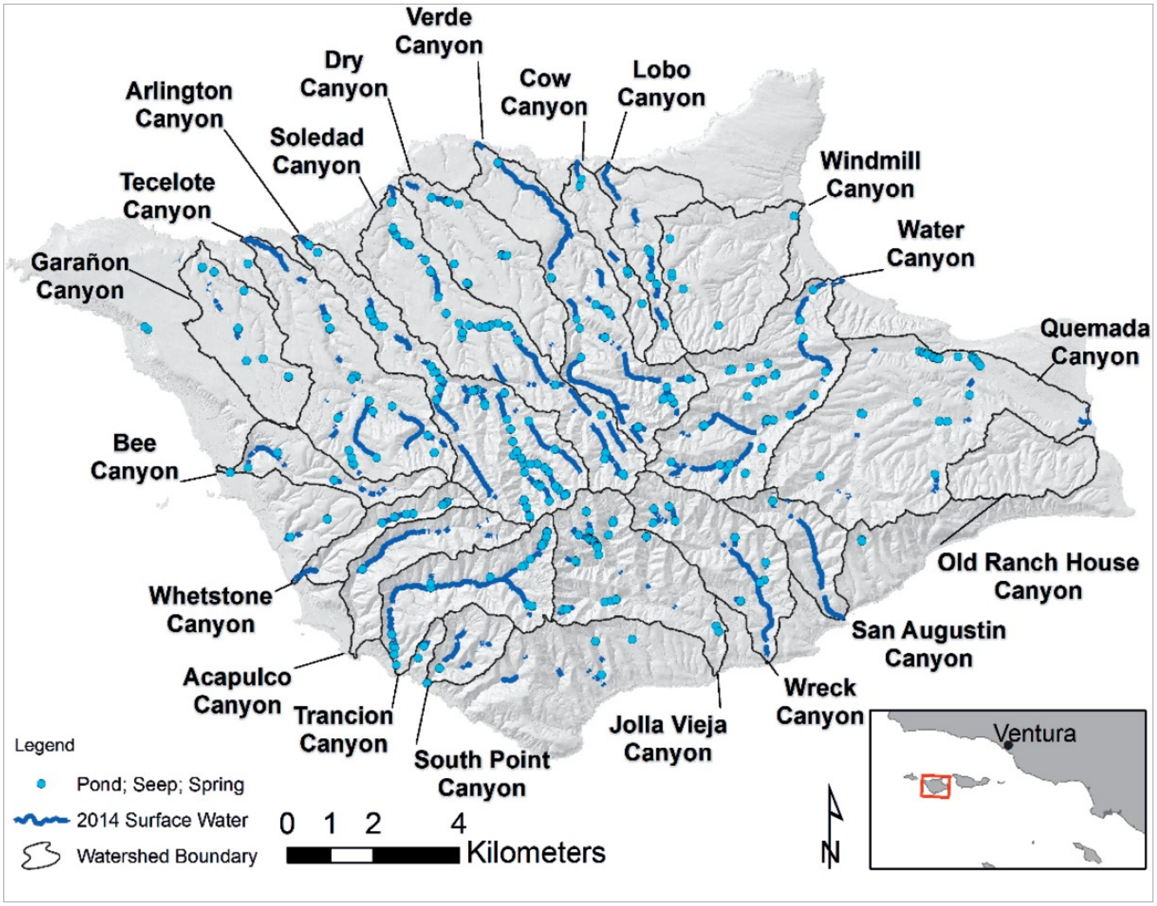


Fig. 2. Surface water presence on Santa Rosa Island from first channel survey in 2014 (*from* Power and Rudolph, 2018). Of the 293 km of channels examined, 759 water features and 67 km of surface water were observed.

To assess the spatial correlation between the field-surveyed, discontinuous occurrences of surface water during base-flow conditions depicted in Figs. 1 & 2, we compared mapped geology (Weaver et al., 1969; Dibblee et al., 1998) to the corresponding field-measured permeability of characteristic rock types, as well as their fault- deformed equivalents. Permeability is here defined as the ability of porous earth materials to allow fluids (air and water) to pass through it.

CHANNEL ISLANDS STUDY AREA

Fig. 3. The five islands (labeled in **red**) of Channel Islands National Park are located ~20-60 km offshore of southern California.

GEOGRAPHY, CLIMATE & LAND USE

The area is situated in the California Borderlands south of the Santa Barbara Channel and southwest of the Western Transverse Range.

The islands are located in a semi-arid to sub-humid Mediterranean climate characterized by cool, wet winters and warm, dry summers. Cumulative annual rainfall is highly variable ranging from 20 to 100 cm per year (Redmond and McCurdy, 2005).

Ranching and domestic livestock grazing, beginning in 1844 and continuing for 150 years, introduced non-native ungulates that negatively impacted native plant communities resulting in increased soil erosion. Present restoration efforts aim to restore soil cover and native vegetation.

