Modeling fluid migration in subduction zones: Community perspectives from a MCS RCN workshop

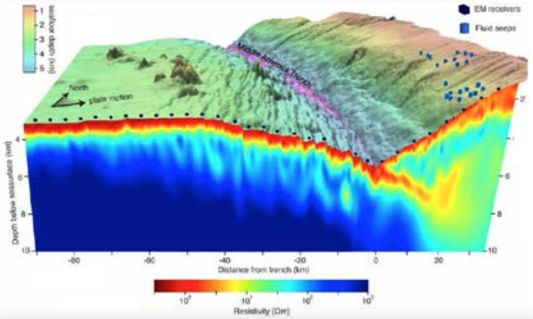
Ikuko Wada and Leif Karlstrom

Modeling Collaboratory for Subduction (MCS):
Community and Numerical Model Building

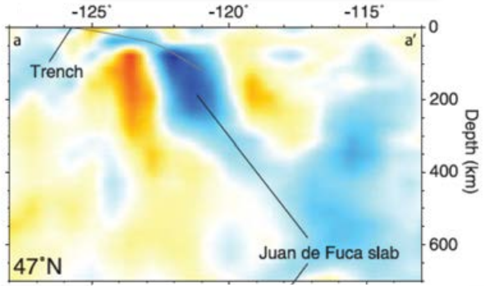
- Modeling framework for multidisciplinary data integration
- Open, reproducible collaboration across the Earth sciences
- Computational geoscience and STEM capacity building

