Geophysical imaging of hydrothermal shallow degassing in Yellowstone National Park

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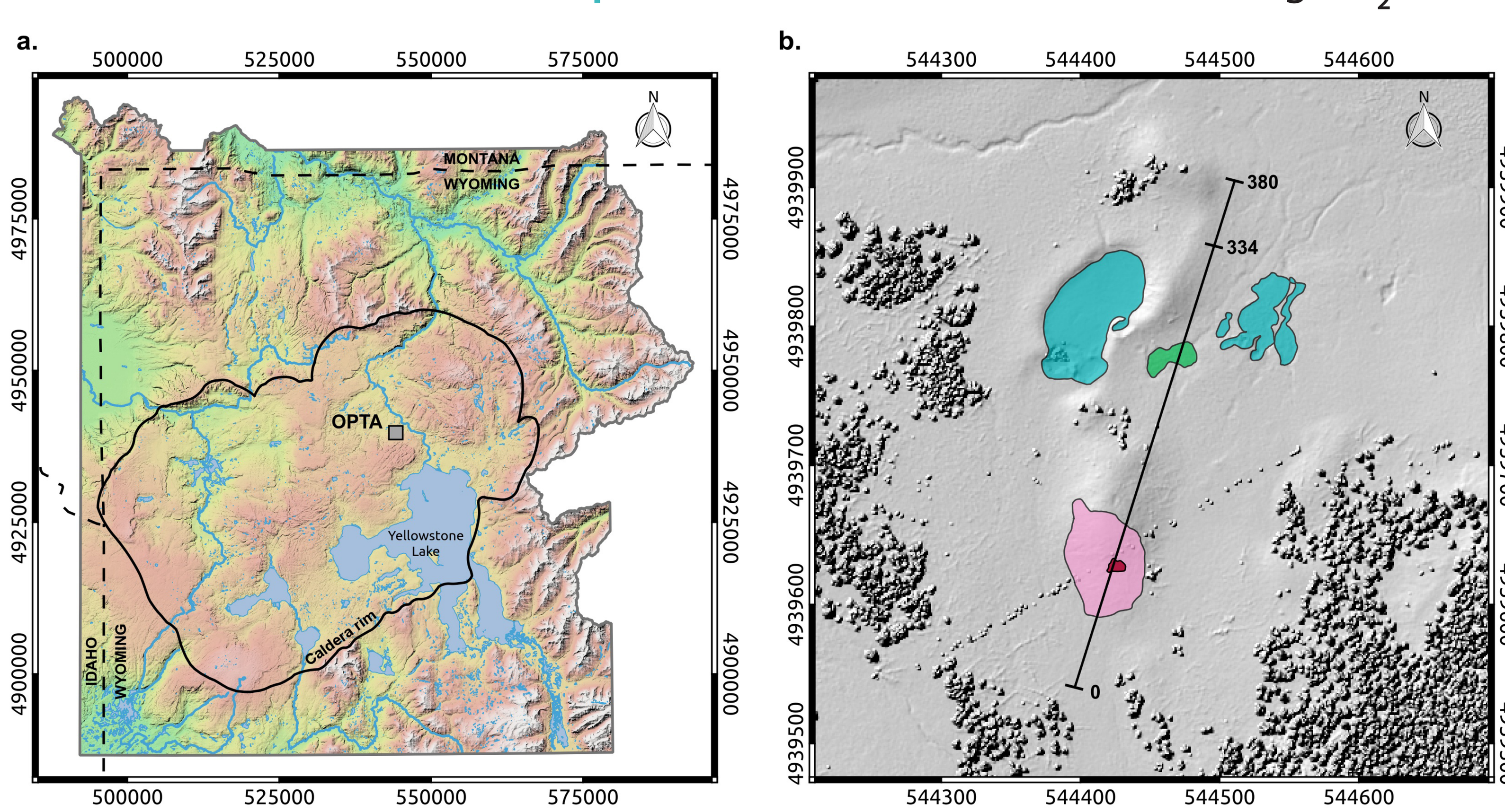
The Yellowstone Plateau Volcanic Field, which hosts over 10,000 thermal features, is the world's largest active continental hydrothermal system, yet very little is known about the shallow ``plumbing" system connecting hydrothermal reservoirs to surface features. Knowledge of fluid pathways and subsurface physical properties would improve understanding of liquid-gas phase separation depth, large-scale hydrological flow paths and fracture systems controlling the location, chemistry and microbiology of hot springs. Since drilling in these sensitive hydrothermal areas is rare, near-surface geophysical techniques are generally the only available options to image the shallow subsurface. Here we present the results of geophysical investigations of shallow hydrothermal degassing in Yellowstone. In addition to electrical methods, we combined seismic refraction and surface-wave profiling to estimate pressure and shear wave velocities (*Vp* and *Vs*, respectively), together with Poisson's ratio. We also applied a rock physics model, based on Hertz-Mindlin contact theory, to quantitatively predict subsurface porosity and saturation from seismic velocities.