GEOLOGY OF SANTA ROSA ISLAND

The Channel Islands consist mainly of variably deformed marine and nonmarine sedimentary rocks and deposits that range in age from Jurassic to the present. These strata record a long history of continental-margin sedimentation, and deposits as young as middle Pleistocene record considerable protracted deformation that includes Neogene and Quaternary transtensional-to-transpressional faulting, folding, and large clockwise vertical-axis rotations of the crustal blocks (Namson and Davis, 1988; Luyendyk, 1991). The east-striking, sinistral Santa Rosa Island fault bisects the island roughly in half (Fig. 4). The northern portion of the island is exemplified by relatively low elevation and moderate relief, with intact bedrock stratigraphy underlying early to middle Pleistocene marine wave-beveled platforms mantled by extensive eolian and alluvial deposits of of middle Pleistocene to Holocene age. South of the island-spanning fault, the landscape is rugged with much greater dissection, exposed bedrock, and topographic relief.

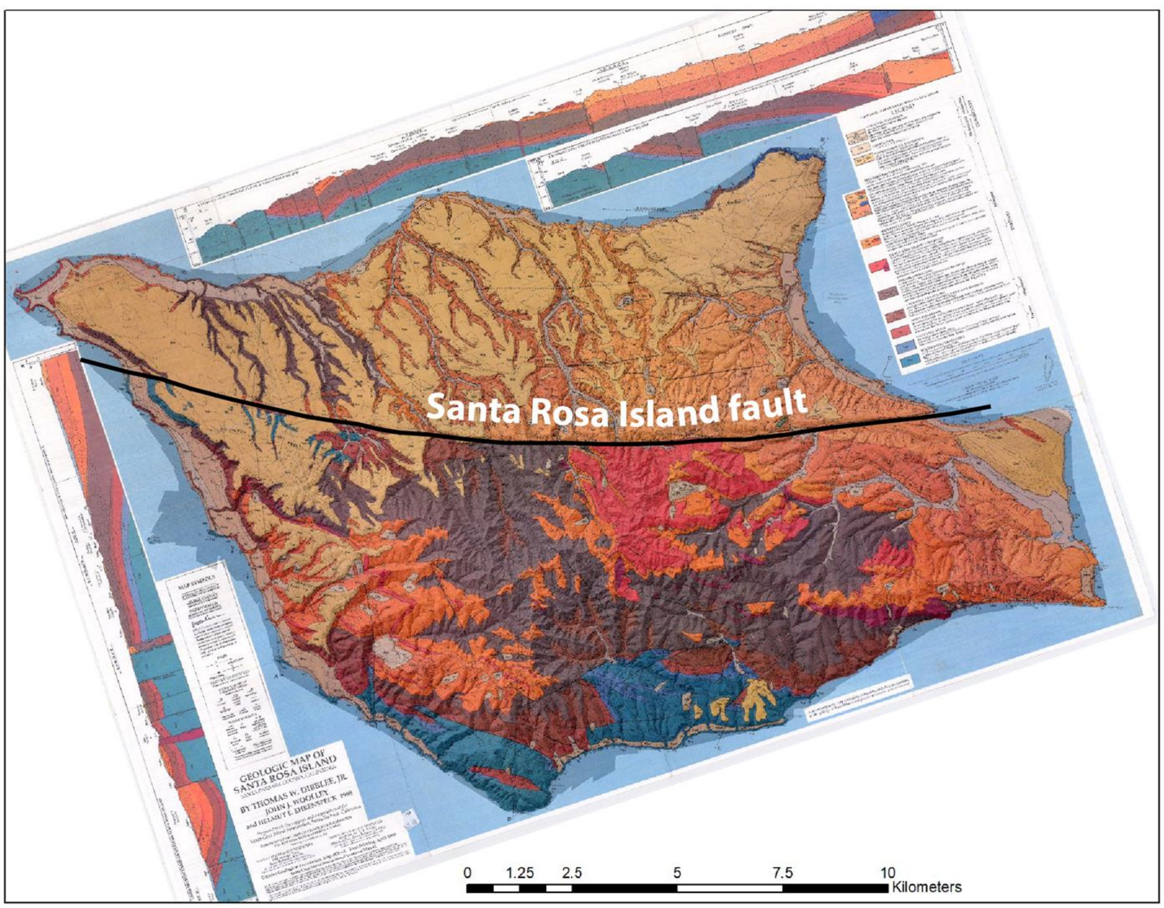


Fig. 4. Bedrock geology (Dibblee et al., 1998) showing prominent Santa Rosa Island fault (SRIF) bisecting the island; targeted for permeability measurements.