geological constraints

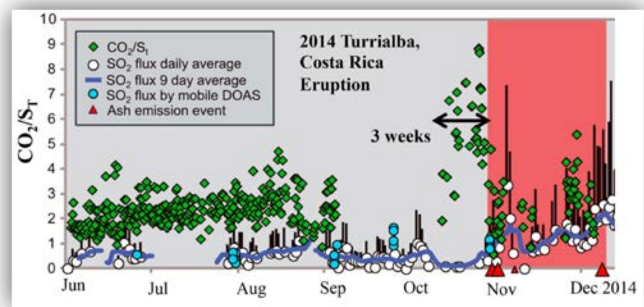
active source and MT

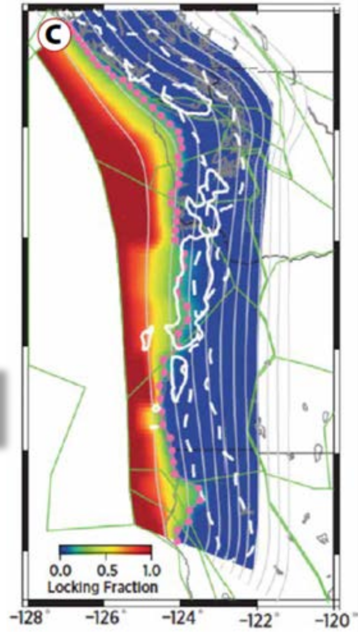


passive source

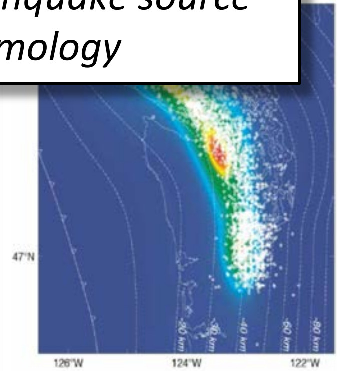


geomorphological constraints

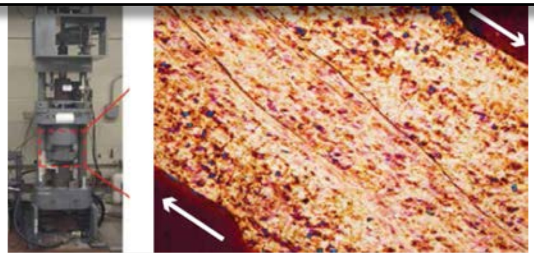




earthquake source seismology



Volcano and earthquake precursors



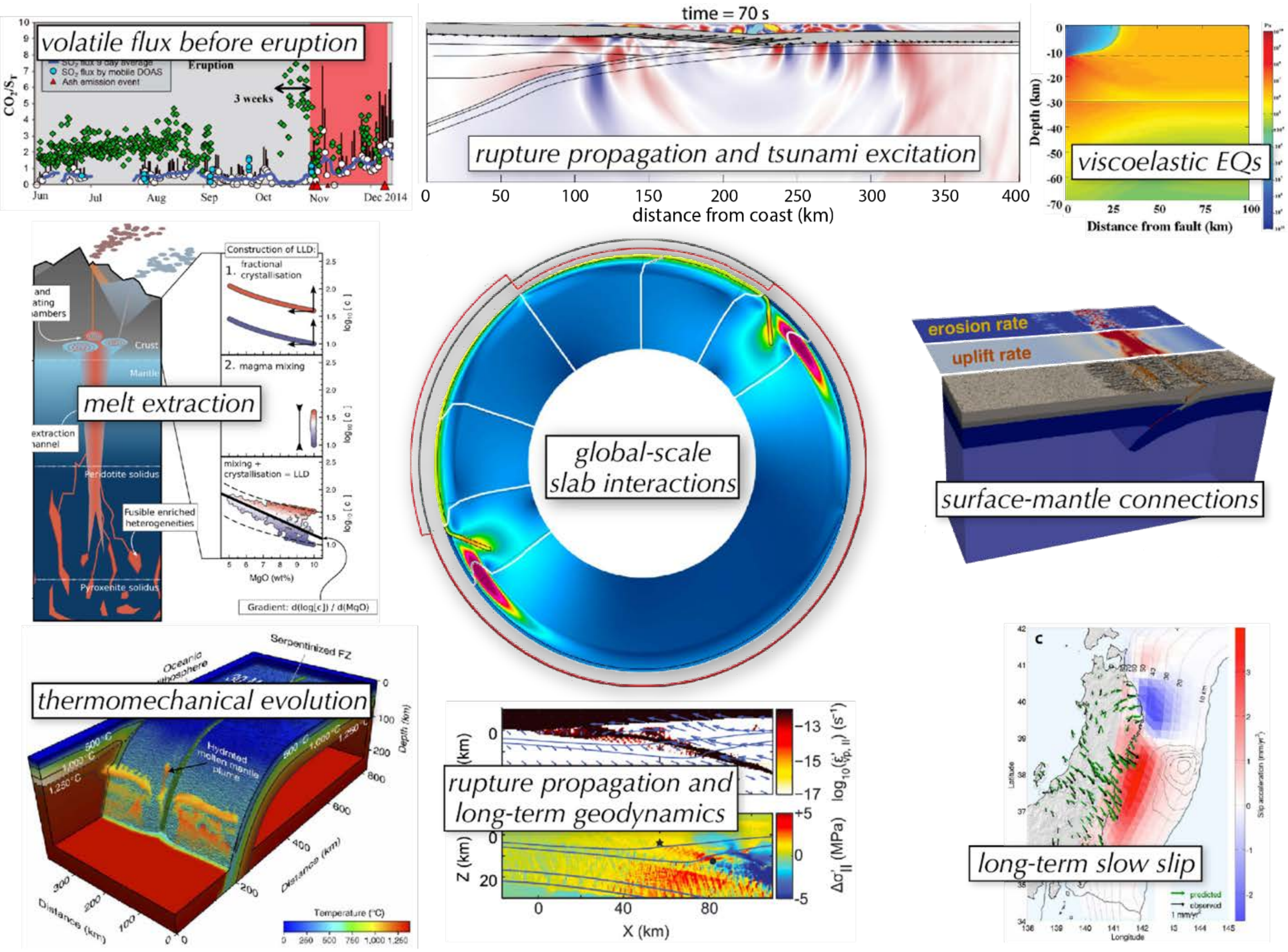
rock mechanics experiments

On- and off-shore geodesy

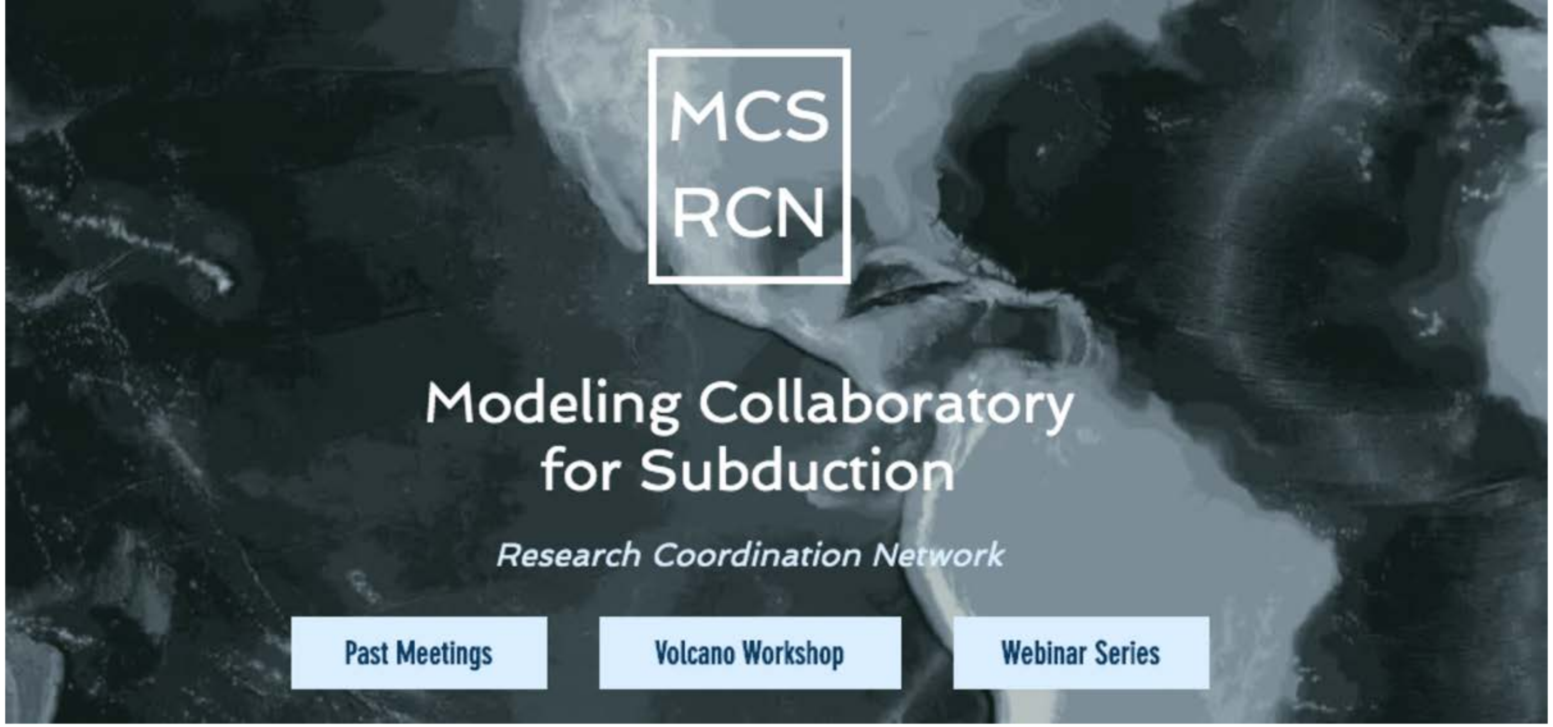
Gomberg et al. (2010); Naif et al. (2015); Chadwell et al. (2015); Schmalzle et al. (2014); Hawley et al. (2016); Tong & Lavier (2017); Proctor & Hirth (2015); W. Behr (pers. comm.); Kristen Cook

MCS addresses the challenge of

- Integrating multi-scale, multi-physics processes
- Understanding the dynamics of subduction earthquakes and volcanoes in a hazards context



Mavrommatis et al. (2014); deMoor et al. (2016); Ueda et al. (2015)van Dinther et al. (2014); Allison & Dunham (2017); McCormack & Hesse (2017); Kozdon & Dunham (2014); Manea et al. (2014) Wilson et al. (2014); Gerault et al. (2012)



