Geo PRISMS Geodynamic Processes at Rifting and Subducting Margins

2019 Synthesis & Integration TEI – Early Career Symposium

Mass fluxes

Overview, big-picture questions, and how to solve them

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Contributors

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Metamorphic petrology;
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Amphibious seismology;
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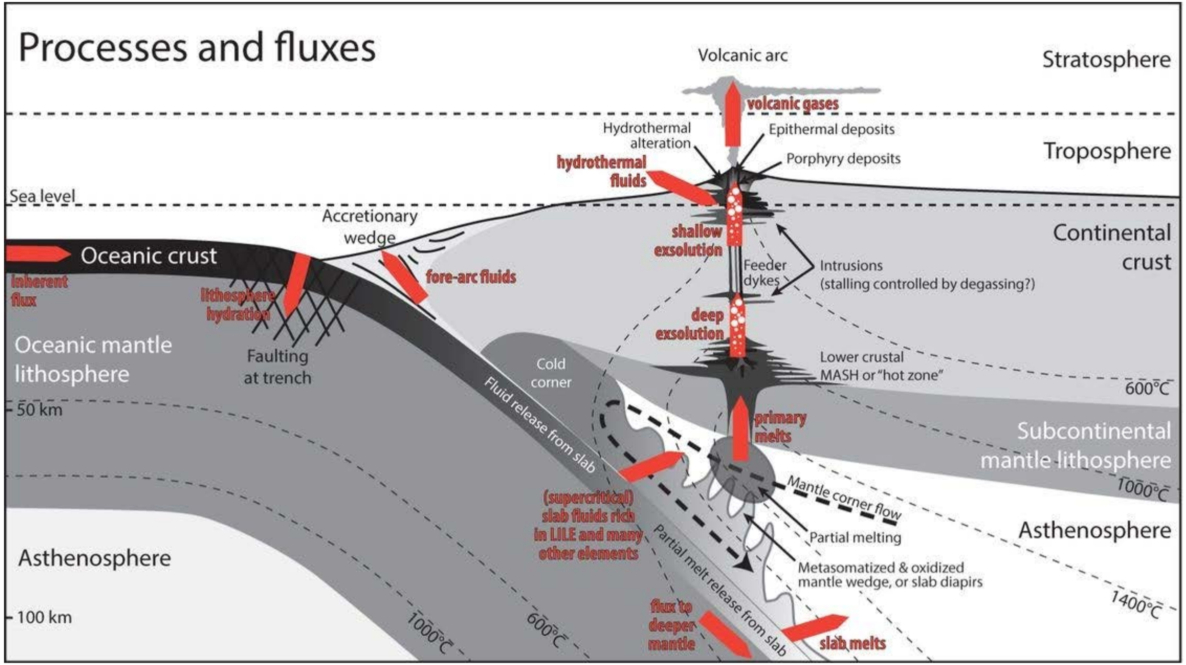
Igneous petrology;
geochemistry

Overview – Mass fluxes in subduction zones

- **Solid** masses
  - Sediments
  - Crust
  - SOLM
  - Fragments of the upper plate
- **Fluid** masses
  - Seawater
  - Pore fluids
  - Structurally bound volatiles
- Any or all phases may ‘come out’ again

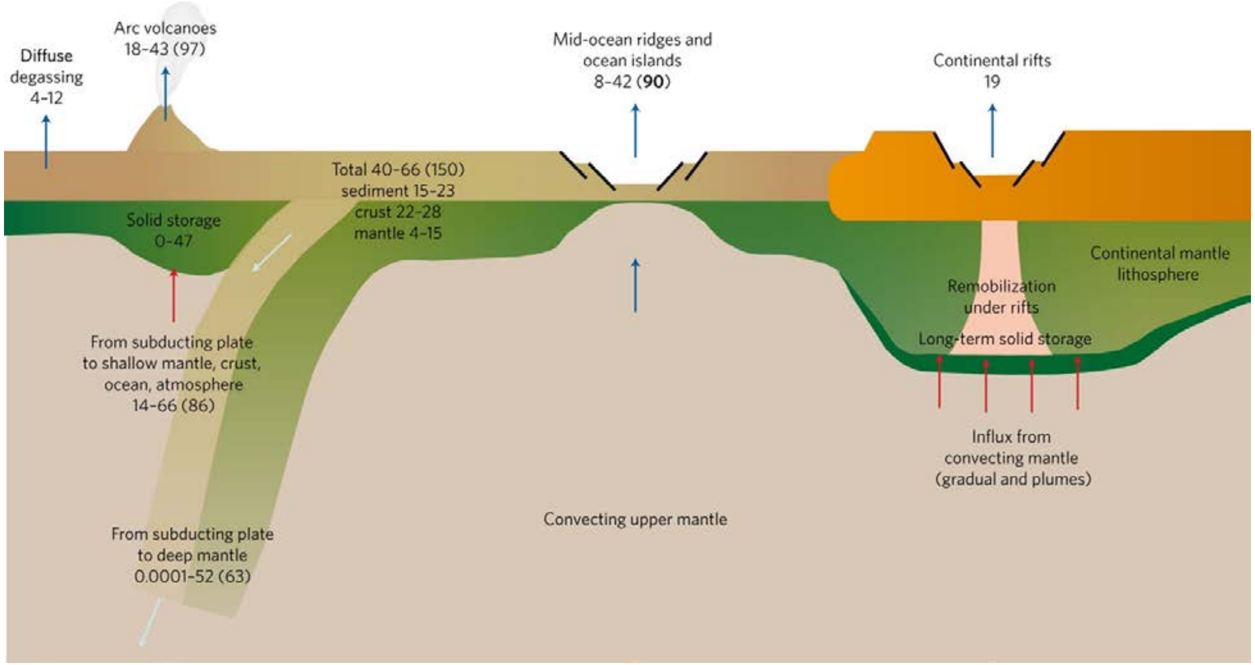


Zellmer *et al*. (2015) *Geol. Soc. Lond. Spec. Publ.*

Overview – Mass fluxes in rifted margins

- **Solid** masses
  - Magma -> lava
  - Xenoliths
- **Fluid** masses
  - Extensive degassing via volcanism