FIELD-MEASURED PERMEABILITY

METHODS

To assess potential spatial correlation between field-surveyed, discontinuous occurrences of surface water during base-flow conditions with geologic substrate, we compared mapped geology to the corresponding permeability. We used a portable, handheld air permeameter (Brown and Smith, 2013)(NER TinyPerm II; website link (http://www.ner.com/site/systems/item/27-tinyperm.html)) to measure in situ rock matrix permeability on outcrops located with GPS, under ambient moisture conditions, at the core scale. Sites represent a range of surface-water conditions, from wet to dry, and geologic features such as rock type or structure, including unit contacts and Quaternary active faults. Along the island-spanning Santa Rosa Island fault (Fig. 4) and other subsidiary faults, we measured permeability within i) fault cores, ii) nearby damage zones, and iii) in adjacent rock protolith.

Fig. 5. Measuring permeability of marine sedimentary bedrock using TinyPermII field instrument. Author (Minor) waiting for permeability measurement to complete above channel bottom with surface water.

To operate the permeameter, a rubber-tipped nozzle is pressed against the earth material and air is withdrawn from the material with a single stroke of the syringe (Fig. 5). As air is pulled from the sample, a microcontroller unit simultaneously monitors the syringe volume and the transient vacuum pulse created at the sample surface to estimate material permeability. Numerous measurements were taken at an outcrop to evaluate variability. Empirical calibration relations determined for the instrument (Brown and Smith, 2013) were used to estimate both matrix permeability as well as the effective fracture-flow aperture. The effective fracture-flow aperture width was determined experimentally and represents the equivalent permeability of a single gap, of a given aperture, between two polished rock slabs.

MEASUREMENT SITES

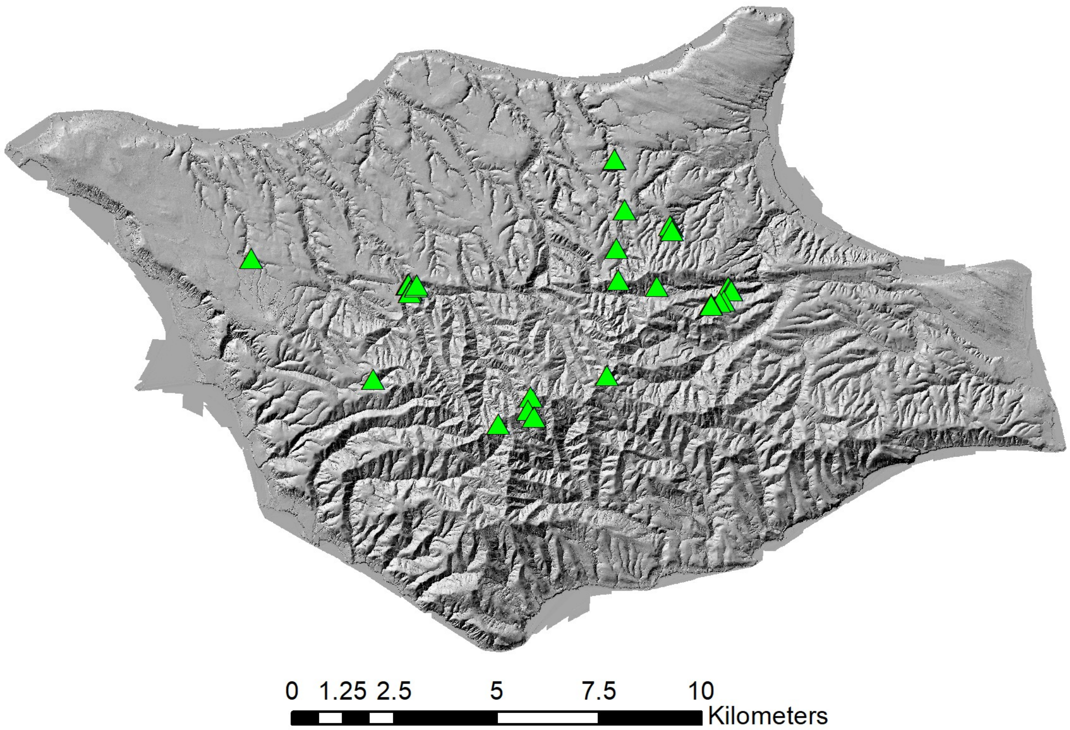


Fig. 6. Lidar hillshade image of Santa Rosa Island showing locations of permeability measurements at 31 sites (**green** triangles) relative to island-spanning Santa Rosa Island fault (see Fig. 4) and landscape features.