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Science Update

Modeling Fluid Migration in Subduction Zones

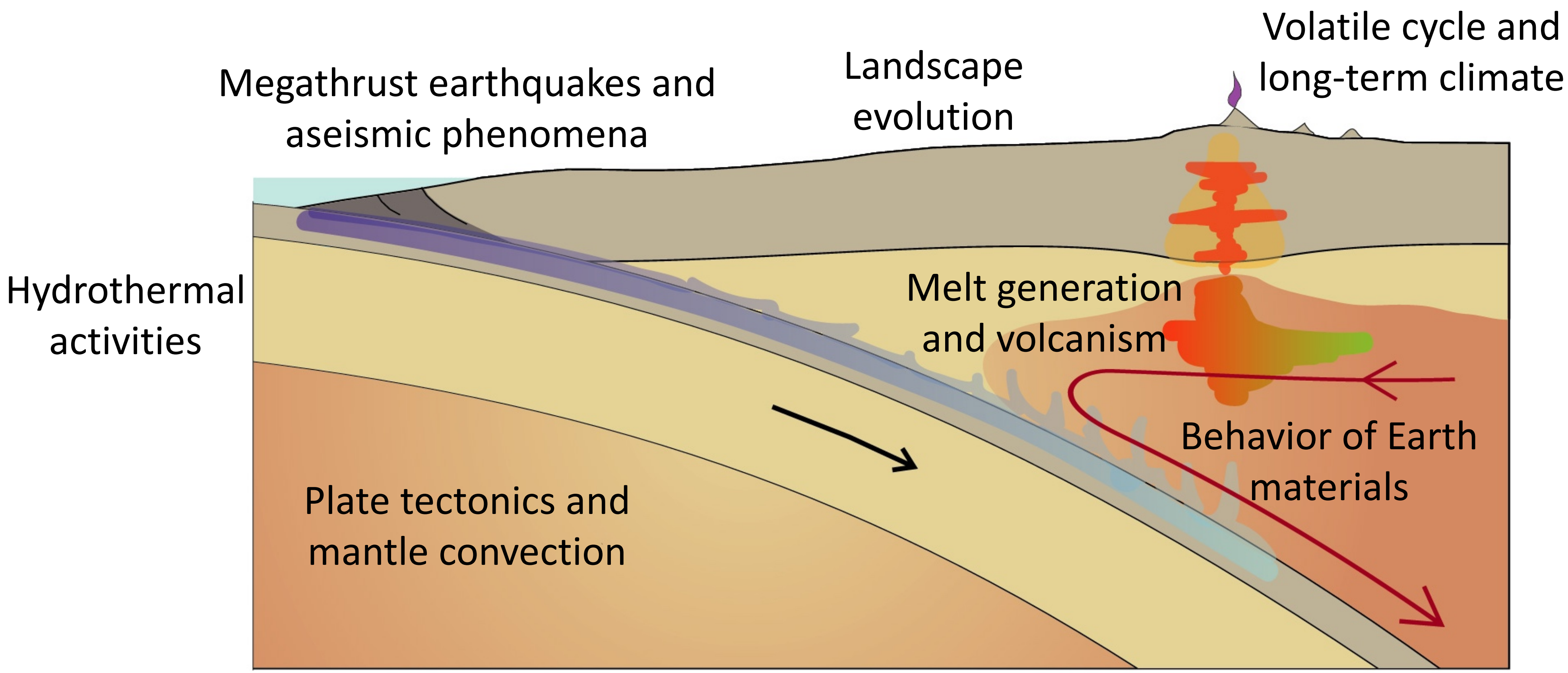
Scientists from different disciplines are working together to identify common challenges in and techniques for modeling fluid migration associated with subduction zone processes.

By Ikuko Wada and Leif Karlstrom

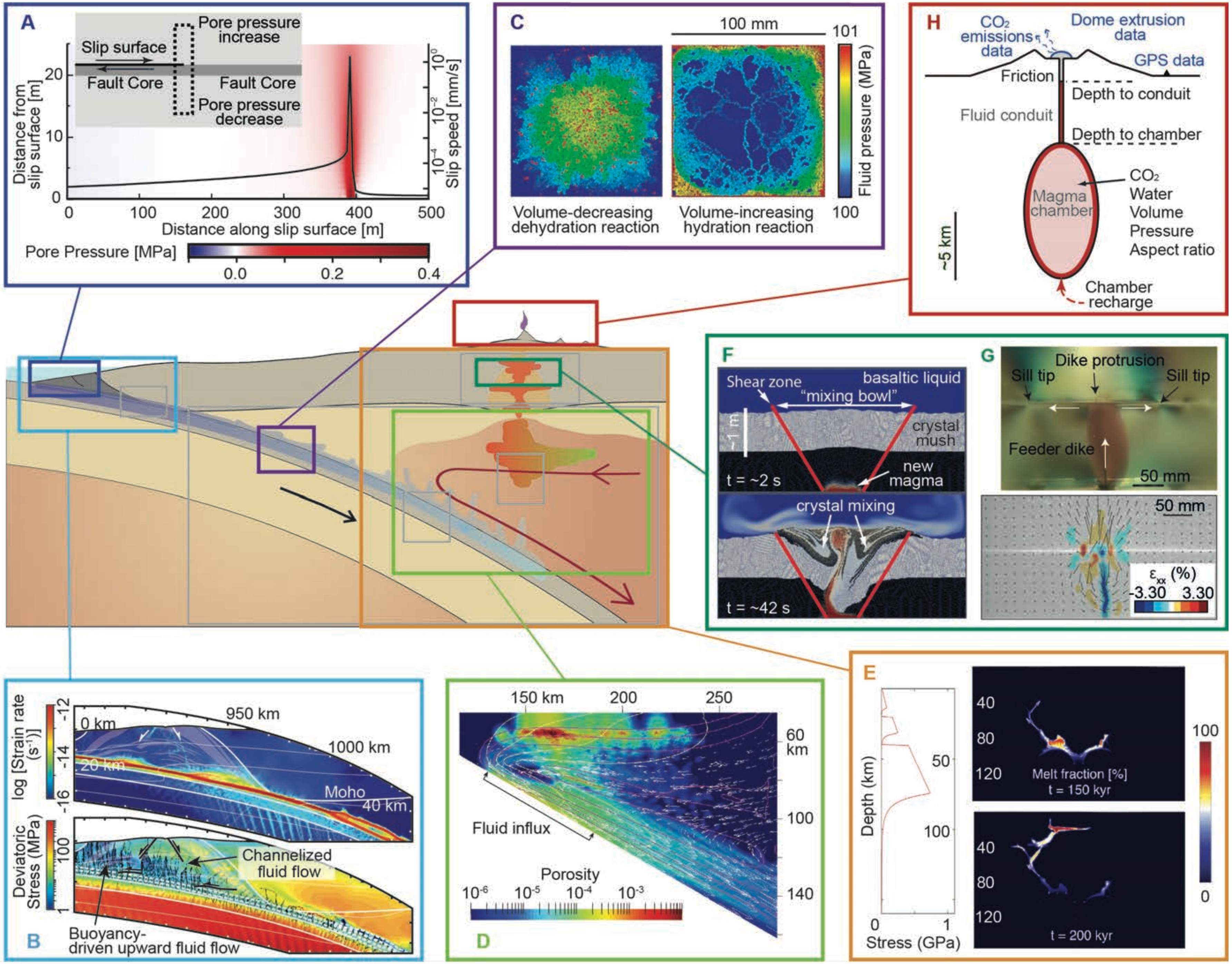
16 June 2020

Credit: John Paul Platt

Fluid Migration



Fluid Transport Models for Selected Subdomains



A. Heimisson et al., 2019
B. Menant et al., 2019
C. Okamoto and Shimizu, 2015
D. Cerpa et al., 2017
E. Keller et al., 2013
F. Bergantz et al., 2015
G. Kavanagh et al., 2018
H. Anderson and Segall, 20130