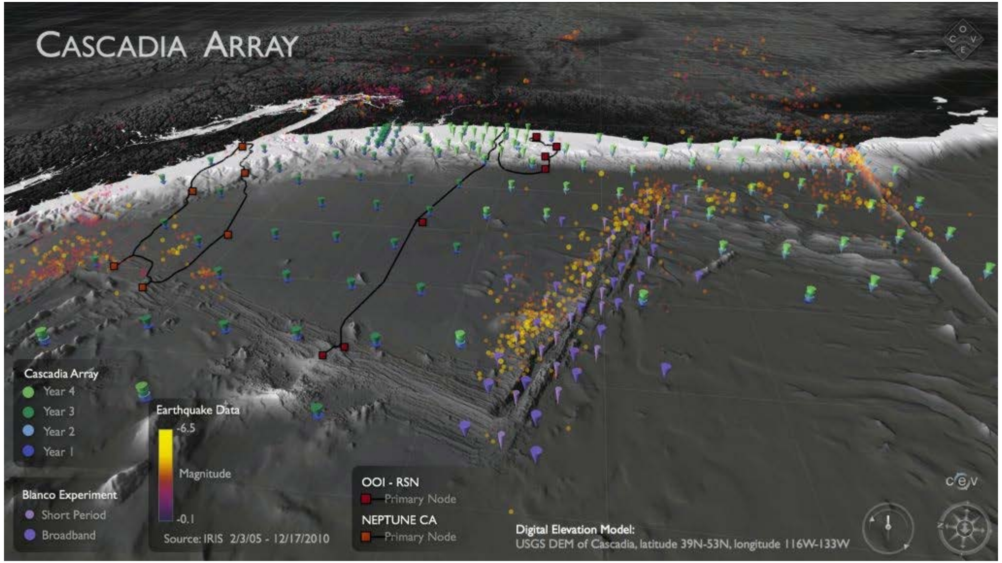
Major measurement techniques comprise **geophysics**, **isotope geochemistry**, and **petrology**

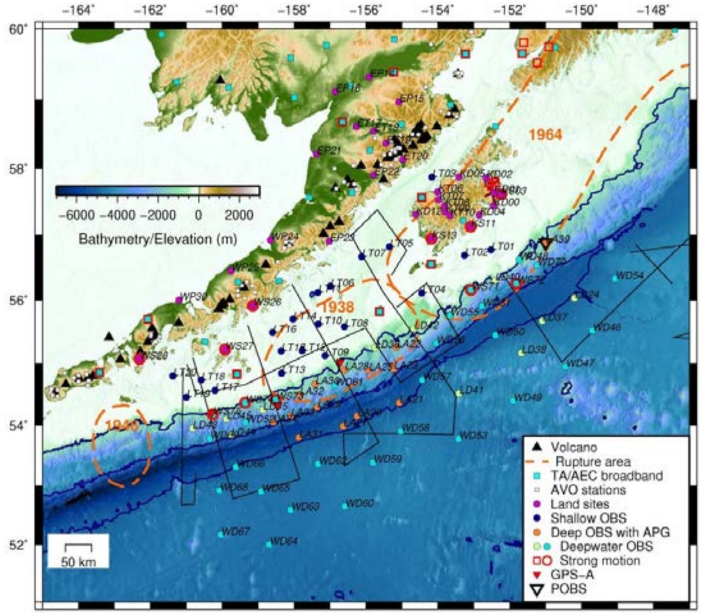


Foley and Fischer (2017) *Nature Geosci.*

Techniques – Passive-source seismic studies

Amphibious seismic arrays

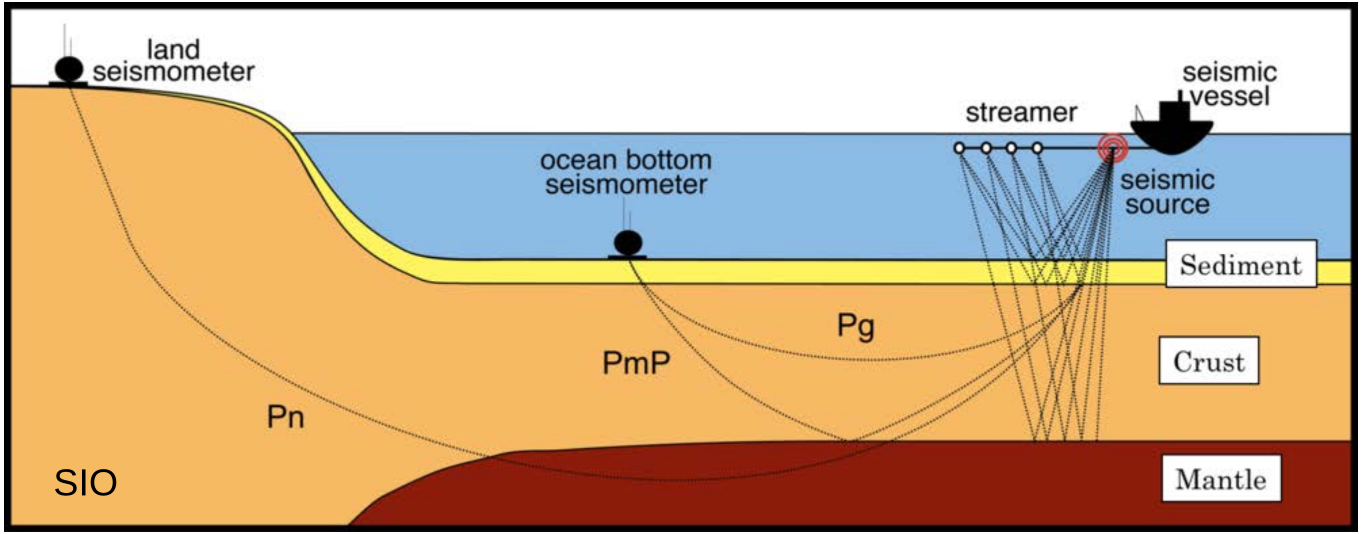




- Crustal, lithospheric, upper asthenospheric mantle scale imaging
- Uses earthquakes, or ambient noise, or other “natural” sources

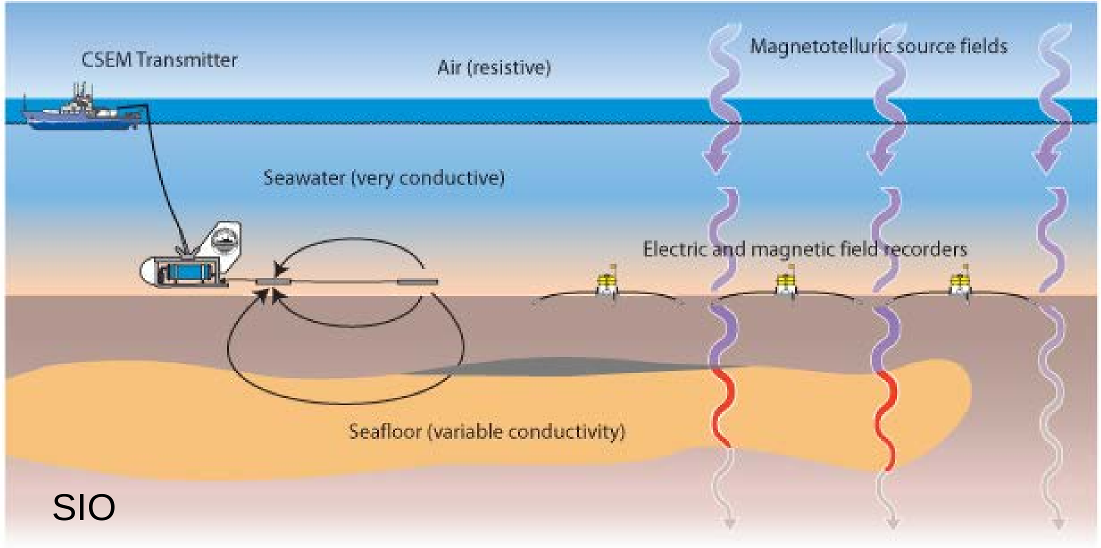
Techniques – Active-source seismic studies

