Physical Properties of the Bishop Tuff (RORD REU Program)

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Isabelle Caban, Amherst College, Amherst, MA, United States, Kathryn Cornette, UNC Chapel Hill, Chapel Hill, United States, Melodie E French, Rice University, Houston, TX, United States, David L Goldsby, Brown Univ, Providence, United States, Lars N Hansen, University of Minnesota - Twin Cities, Department of Earth and Environmental Sciences, Minneapolis, United States, Steven Johnson, Missouri S&T, Rolla, United States, Lauren Kreeger, College of Wooster, Earth Sciences, Wooster, OH, United States, Christine McCarthy, Lamont-Doherty Earth Observatory, Columbia University, Palisades, United States, Matej Pec, Massachusetts Institute of Technology, Earth, Atmospheric and Planetary Sciences, Cambridge, MA, United States, Cade Quigley, Colorado College, Colorado Springs, CO, United States, Anna Redanz, Georgia Institute of Technology, Atlanta, United States, Francesca Riley, University of Michigan, Ann Arbor, United States, Eleanor Ruos, Scripps College, Claremont, United States, Heather M Savage, University of California Santa Cruz, Earth and Planetary Sciences, Santa Cruz, United States, Philip A Skemer, Washington University in St Louis, Department of Earth and Planetary Sciences, St. Louis, MO, United States, Hannah Tebbens, The College of William and Mary, Williamsburg, United States and Jessica Wen, Colgate University, Hamilton, United States

Background

Bishop Tuff

- ***Long Valley, California***
- welded rhyolitic tuff composed of ash and pumice lapilli
- deposited 0.76 Ma during a large caldera-forming eruption, estimated as a VEI 7 event
- eruptive remnant: Long Valley Caldera

***Above**: Members of 2022 RORD cohort investigating faults in the Bishop Tuff*

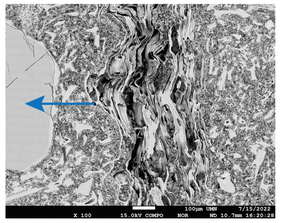
***Above**: deformed Bishop Tuff*

Rock mechanics experiments

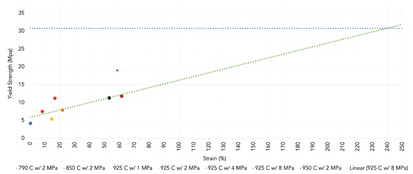
- pyroclastic deposits have unique mechanical and hydraulic properties
- rock mechanics experiments can give insight to these properties and how volcanic tuff deforms over time
- 2022 RORD REU program:
  - ***5 labs***
  - ***10 students***
  - ***8 faculty collaborators***

University of Minnesota Isabelle Caban, Lauren Kreeger, Lars Hansen

- **Research Objectives**: Conducted welding experiments on unconsolidated Bishop Tuff and yield strength tests on both unconsolidated and densely welded tuff.
- **Measurements**: strain %, yield strength (MPa), density (g/cm^3)



- **Figure 1**: SEM image of deformed pumice. Bubbles in the pumice are highly deformed and crinkly, indicative of high temperatures and stresses. The blue arrow indicates the direction of applied stress.



Apparatus: **Uniaxial compression apparatus**

- **Figure 2**: strain (%) versus yield strength (MPa) from uniaxial compression tests. Samples were loaded at room temperature and squished until failure to calculate yield strength. Density and yield strength were used as proxies for the degree of welding.

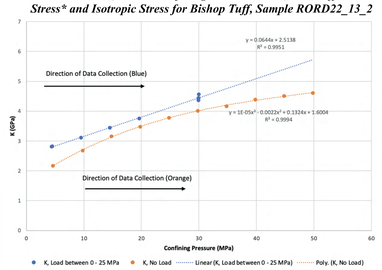
Conclusions: The degree of welding primarily correlates with strain at high temperature and would require 120 - 250 % strain to achieve welding similar to naturally welded Tuff.

Massachusetts Institute of Technology Francesca Riley, Anna Redanz, Ulrich Mok, Matej Pec

Apparatus: **New England Research Autolab 3000**

- **Research Objectives**: Physical properties and strength of Bishop Tuff
- **Measurements**: pore pressure, permeability, bulk modulus, shear modulus, Young's modulus
- **Figure 3**: bulk modulus, K (GPa), versus confining pressure (MPa) with isotropic stress and differential stress.
  - Data was collected from low to high confining pressure.