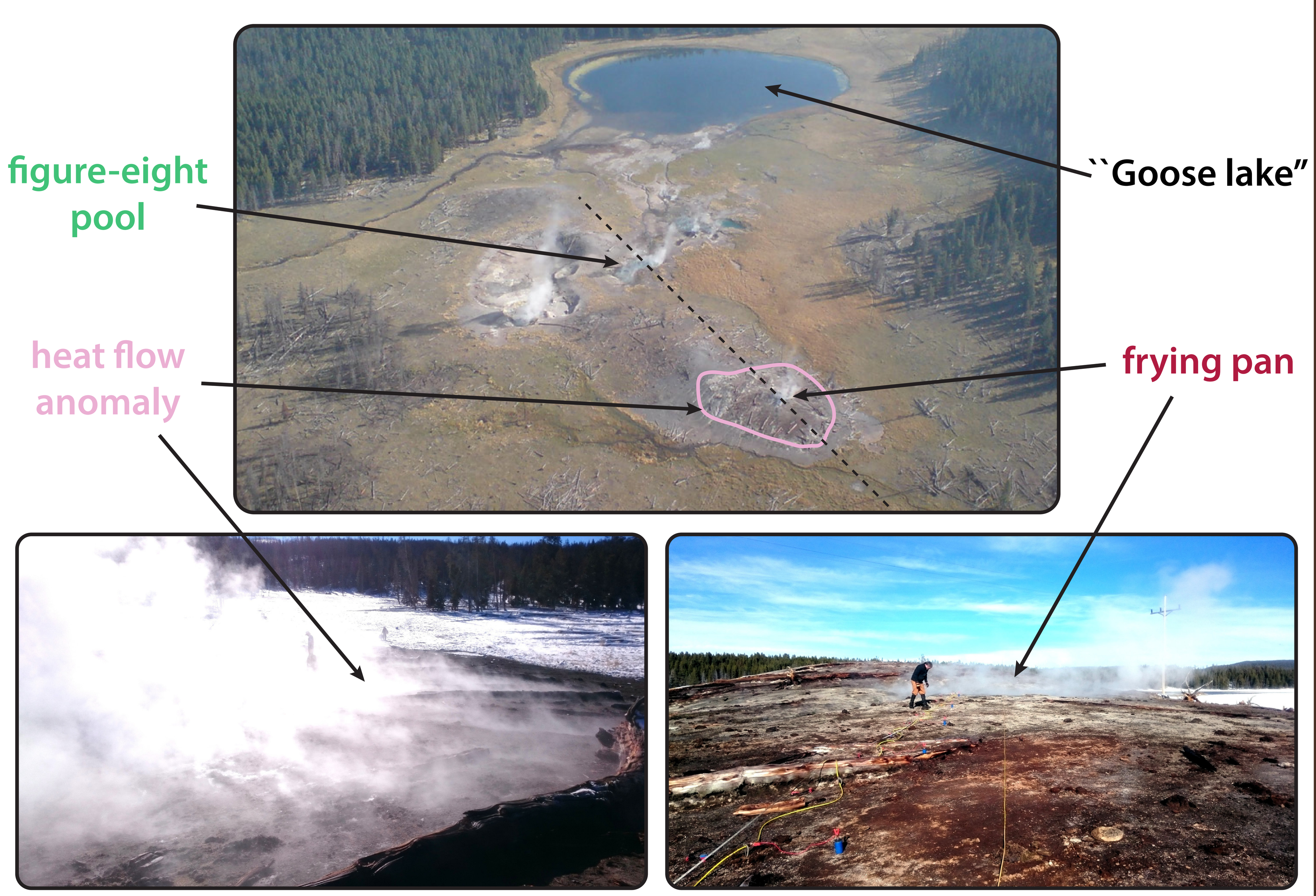
1 Obsidian Pool Thermal Area

Eastern part of the Yellowstone caldera, within Mud Volcano thermal area
=> **rhyolitic** tuff covered w/ **glacial tills**
=> **acid-sulfate thermal pools** w/ 21.9°C<T<84.0°C and strong CO_2 **influx**



Lidar data available at http://opentopography.org

Geophysical data collected along a 380 m SSW-NNE transect crossing:
=> an acid-sulfate thermal pool, referred as **``figure-eight" pool** (245-260 m)
=> a heat flow anomaly (50-120 m) [*Hurwitz et al.*, 2012]
=> intense degassing feature, referred as **``frying pan"** (86-96 m)