- Typically seismically image crust to upper mantle
- Involve using a seismic source, like airguns or explosives
- Higher resolution than passive imaging techniques, but covers a more limited area



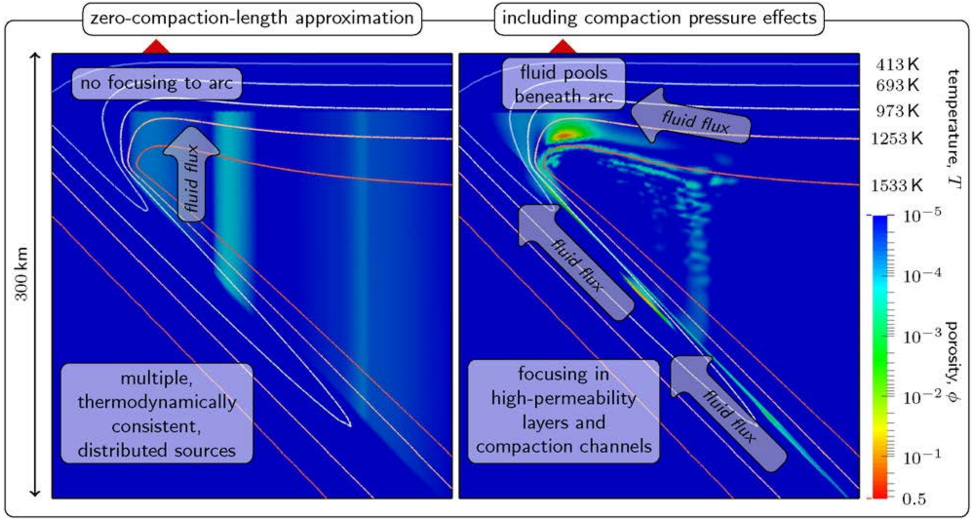
Techniques – Magnetotellurics

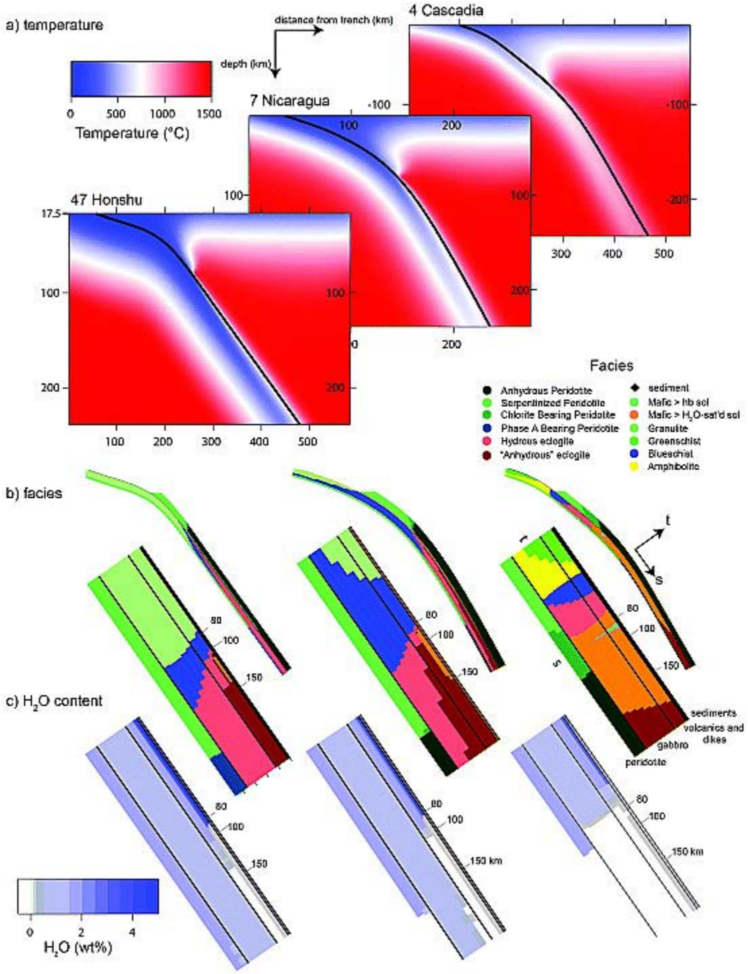
- Electromagnetic geophysical method for inferring the **Earth's subsurface electrical conductivity/resistivity**
  - Measures natural geomagnetic and geoelectric field variation at the Earth's surface



- Complements seismic velocity measurements
  - Useful for discriminating between **temperature/fluid/melt anomalies**
- Can also be "active" or "passive" – similar differences in resolution
  - From ~300 m depth (high frequencies) to >10,000 m depth (long-period sounding)

