Mass fluxes

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

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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

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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**

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 $\text{H}_2\text{O}$ and $\text{CO}_2$ 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

- **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

Palin and Dyck (2018)
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?

- 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?

Shirey and Shigley (2013)
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