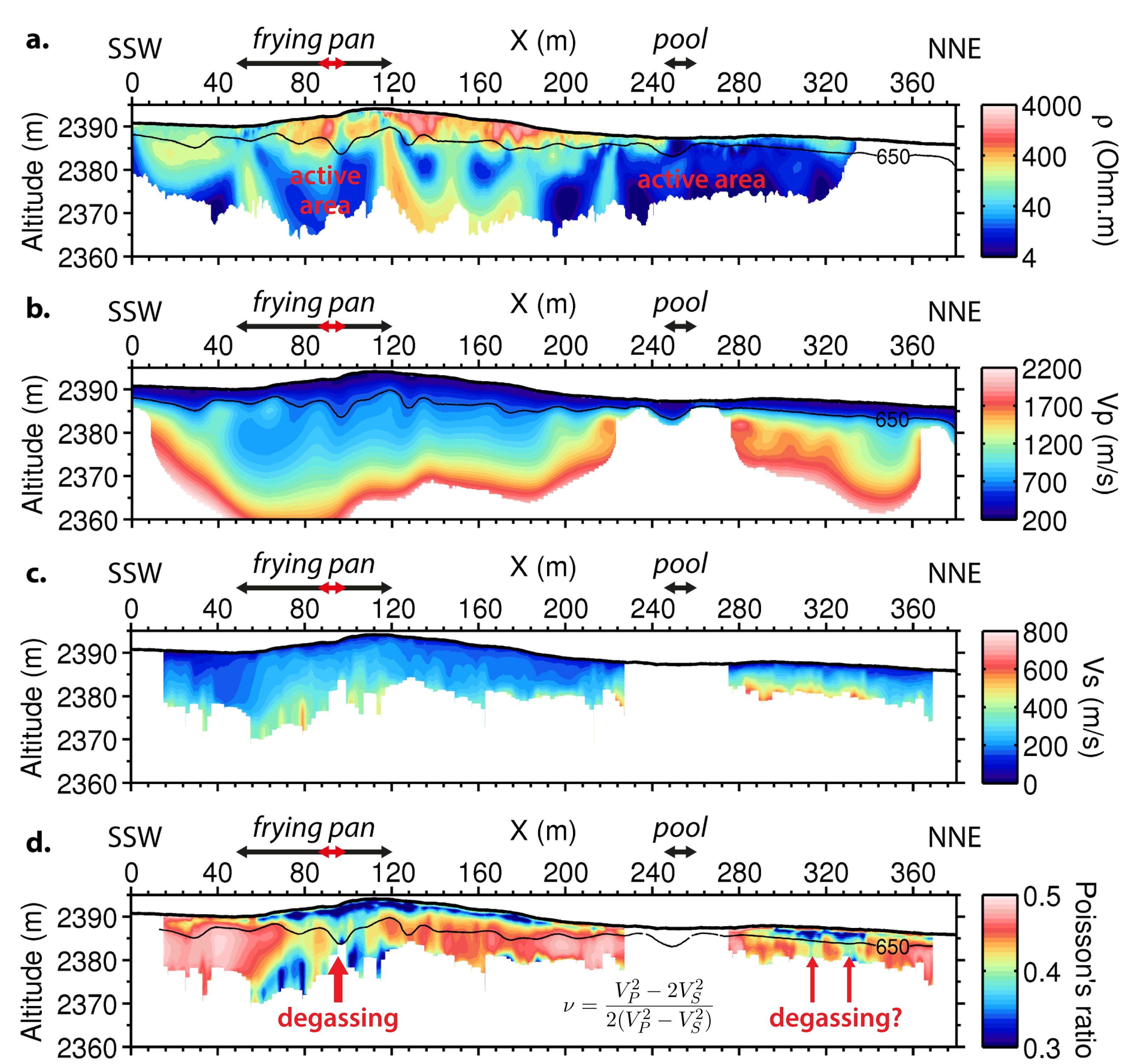


2 Geophysical Data Processing

Electrical resistivity tomography
=> apparent electrical resistivity data inverted with R2 software to retrieve **electrical resistivity ρ** [*Binley and Kemna*, 2005]
http://www.es.lancs.ac.uk/people/amb/Freeware/R2/R2.htm