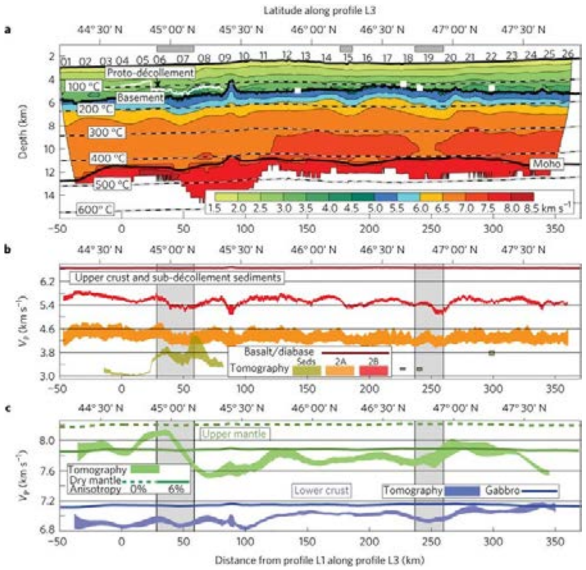
Techniques – Geodynamic modeling



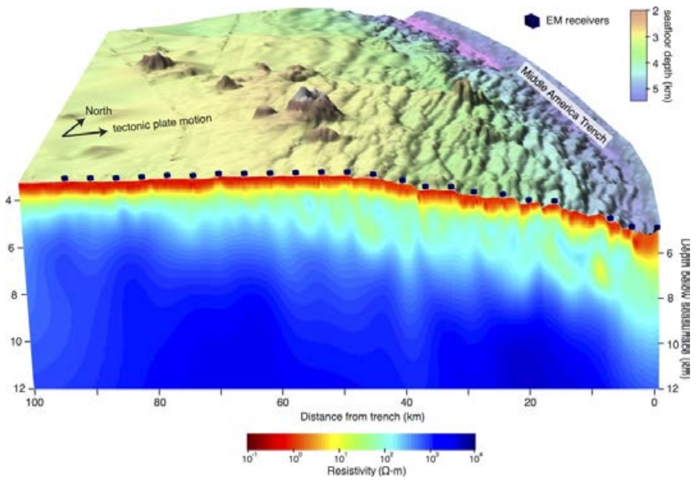


- Top: fluid pathways (Wilson *et al*., 2014)
- Right: stability of hydrous minerals in subducted crust (van Keken *et al*., 2011)

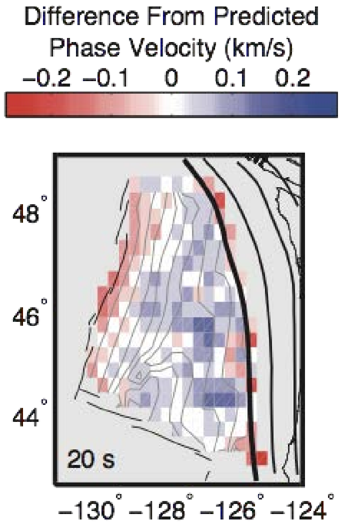
OQ – What are the properties of the oceanic plate?



Imaging a **relatively dry** Juan de Fuca crust and mantle in Cascadia from active source seismics (Canales et al., 2017)

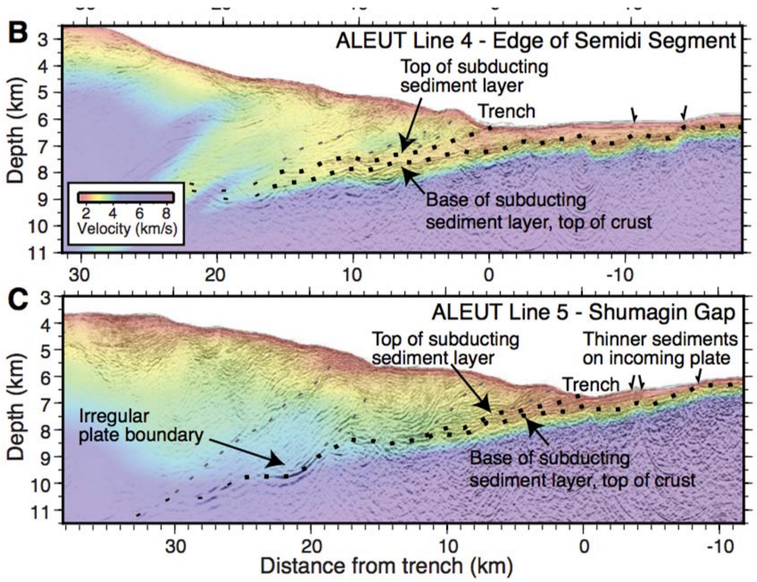


Fluid-rich **bending faults** at middle America Trench from MT (Naif *et al.*, 2015)

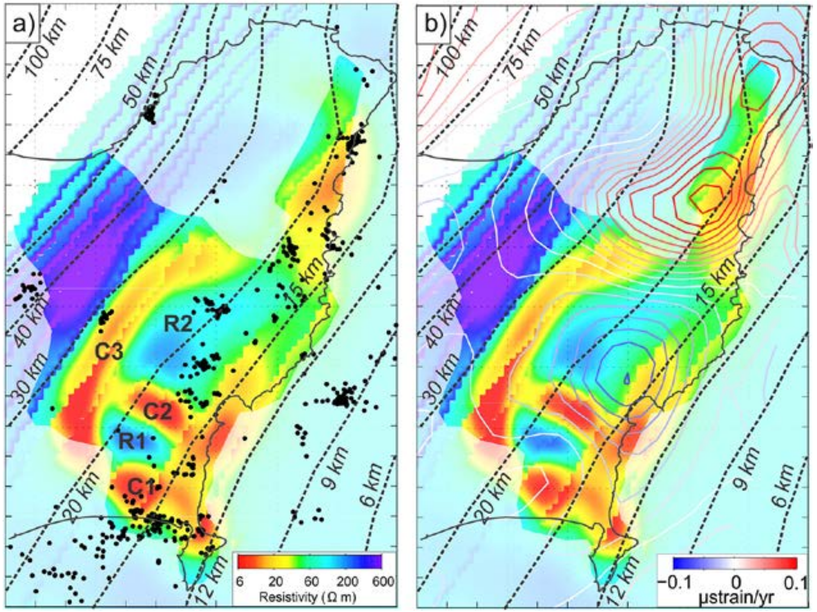


Deviations from conductive cooling observed in the Juan de Fuca plate (Janiszewski *et al.*, 2019)

OQ – How much sediment is subducted?

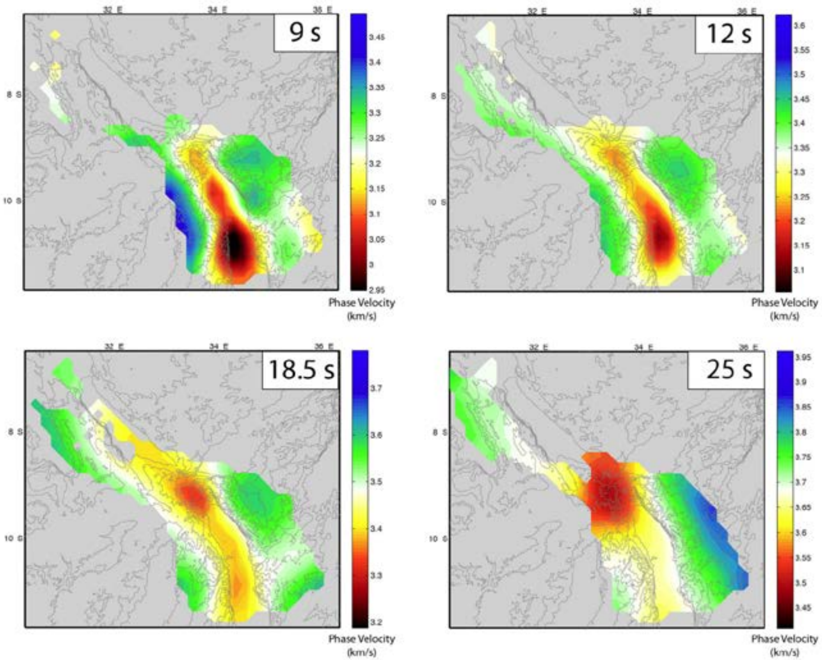


Variations in **thickness of subducting sediment** in Alaska correspond with variations in downdip seismic behavior (Li *et al*., 2018).