[*Wada and Karlstrom*, 2020]

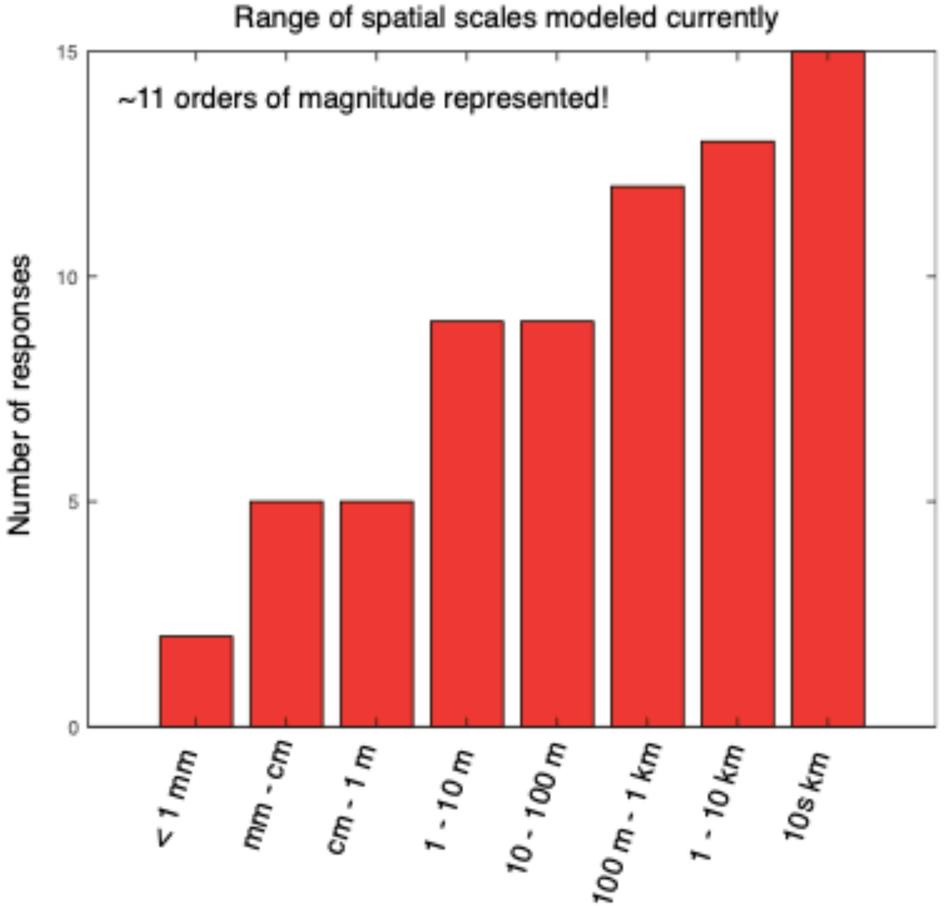
Objectives of the Workshop

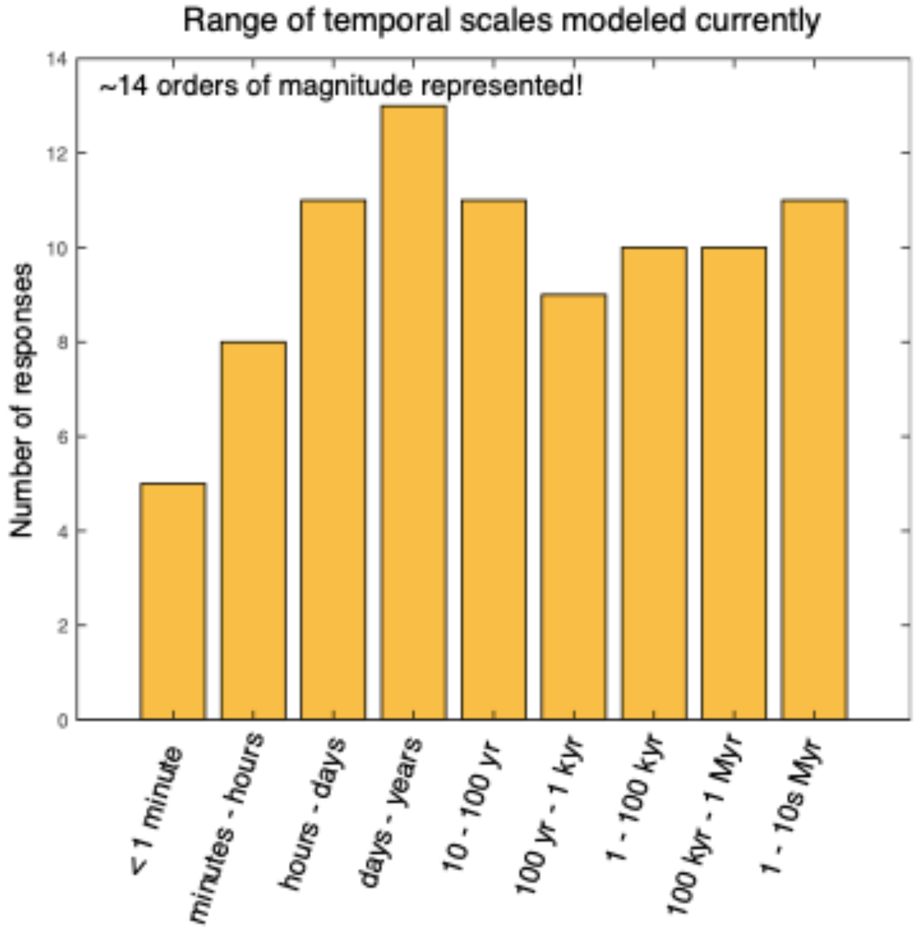
(1) Bring diverse groups of scientists together
(2) Evaluate the current state of our understanding of fluid migration
(3) Identify disconnects among models and knowledge gaps among scientists
(4) Build a community plan for integrative fluid migration modeling

Sessions and *Keynote Speakers*

1. **Models for fluid migration in the subducting material and along/across the subduction interface**
    - 1.1. Fluids in megathrust fault zones – *Taras Gerya*
    - 1.2. Fluid pathways in the slab crust and the role of the subduction interface – *Rachel Lauer*
    - 1.3. Fluid pathways in the slab and the mantle wedge – *Johannes Vrijmoed*
2. **Crust/lithosphere-scale models for magma transport**
    - 2.1. Spatial distribution of volcanoes – *Richard Katz*
    - 2.2. Dynamics of volcanic plumbing systems – *Janine Kavanagh*
    - 2.3. Patterns of crustal magma transport – *Tobias Keller*
3. **Models for microscopic and short-time-scale mechanisms**
    - 3.1. Rock deformation and hydraulic fracturing – *Pengcheng Fu*
    - 3.2. Micromechanics of rock deformation and macroscopic fluid transport – *Viktoriya Yarushina*
4. **Integrating/Bridging processes and models across scales**
    - 4.1. Fluid interactions – *Eric Sonnenthal*
    - 4.2. Advancement through multi-scale modeling – *Diane Arcay*
    - 4.3. Numerical challenges – *Cian Wilson*

"Indicate the ranges of spatial and temporal scales of your subduction fluid migration research efforts."