ROCKS, FAULTS, & PERMEABILITY

RESULTS

Rock-matrix permeability estimates at 31 sites (>600 measurements) reveal trends associated with rock type and geologic structure consistent with presence or absence of surface-water occurrence:

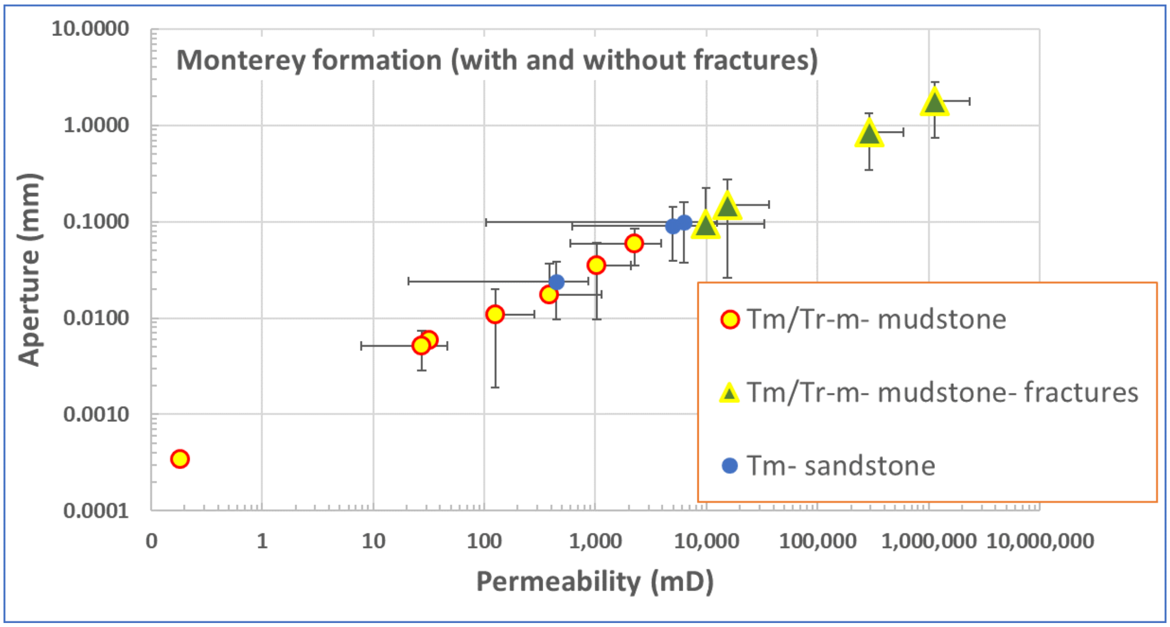
i) Volcanic rocks and intact, indurated sandstones and shales express lower and intermediate averaged permeabilities:

~10^{-1} – 10^{2} millidarcys (mD), correlating with more continuous surface-water presence.

ii) Similar rocks, but with secondary fractures induced by tectonic and/or topographic stresses, express intermediate to higher averaged permeabilities:

~10^{3} – 10^{6} mD and little correlation with surface water leading to generally dry valley floors.

A)



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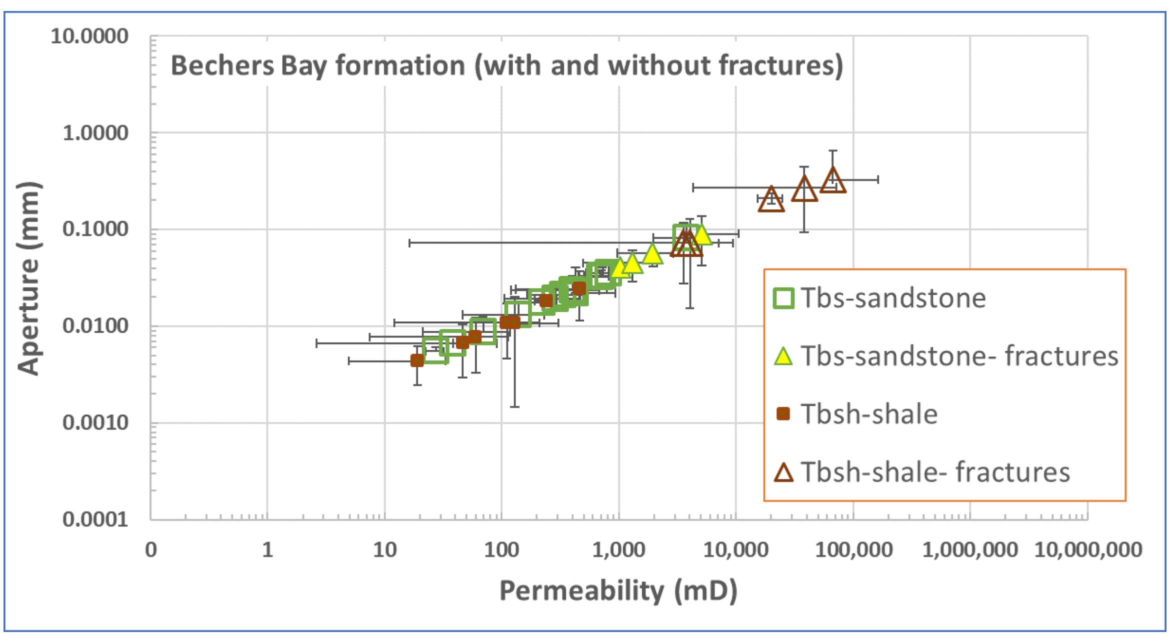