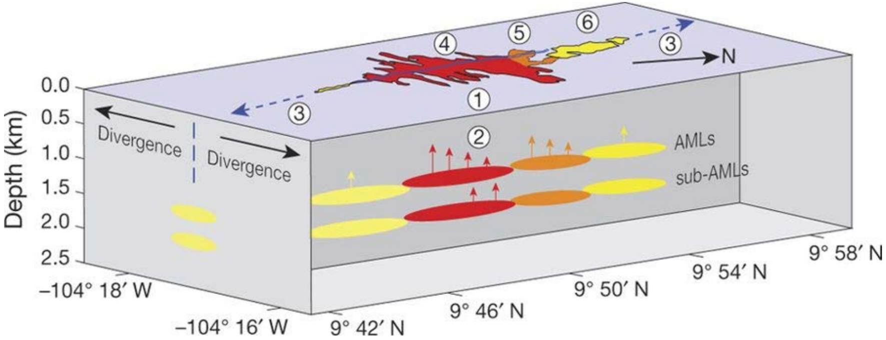


Variations in **fluids and/or sediments** along the Hikurangi plate interface correlate with variable plate movement (Heise *et al*., 2017).

OQ – What is the role of melt in rifting?

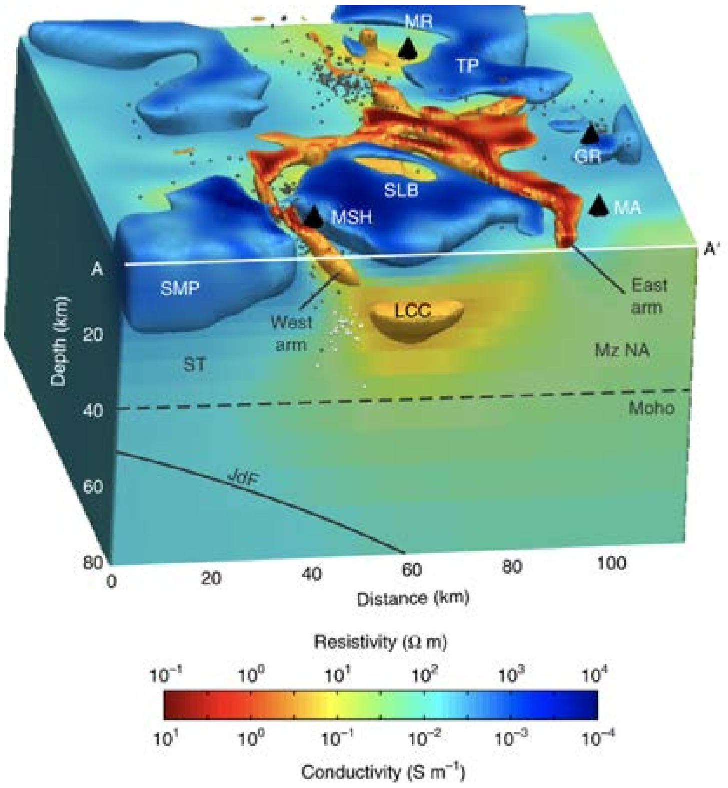


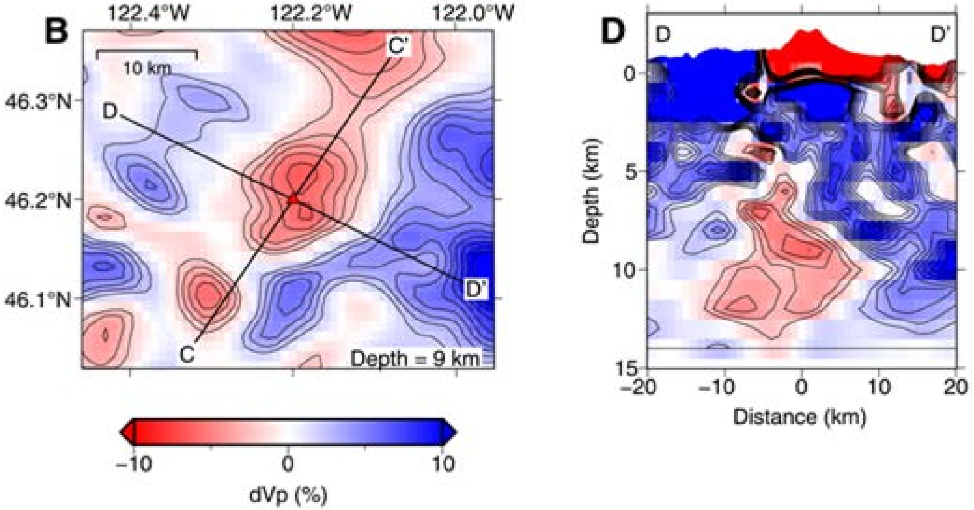
How much rifting requires melt vs. faulting (Accardo *et al*., 2017)?



What are the dynamics of a **seafloor-spreading episode** at the East Pacific Rise (Tan *et al*., 2016)?

OQ – What magmatic architecture lies beneath volcanoes?