Bulk Modulus (K) versus Confining Pressure (MPa) with Differential Stress* and Isotropic Stress for Bishop Tuff, Sample RORD22_13_2



*Loads between 0-25 MPa
Differential stress (blue) first, isotropic stress (orange) second

Conclusions: Bulk modulus with isotropic stress increases non-linearly with increasing confining pressure whereas bulk modulus with differential stress (varying between 0 -25 MPa) increases linearly with increasing confining pressure.

Overall motivation

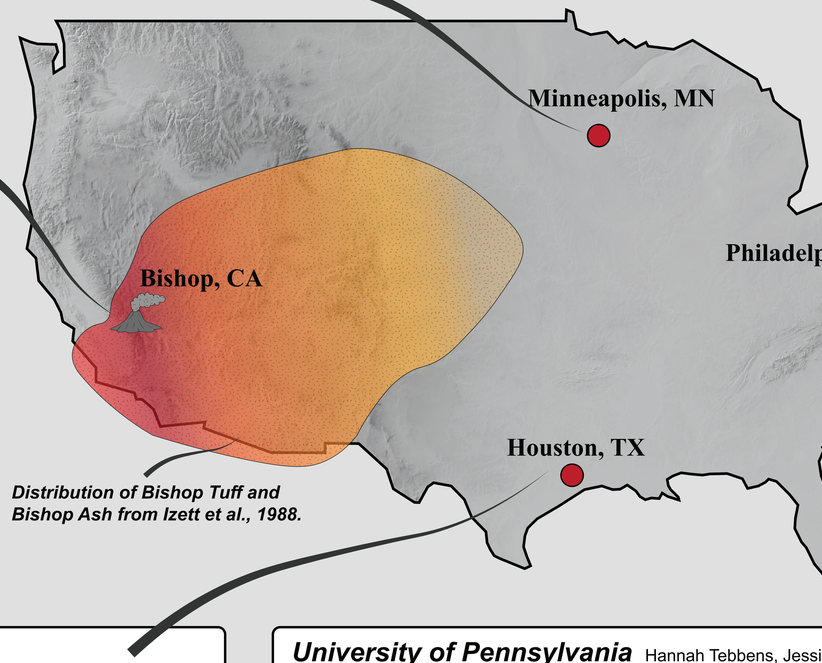
Massive volcanic eruptions often create thick rock sequences that have significantly different mechanical and hydraulic properties from the rest of Earth's crust. Defining the full yield surface for welded tuff provides critical knowledge for understanding and evaluating the mechanical properties of tuff deposits, and may give insight to the mechanisms of explosive volcanic eruptions.

About RORD *Faculty Leaders*: Heather Savage, Philip Skemer, Lars Hansen

Research Opportunities in Rock Deformation (R.O.R.D.) is an NSF-funded REU (Research Experiences for Undergraduates) internship program that provides laboratory and field-based research experience in rock mechanics and structural geology. R.O.R.D. is designed to introduce undergraduate students from diverse backgrounds in earth science, geoscience, and engineering to the field of rock deformation, even if they've never heard of it before! We are currently accepting applications for our 2023 cohort. Please see sites.wustl.edu/rord for more information.

***Left**: Faculty leaders Phil Skemer, Heather Savage, and Lars Hansen.*

***Right**: 2022 RORD Cohort in Yosemite National Park. Not pictured: Steven Johnson.*

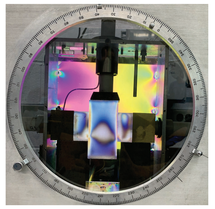


Distribution of Bishop Tuff and Bishop Ash from Izett et al., 1988.

Lamont-Doherty Earth Observatory

Eleanor Ruos, Cade Quigley, Jacob Tielke, Christine McCarthy

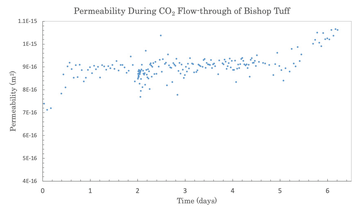
Apparatus: **New England Research Autolab 2000 HPHT**

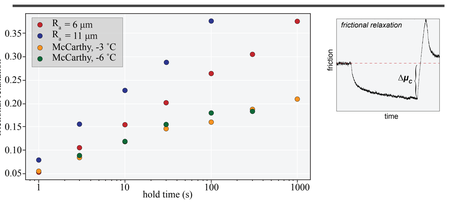


Apparatus: **Cryogenic Biaxial Friction Apparatus**

- **Research Objectives**: Carbon sequestration capacity of the Bishop Tuff and Ice-on-rock friction experiments using the Bishop Tuff.
- **Measurements**: pore pressure, permeability, P-wave velocity, acoustic emissions, friction, frictional healing and relaxation, *a - b*

- **Figure 4**: Permeability measurements after liquid CO2 saturation experiment in the Triaxial apparatus. Permeability was recorded every hour over 6 days, and parameters were set to 50 MPa confining pressure and 150°C.