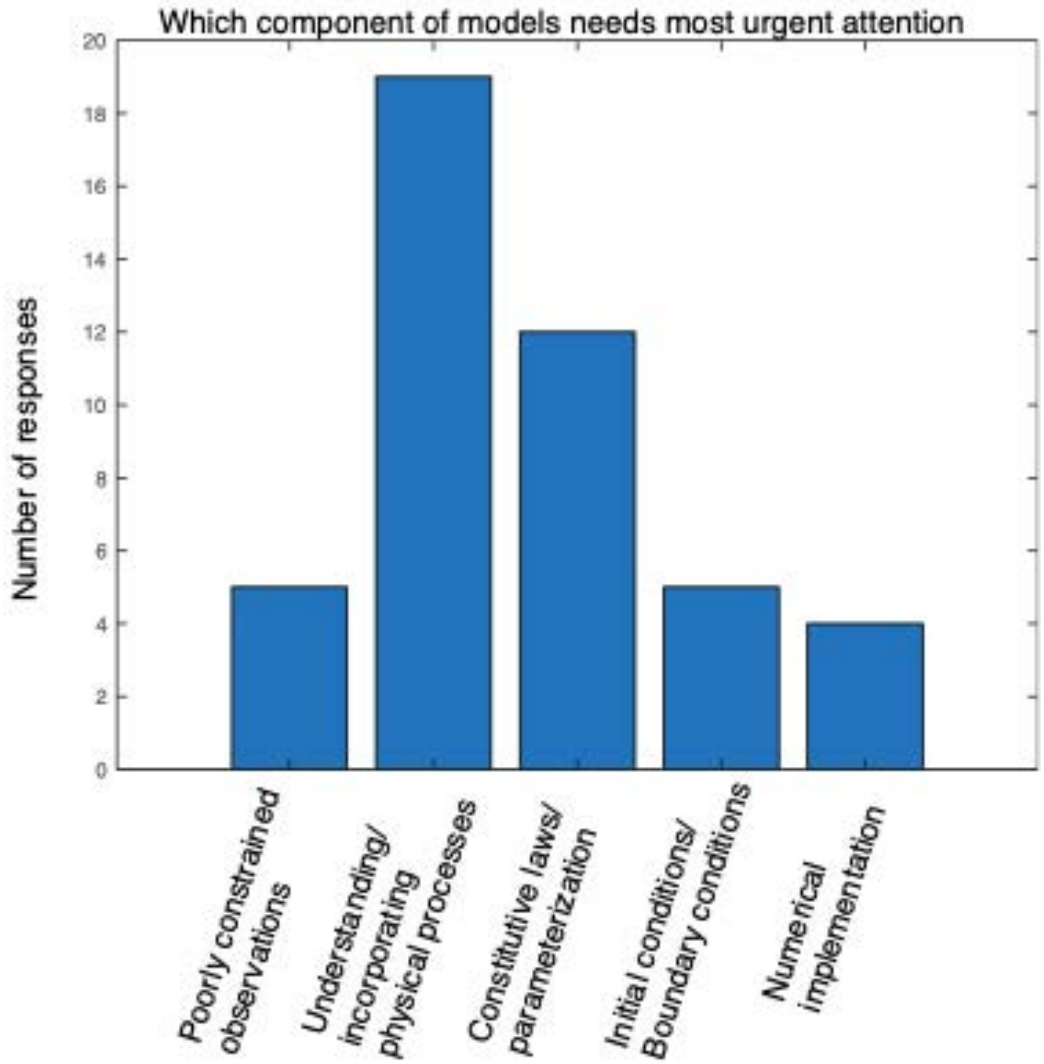


General Community Consensus

We need …

1. A better understanding of processes that control fluid migration.
2. To interface scientists across disciplines is as important as interfacing models.
3. To provide cross-disciplinary training and knowledge exchange for students and scientists.
4. To identify and resolve related challenges that exist across subduction zone science.
5. To include approaches for model validation.

"For the fluid migration model that you work on, what aspect do you personally view as needing the most work?"



Early Career Scientist (ECS) Discussion

What are the key questions to be addressed by the field in the next 10 years?

How can we better constrain spatial and temporal scales of volatile cycling?

What are numerical challenges in multiphysics and multiscale modeling?

Linking physical and chemical processes within and across domains and epistemic uncertainties in the equations to be used

How do we compare the modeling results with the observations?

Iteration between models and observations

Workshop Discussion

Is it appropriate to model each domain separately or is a holistic approach necessary?

A holistic model is probably not necessary or possible.

How should the interfaces between different domains be treated?

Outputs from one model as inputs for another.

Are there common/dominant fluid migration pathways?

The relative importance of a pathway/process to another is unclear.

A modular ("Lego brick") approach

Courtesy of Thorsten Becker

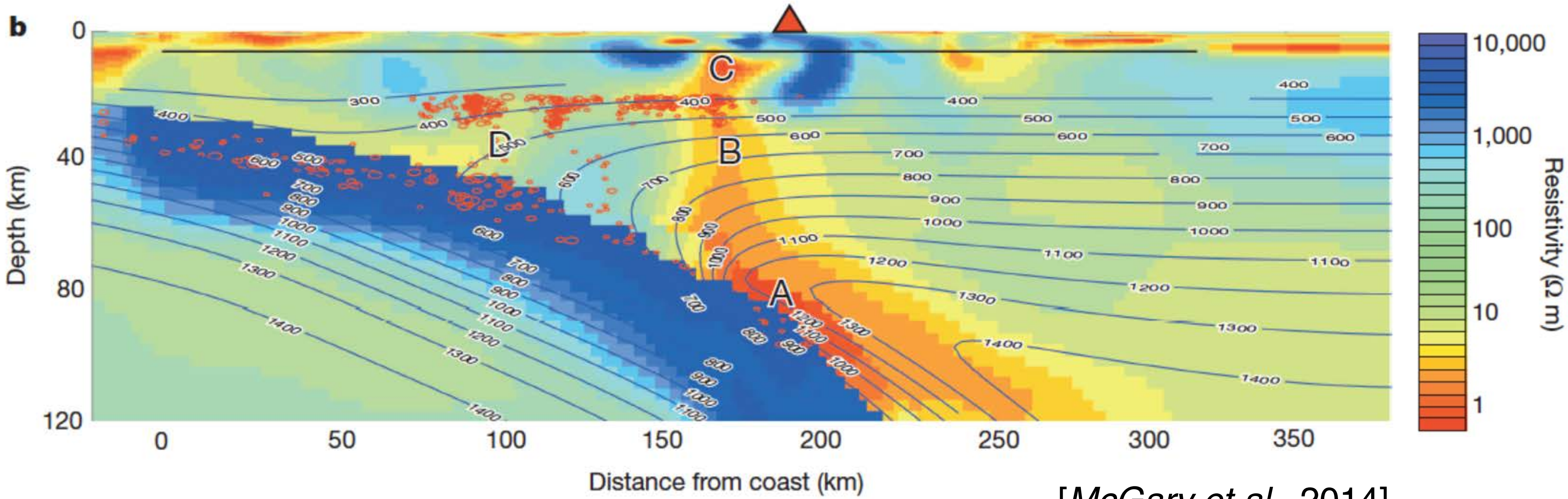
What are the essential elements of fluid behavior across different domains?