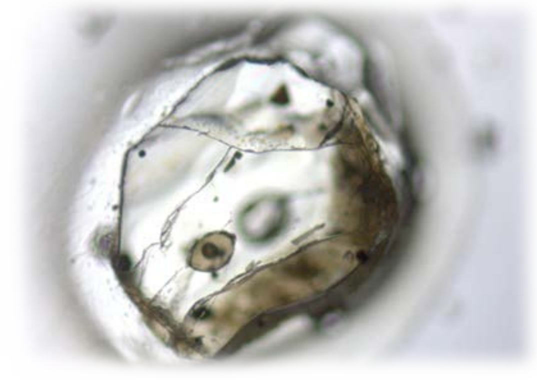


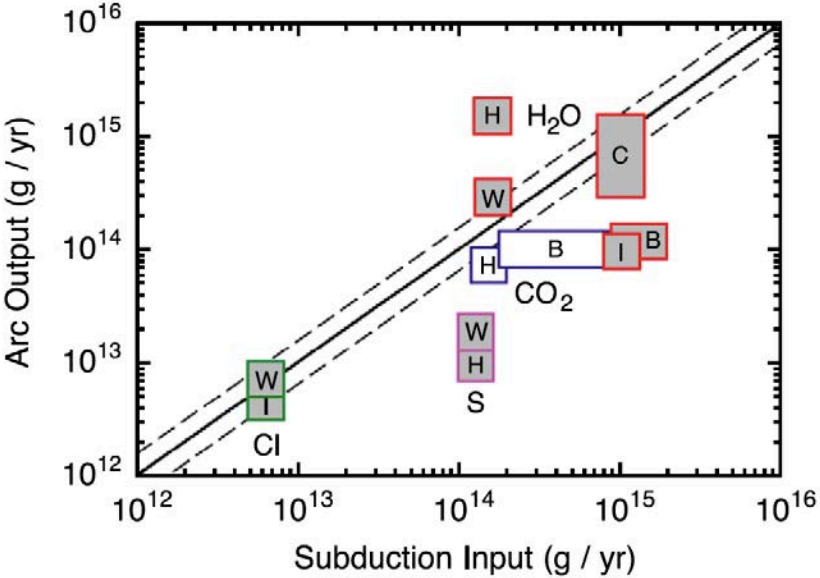
Left: **Magnetotelluric imaging** beneath Mt. St. Helens, Mt. Adams, and Mt. Rainier reveal a complex conductive melt region (Bedrosian *et al*., 2018)

Right: **Seismic imaging** of magma architecture beneath Mt. St. Helens (Kiser *et al*., 2018)

Techniques – Arc magma volatiles and geochemistry

- Direct methods for measuring volatiles
  - Melt inclusions/pillow rim glasses
    - FTIR, SIMS, EPMA
  - Gas monitoring/ sampling
    - Remote sensing
    - Fumarole sampling

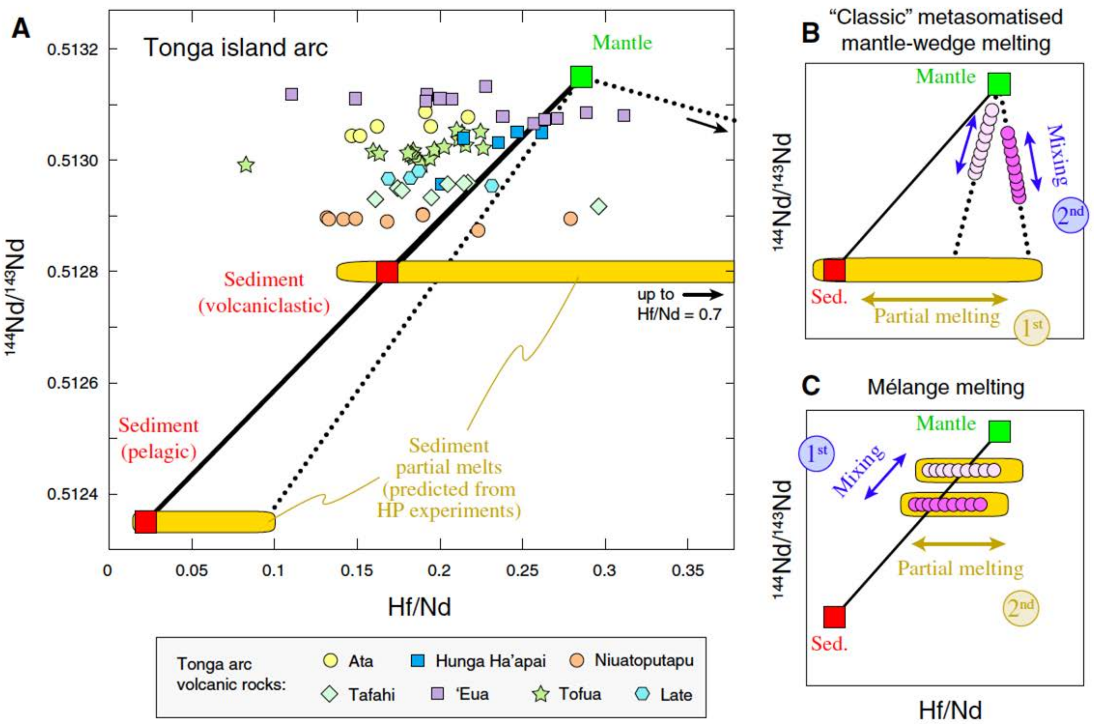




Wallace (2005)

Techniques – Arc magma volatiles and geochemistry

- Indirect methods
  - Isotope/ trace element systematics
    - LA-ICP-MS, SIMS, EPMA
  - Experiments
    - Phase equilibria
    - Trace element partitioning
    - Volatile solubility

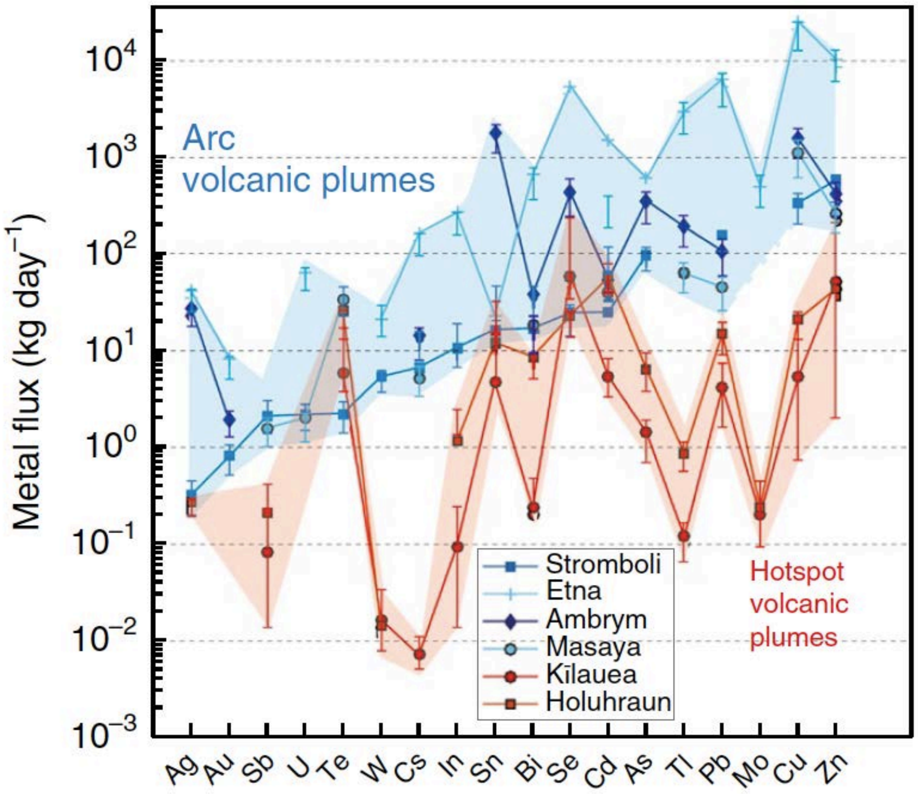


Nielsen and Marschall (2017)

OQ – Arc magma volatiles

- How are volatiles **stored** in the slab and **released** during subduction?
  - What is the fate of H_2O and CO_2 released into the forearc?
  - How does subducted S affect magma redox and the behavior of ore-forming metals, such as Cu?
- How does lower crustal differentiation affect the volatile contents measured at arc volcanoes?