C)

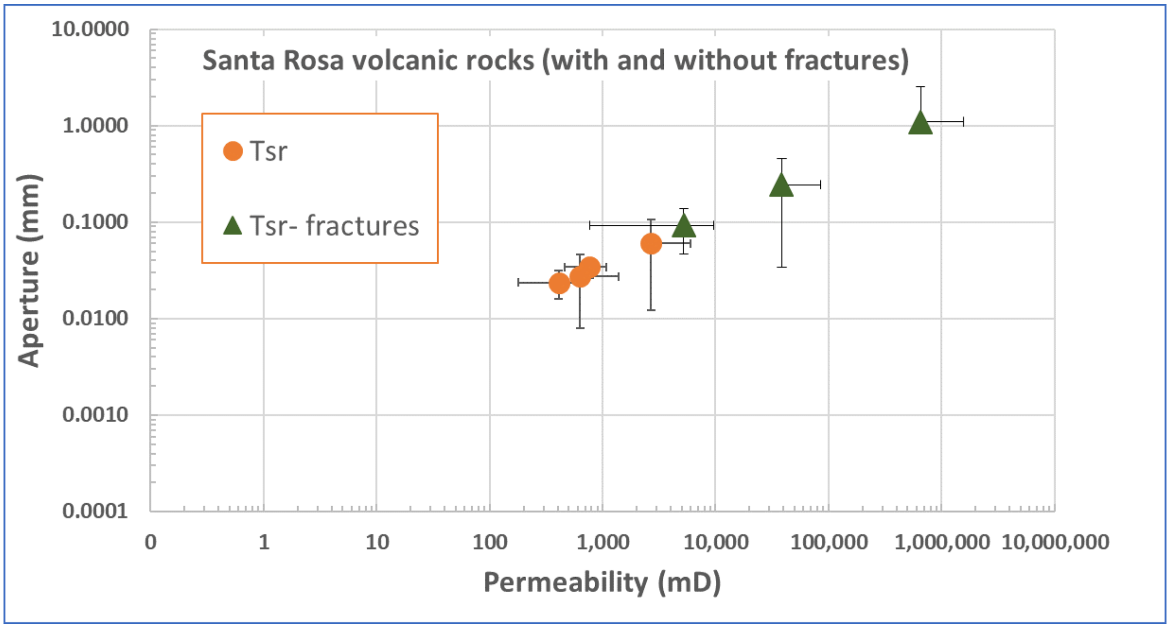

Fig. 7. Log-log plot of field-measured rock-matrix permeability and effective fracture-flow aperture width for: A) intact Monterey formation (Tm) sandstone and mudstone, B) Bechers Bay formation (Tbs) sandstone and shale, and C) Santa Rosa submarine volcanic rocks (Tsr) as well as their fractured equivalents (triangles).

Fig. 8. Permeability measurement on older marine sedimentary rock with low primary permeability, but high secondary permeability from accompanying secondary fractures.

iii) Faults may act as both conduits and barriers to water flow with clay-rich, sheared, and comminuted cores exhibiting low averaged permeability:

$\sim 10^{-1} - 10^{2}$ mD,

whereas adjacent damage zones containing fractured rock exhibit intermediate to higher permeabilities:

$\sim 10^{2} - 10^{7}$ mD.

Outside the damage zones, non-fractured rock protoliths generally express lower permeability:

$\sim 10^{0} - 10^{3}$ mD.