A “zeroth order” model is a common goal.

What observations are currently the most significant/needed constraints?

Rheology experiments that address chemical heterogeneity and reactivity; equation of state for non-pure hydrothermal fluids; and analog laboratory experiments, among others.

Magnetolluric model across central Washington state



[*McGary et al.*, 2014]

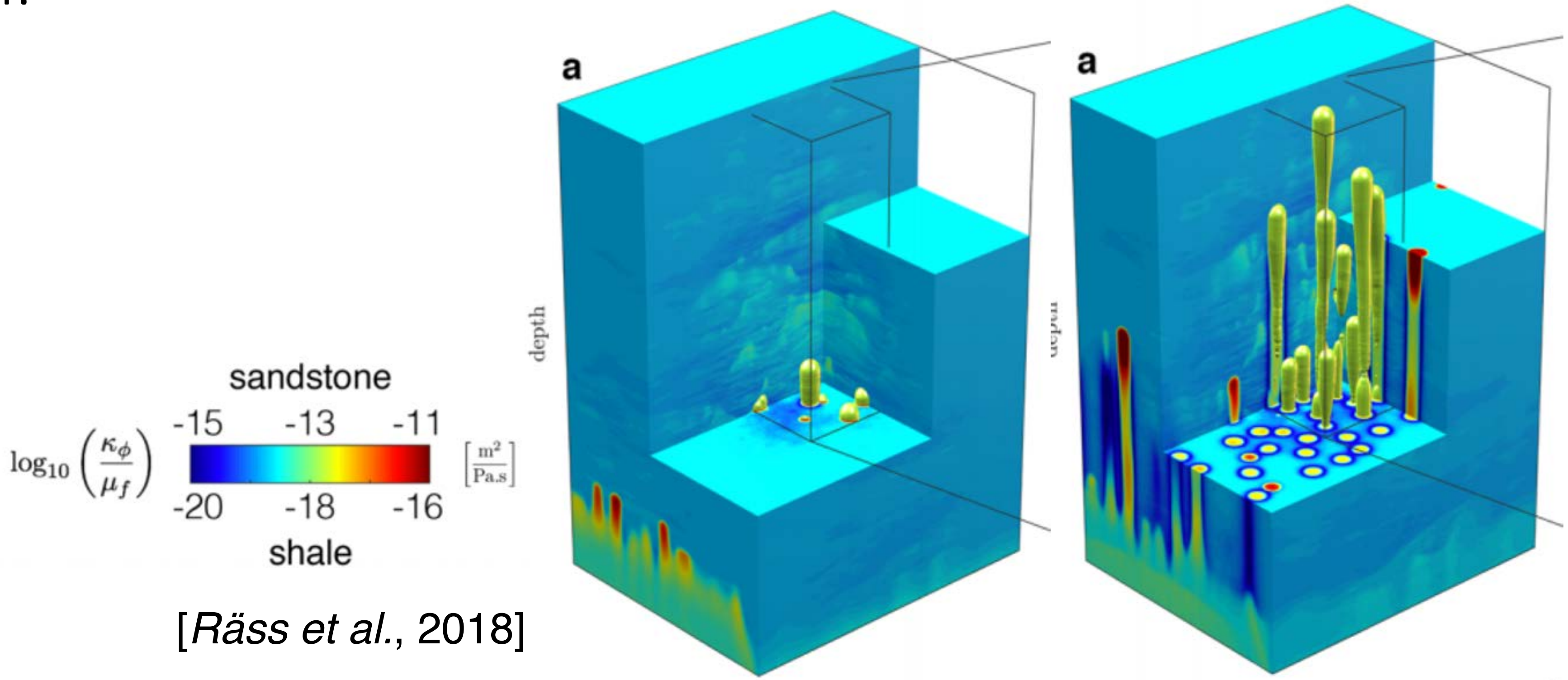
Motivating Questions

How do fluids affect spatio-temporal variations in (a)seismic activities?

How, where, and when are elevated pore fluid pressures generated, and how do they relate to the wide range of interface slip behavior?

How do porosity and permeability evolve with matrix deformation?

Hydro-mechanical model for spontaneous flow locallization into fluid conductive chimneys