Edmonds *et al*. (2018)



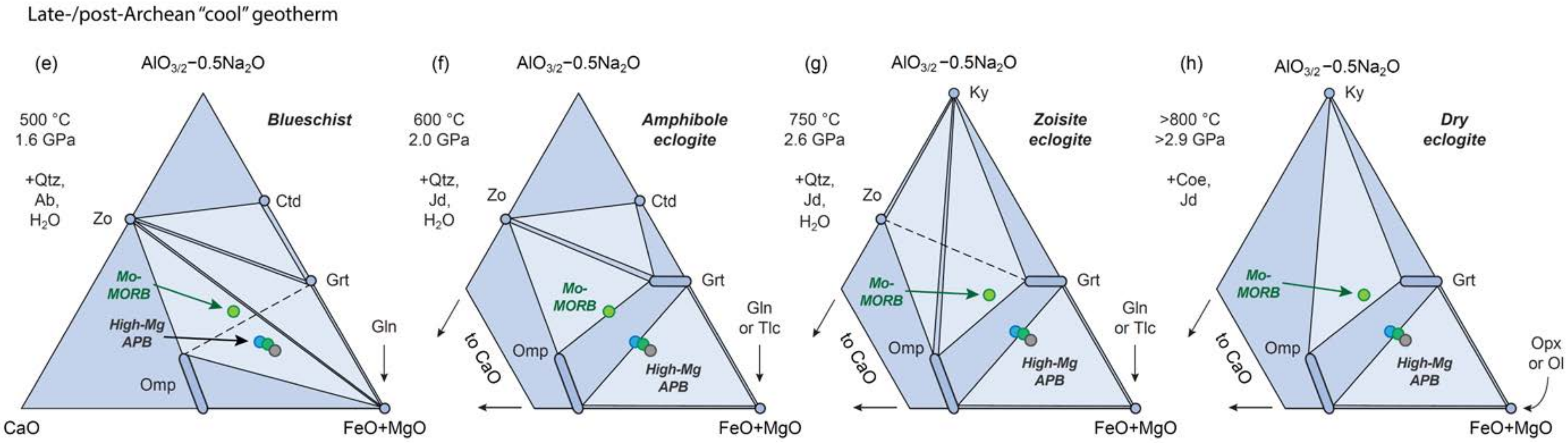
Techniques – Direct sampling and analysis

- **Direct petrological examination** of solid materials before they enter the trench, or afterwards
  - Optical petrography/mineralogy
  - Mineral assemblages and reaction sequences

- **Where** can we get these samples?
  - Dredging from the sea floor
  - Ophiolites
  - Xenoliths in lavas
  - Exhumed crustal terranes

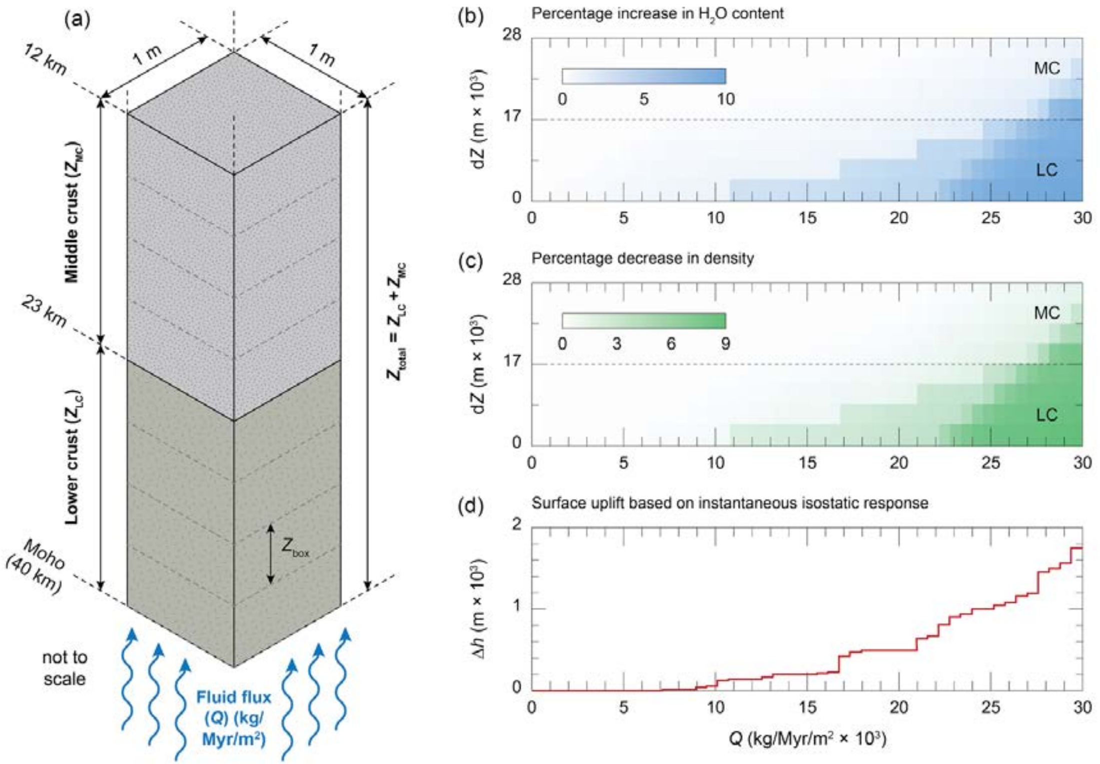
Techniques – Petrological modeling

Palin and Dyck (2018)



- **Calculated phase equilibria** (minerals, fluids, melt) stable at given pressure–temperature (*P*–*T*) conditions along slab-top surfaces or any depth within the slab
  - Forward and inverse modeling as functions of intensive (*P, T, μ*) or extensive (S, V, *X*) variables