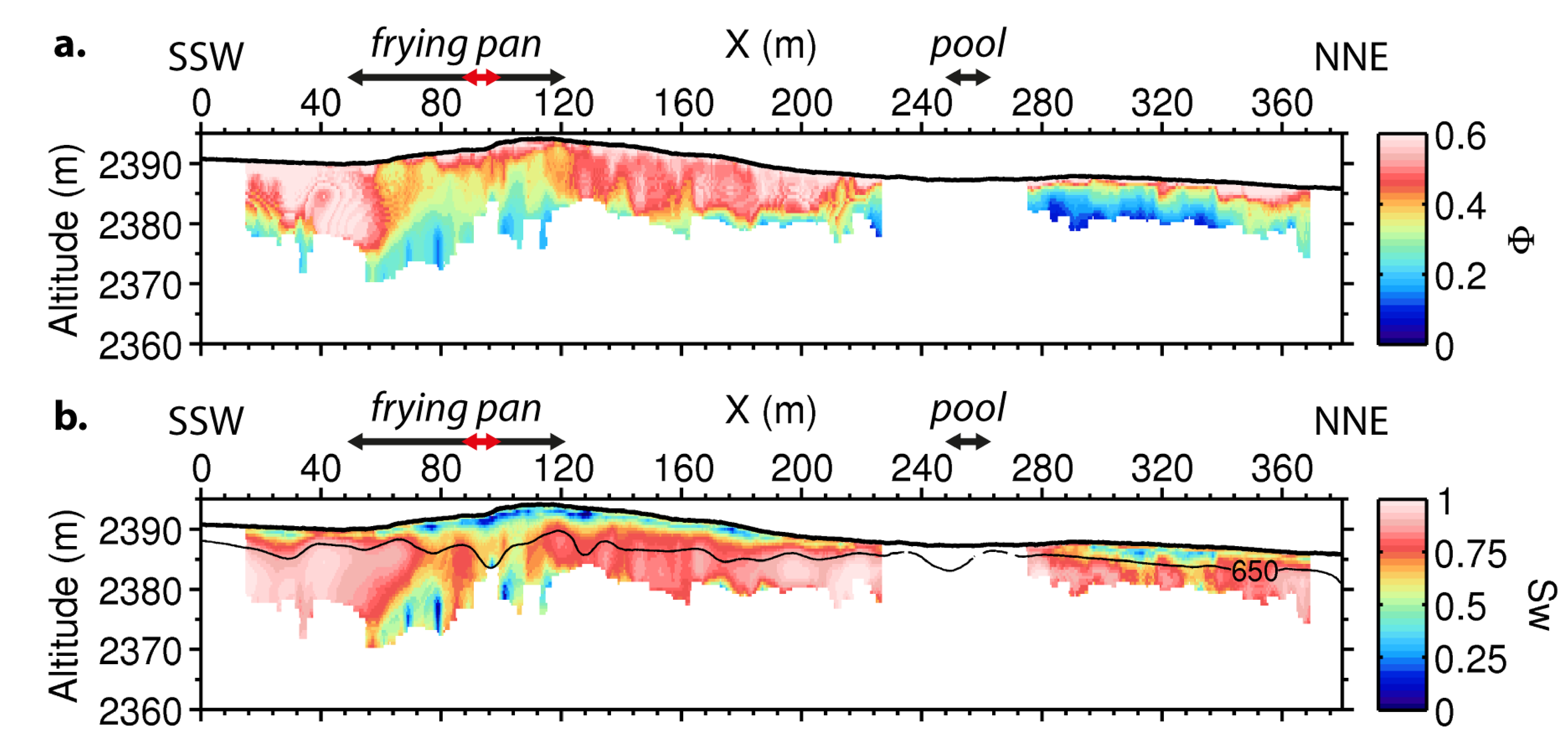
Seismic refraction tomography
=> first arrivals inverted with MATLAB traveltime tomography code to retrieve **compressional wave velocity *Vp*** [*St. Clair*, 2015]

Surface-wave profiling
=> surface-wave dispersion inverted with SWIP open software to retrieve **shear wave velocity *Vs*** [*Pasquet and Bodet*, 2016]
https://github.com/SWIPdev/SWIP/releases



3 Rock Physics Modeling

Hertz-Mindlin contact theory [*Mindlin*, 1949], as formulated by *Helgerud et al.* [1999]:
=> medium described as an **aggregate of randomly packed spheres**
=> altered rhyolitic composition w/ **40% quartz - 10% feldpar - 50% clay**
=> *Vp* and *Vs* inverted to retrieve **porosity *Φ*** and **water saturation *Sw***



- Shallow high porosity and low saturation beneath the hill => **dry soil**
- Low porosity and saturation at depth below the frying pan => **degassing**
- High saturation outcropping in the pool => **local water table**

4 Conclusions

We investigated the subsurface structure of a shallow hydrothermal system in Yellowstone to depths of 15-30 m, using electrical resistivity, P-wave velocity and S-wave velocity.

- **Electrical resistivity** provide first-order images of the **hydrothermal fluids' flow paths** and differentiate **hydrothermally active from inactive areas**.
- **Poisson's ratio** shows good sensitivity to **saturation**, separating the gas-saturated area below the "frying pan" from water-saturated areas surrounding it.
- **Rock physics modeling** validates these qualitative interpretations and provides realistic **estimates of porosity and saturation**.

These results have been published in Geophysical Research Letters [Pasquet et al., 2016].

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