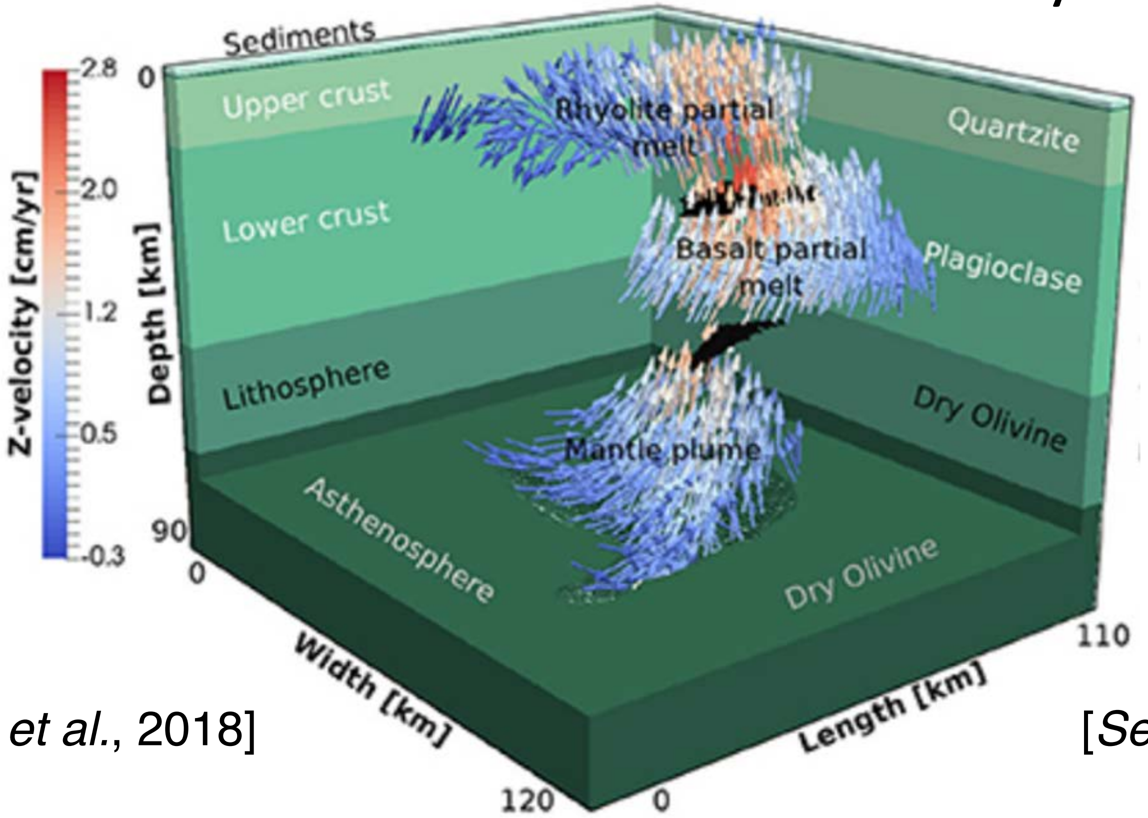
[*Räss et al.*, 2018]

How do fluids affect the spatio-temporal variations in magma ascent?

What processes determine the spatial distribution of magma from wedge to surface?

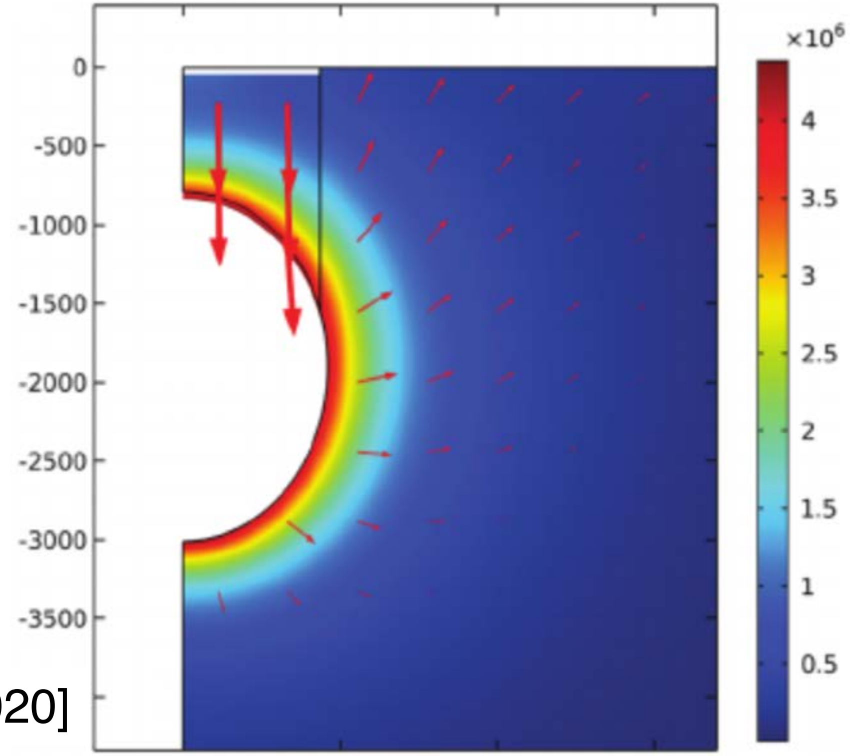
How does the petrology and geochemistry of magma relate to the dynamics of transport?

Lithospheric-scale visco-elasto-plastic model for the Yellowstone system



[*Reuber et al.*, 2018]

Compressible elastic model for the collapse of Kilauea caldera



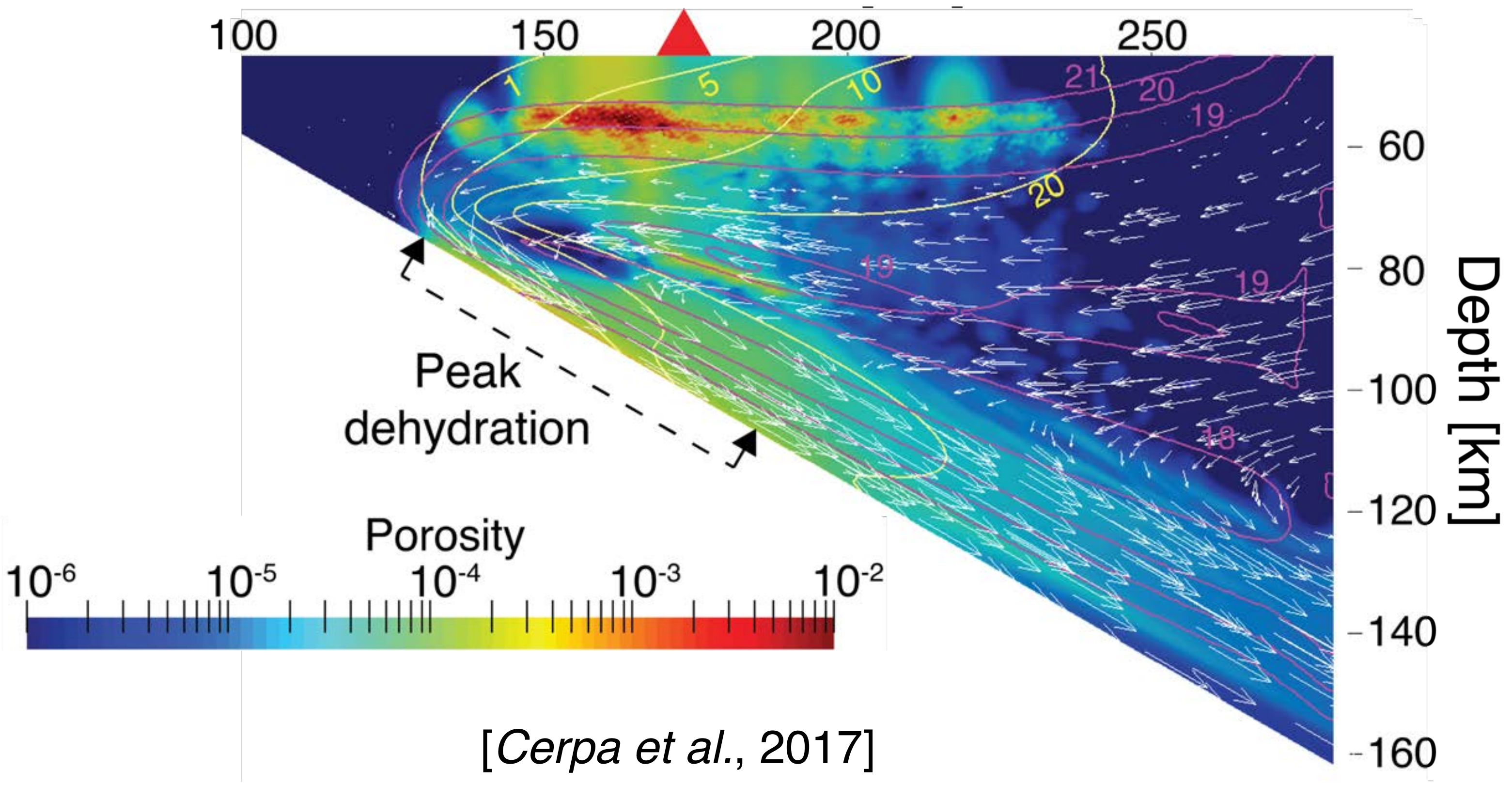
[*Segall et al.*, 2020]