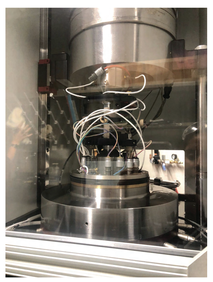


- **Figure 5**: Frictional relaxation measurements from ice-on-rock friction experiments. Blue and red points are from experiments with Bishop Tuff, and green and orange points used granitic rocks. Both tuff experiments were conducted at -6°C and 100 kPa normal stress. R_a values indicate rock surface roughness of sliding surface.

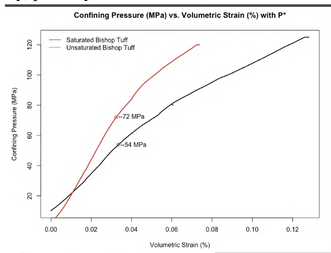
Conclusions: Increasing trends in permeability (**Fig. 4**) exhibits that Bishop Tuff did not sufficiently facilitate carbon mineralization. Ice-on-rock experiments suggest more permeable rocks have higher steady-state friction, frictional relaxation, and frictional healing.

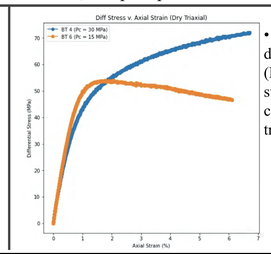
Rice University Kathryn Cornette, Steven Johnson, Melodie French

- **Research Objectives**: The effect of water on P* and finding the brittle-ductile transition zone of the Bishop Tuff.
- **Measurements**: permeability, porosity, bulk modulus, volumetric and axial strain, and pore pressure



Apparatus: **Rapid Rock Triaxial Testing System, RTR-2000**



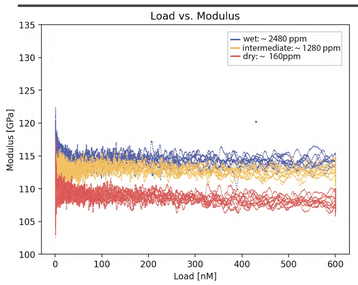


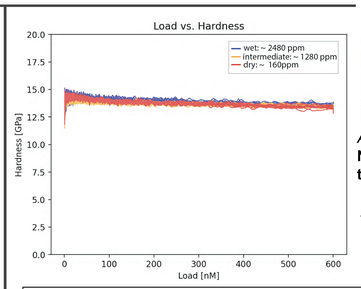
- **Figure 8**: confining pressure (MPa) versus Volumetric strain with P*. Data collected from two isotropic compression tests.
- **Figure 9**: differential Stress (MPa) versus axial strain. Data collected from dry triaxial tests.

Conclusions: Isotropic compression tests (**Fig 8**) showed that the critical hydrostatic pressure, P*, at which inelastic compaction begins, is around 72 MPa under dry conditions and 54 MPa under saturated conditions. Dry triaxial tests (**Fig 9**) showed that the brittle-ductile transition occurs around a confining pressure, Pc, of 15 MPa and a uniaxial compression test revealed an average yield strength of 31 MPa.

University of Pennsylvania Hannah Tebbens, Jessica Wen, David Goldsby, Nir Badt

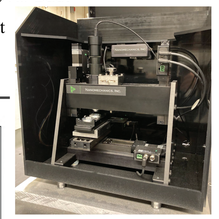
- **Research Objectives**: Investigate the effect of varying amounts of intracrystalline water content on the properties of quartz at room temperature.
- **Measurements**: load (nM), water content (ppm), modulus (GPa)





- **Figure 6**: Load (nM) versus modulus(GPa) for qtz crystals with variable water content. Experiments were conducted on single crystal qtz with water contents varying from 160 to 2480 ppm (H/Si).

Conclusions: Found no significant impact on Hardness or Elastic Modulus at room temperature.



Apparatus: **Nanomechanics Nanoindentor with Berkovich tip**

- **Figure 7**: Load (nM) versus Hardness (GPa) for qtz crystals with variable water content.