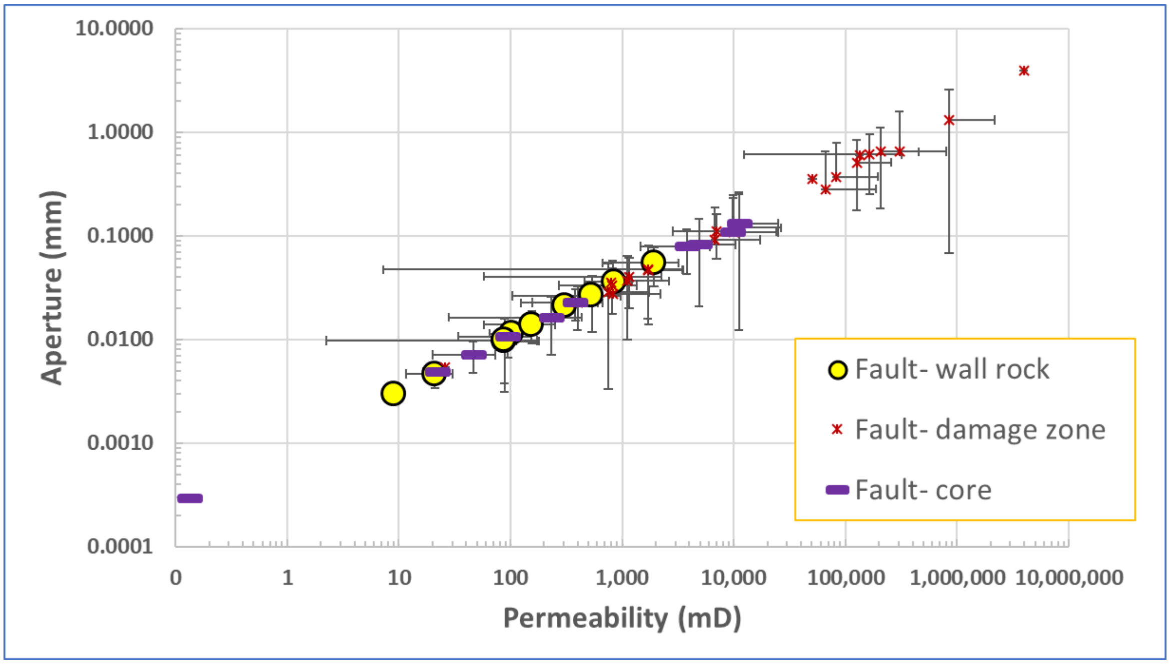

Fig. 9. Log-log plot of field-measured rock-matrix permeability and effective fracture-flow aperture width for sites associated with fault-induced rock deformation.

GEOLOGY & SURFACE WATER

ROCK TYPE AND STRUCTURE CORRELATE WITH WATER

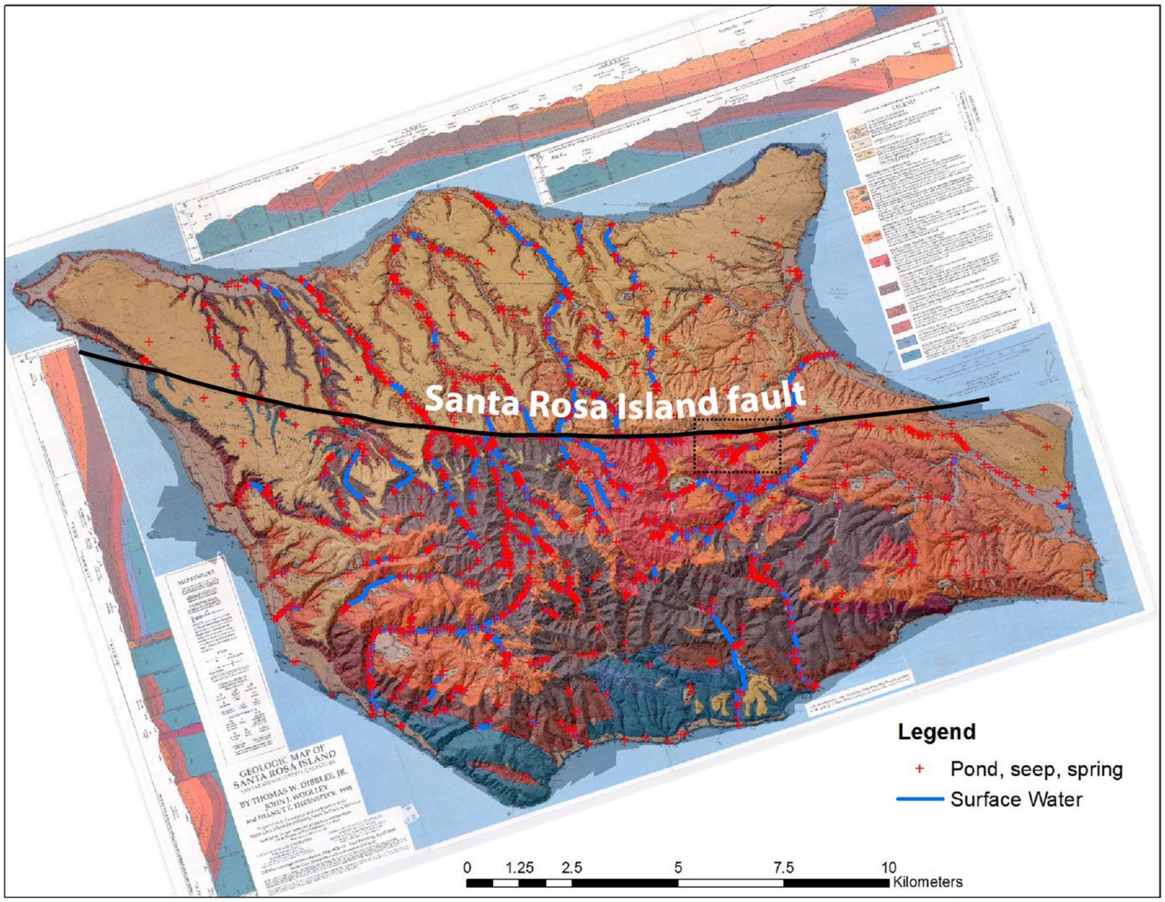

Fig. 10. Bedrock geology map by Dibblee et al. (1998) overlain with field-observed surface water (**blue**). Note dashed-line box denoting Fig. 11 extent. Relations observed are:

- Volcanic rocks (**red**) are more prone to express surface water than fractured marine sediments (**beige** and **orange**)

- Younger marine sediments (**beige**) host dry channels except for drainage originating south of SRI fault

- Surface water is sparse in older marine shale (**orange**) units, likely because of secondary fracture permeability that promotes downward movement of water below the ground surface.