How are fluid-related processes linked to the thermal-chemical-mechanical structure and dynamics of the subduction system?

How do fluid-mediated chemical reactions affect fluid migration?

How does fluid migration affect the large-scale thermo-mechanical structure of the mantle wedge?

Two-phase flow model for the mantle wedge



[*Cerpa et al.*, 2017]

Challenges and Opportunities in Integrating Models across Spatial and Temporal Scales

Resolving model commutability at different length and time scales

e.g., How should elasticity and the brittle behavior of the crust around magma reservoirs be represented in lithospheric-scale magma migration models?

Achieving consistency among models

e.g., Influx and outflux of fluids across boundaries of different domains

Identifying commonalities in the problems

e.g., Can eruption cycle models benefit from numerical approaches developed for the megathrust system?

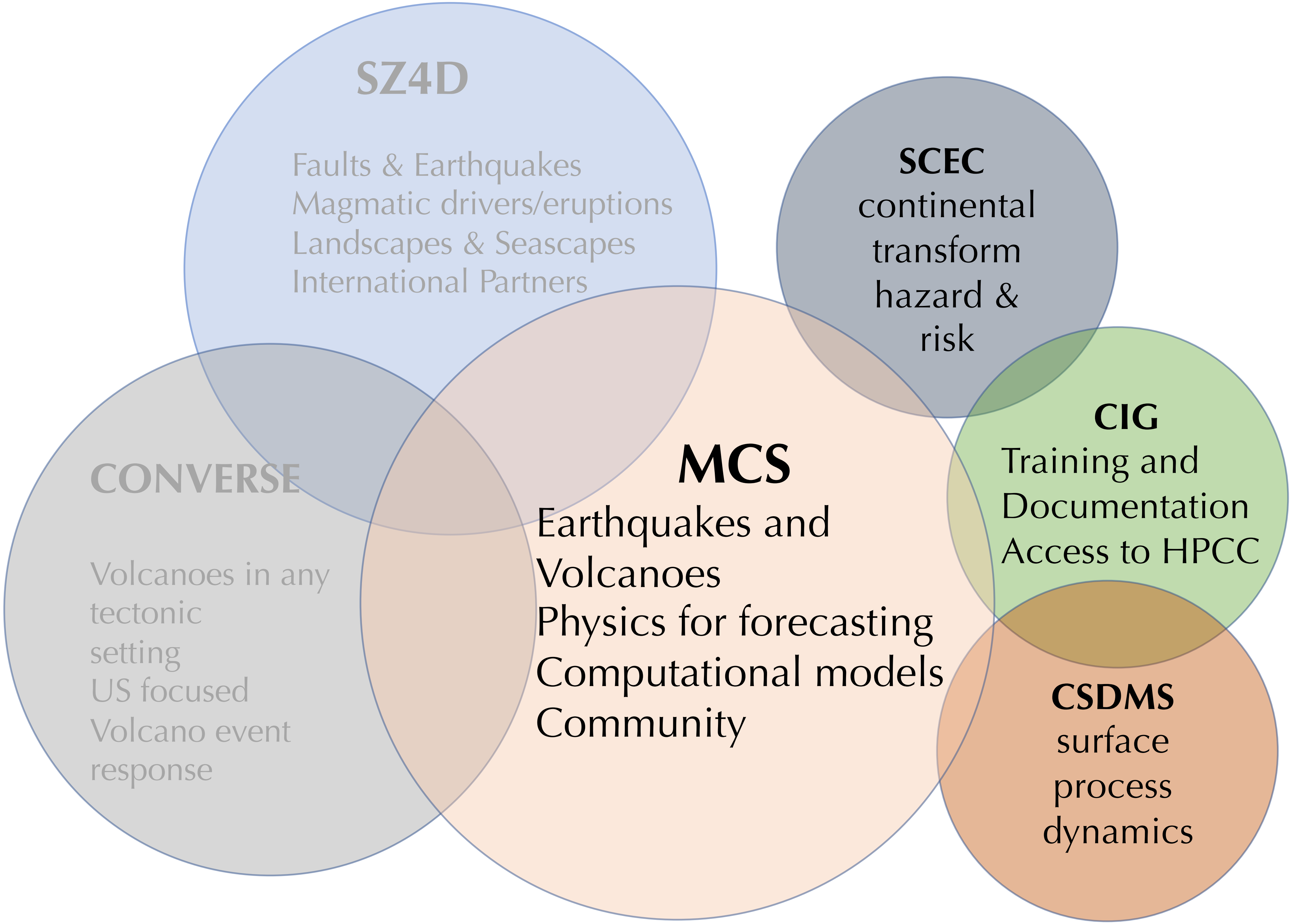
Addressing the variability in the observational completeness

e.g., Magnitude-frequency relations for earthquakes vs. volcanic eruptions; shallow vs. deep

Modeling Collaboratory

In the Workshop, a modeling collaobratory was envisioned to provide a research environment as well as a modeling framework consisting of numerical and data integration tools.

- a modular modeling framework in which different models can be linked in a consistent manner
- a resource for code developers and end-users to communicate
- benchmarking exercises and synthesized sets of observables
- regular, topically focused workshops with broad attendance for community building
- support for individual PIs and the community to access computing technologies



MCS driven by earthquake and volcano systems, but tools and approaches are general, and apply to transforms, intraplate deformation, rifting, etc…