Techniques – Petrological modeling

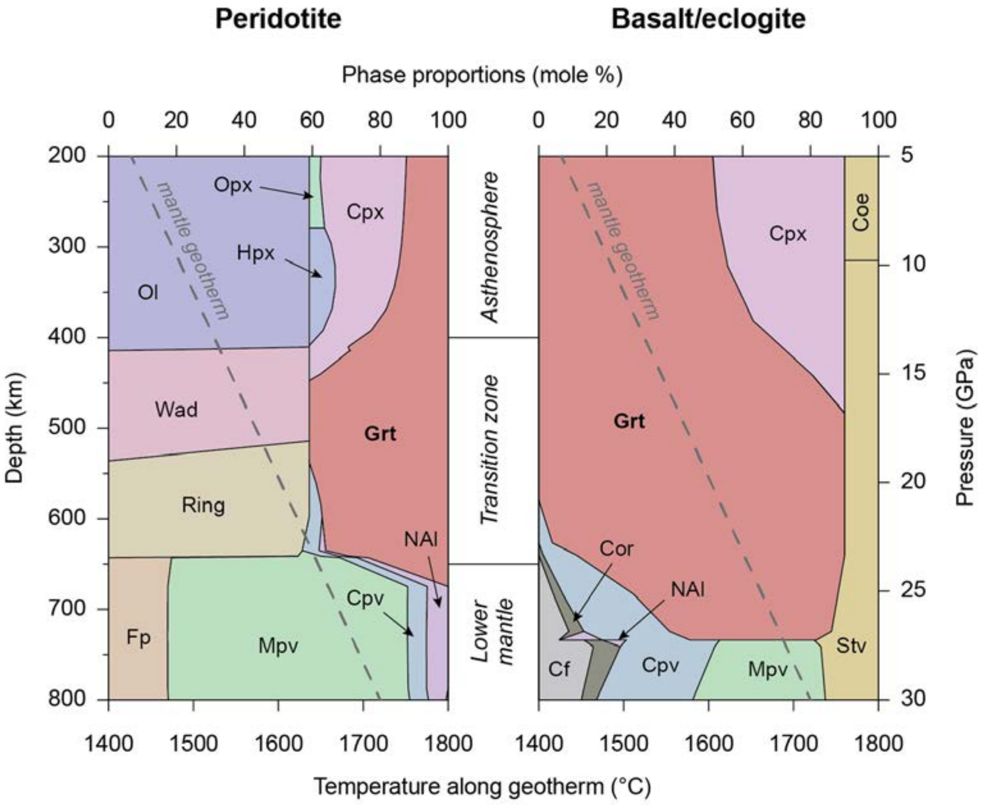


- More complex multivariate calculations involving **internally consistent thermodynamic data** and activity–composition relations for solid-solution phases
- **Predict** the effects of fluid expulsion from a subducted slab and infiltration into the overlying mantle wedge or lower/middle continental crust
    - **Reactive transport**

OQ – What actually goes down?

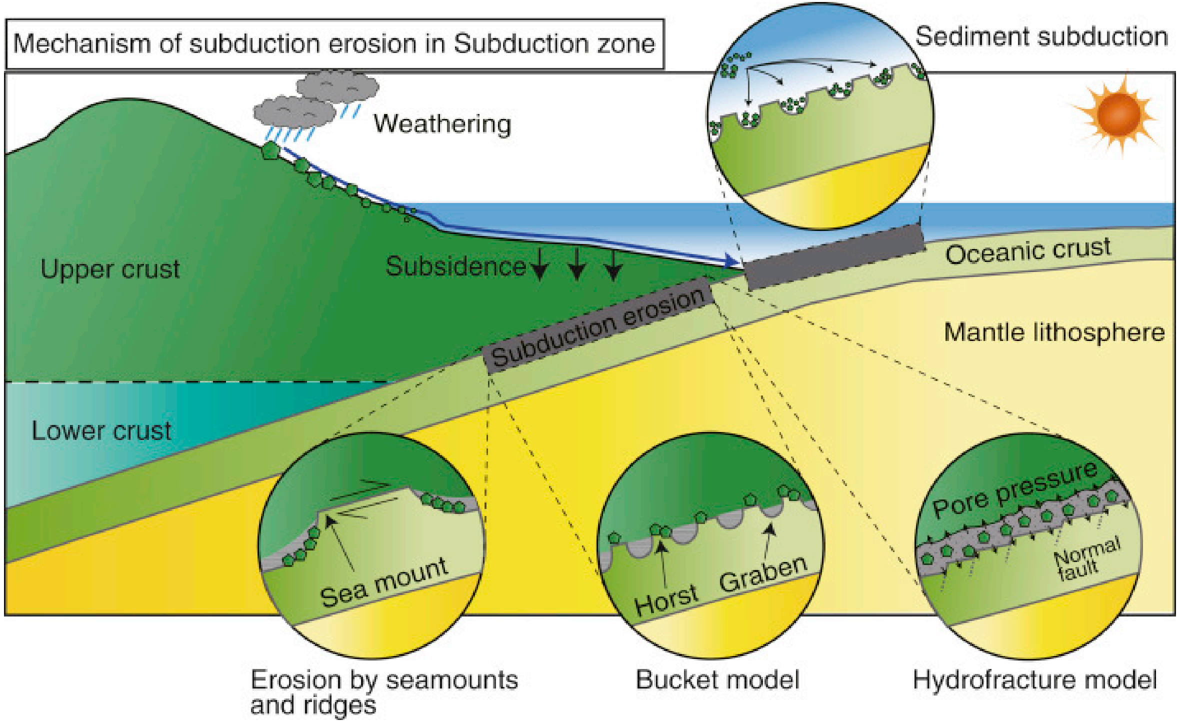
Shirey and Shigley (2013)

- Predicted mineral assemblages in subducted and metamorphosed mafic and ultramafic materials at asthenosphere–transition zone–lower-mantle conditions
    - How does near-ridge or near-trench **metasomatism** affect these equilibria?
    - How does this affect **mass transport** between the hydrosphere and interior?



OQ – How significant is subduction-erosion?

- What **mass** of overlying arc crust is transported beneath the continents during subduction erosion?
  - How much can be removed and where does it end up (i.e. distance from the trench)?



Azuma *et al*. (2017)

OQ – Relamination?

- Is lower crust really *that* mafic?
  - Hacker *et al*. (2011) suggest that felsic subducted crust can be re-added/laminated to the base of the overlying arc
- How can this be proven?
- Has this effect varied in efficacy throughout geological time?
  - Subduction has not always operated, and when it has, has not always done so in the same way