- Bedding and fracture planes impart local permeability anisotropy as reflected in observed reduced permeability in directions perpendicular to such planes.

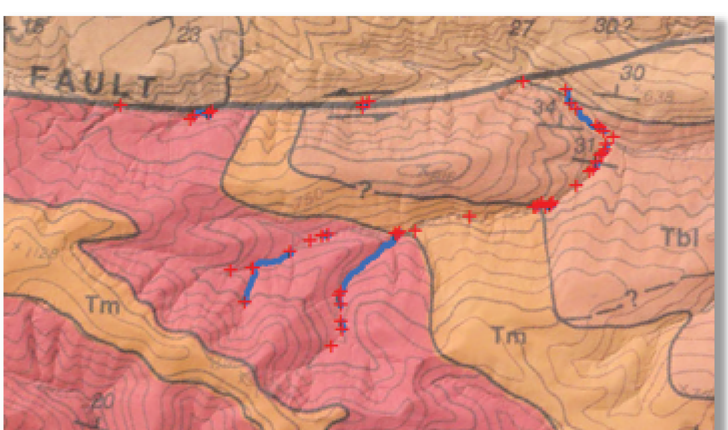

Fig. 11. Close up of part of Fig. 10 (see figure for location) with numerous ponds in blue dots and water springs/sinks as **red** crosses along sinistral Santa Rosa Island fault trace. Note, surface water is present in volcanic rocks (Tsr, **scarlet**), but absent at contact with overlying marine sediments of Monterey Shale (Tm, **orange**).

Observations throughout the island reveal that water presence correlates with:

- Contacts between different units, which forces groundwater to the surface

- Bedding orientation of bedrock; dip slopes are associated with surface water more than anti-dip slopes

FAULTS

- Faults can act as both conduits and barriers to groundwater flow

- Laterally continuous fault-core gouge, and juxtaposition of rock types with contrasting permeabilities, act as effective barriers to cross-fault flow, forcing groundwater to the surface.

Fig. 12. Santa Rosa Island fault exposure juxtaposing old beach sands (Qobs), fault core (SRIFc), inner damage zone (SRIFidz), and outer damage zone (SRIFodz) of marine sedimentary bedrock. Dashed blue lines added to highlight unit boundaries. Author (Minor) taking permeability measurement in fault core.

ECOSYSTEM IMPLICATIONS

This research could benefit vegetation restoration strategies in water-limited landscapes where ecosystems are reliant on surface water and where mapped geology can be used to infer permeability.

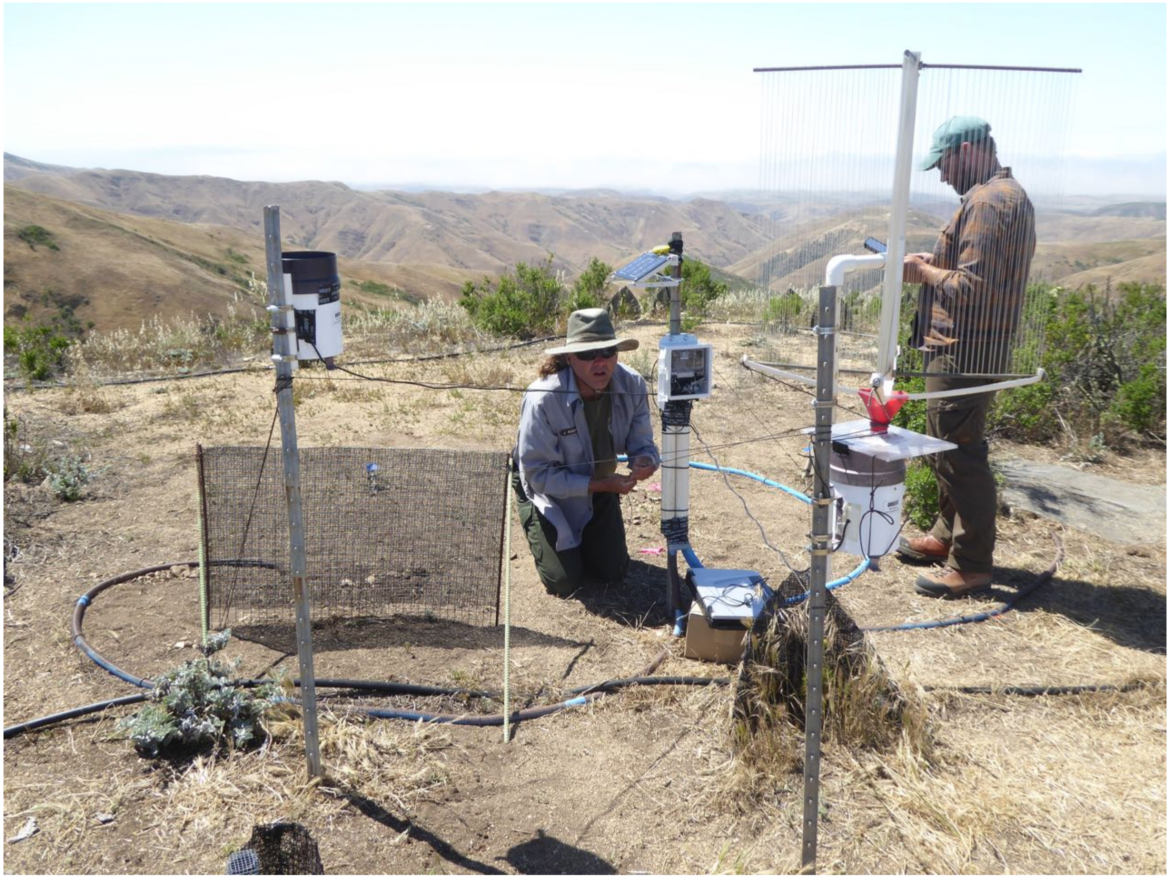

Fig. 13. Rain gage, fog drip harp, and soil moisture monitoring array with data logger installed to assess restoration strategy effectiveness. Note filaments in vertical "fog fence" (below white cylindrical rain gage) and fog drip harp, connected to retrofitted rain gage, used to trap atmospheric moisture.

Fig. 14. Temporary "fog fencing" installed in "Cloud Forest" indended to trap fog drip, hence naturally watering restored native vegetation. Note darker wet patches adjacent to fencing and under Island Oak (*Quercus tomentella*) trees relative to lighter colored rock exposed by accelerated erosion from legacy grazing practices.

For more information see U.S. Geological Survey project websites:

GeoMapping for Integrated Science (https://www.usgs.gov/centers/gmeg/science/geomapping-integrated-science)

and

Channel Islands Field Station (https://www.usgs.gov/centers/werc/science/channel-islands-field-station?qt-science_center_objects=0#qt-science_center_objects)

DISCLOSURES

This information has been peer-reviewed, but is preliminary and is subject to revision. It is being provided to meet the need for timely best science, on the condition that neither the U.S. Geological Survey no rthe U.S. Government shall be held liable for any damages resulting from its authorized or unauthorized use.

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ABSTRACT

To assess spatial correlation between field-surveyed, discontinuous occurrences of surface water during base-flow conditions on Santa Rosa Island, Channel Islands National Park with geologic substrate, we compared mapped geology to the corresponding permeability at GPS-located sites. We used a portable, handheld air permeameter (NER TinyPerm II) to measure in situ rock permeability on outcrops, under ambient moisture conditions, at the core scale. Sites represent a range of surface water conditions, from wet to dry, and mapped geologic features such as rock type or structure, including unit contacts and Quaternary faults. Along the island-spanning Santa Rosa Island fault and other subsidiary faults, we measured permeability within fault cores and damage zones, and in adjacent rock protolith.

Permeability estimates at 31 sites (>600 measurements) reveal four trends associated with rock type and geologic structure consistent with presence or absence of surface-water occurrence:

i) Volcanic rocks and intact, indurated sandstones and shales express lower and intermediate permeabilities:

(~10^{-1} – 10^{2} milli-Darcy, mD), correlating with more continuous surface water presence.

ii) Similar rocks, but with secondary fractures induced by tectonic and/or topographic stresses, express intermediate to higher permeabilities:

(~10^{3} – 10^{6} mD) and little correlation with surface water leading to generally dry valley floors.

iii) Faults may act as both conduits and barriers to flow with clay-rich cores exhibiting low permeability:

(~10^{-1} – 10^{2} mD) whereas adjacent damage zones contain broken rock with intermediate to higher permeabilities (~10^{2} – 10^{7} mD).

Outside the damage zones, non-fractured rock protoliths generally express lower permeability (~10^{0} – 10^{3} mD). Laterally continuous fault-core gouge, and juxtaposition of rock types with contrasting permeabilities, likely act as effective barriers to cross-fault flow, forcing groundwater to the surface. iv) Bedding, parting, and fracture planes appear to impart local permeability anisotropy as reflected in observed reduced permeability in directions perpendicular to such planes. This research could benefit vegetation restoration strategies in water-limited landscapes where ecosystems are reliant on surface water and where mapped geology can be used to infer permeability.

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