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Quantitative models of subduction zone fluids: How hydrous phases in the slab determine the composition of subduction zone lavas

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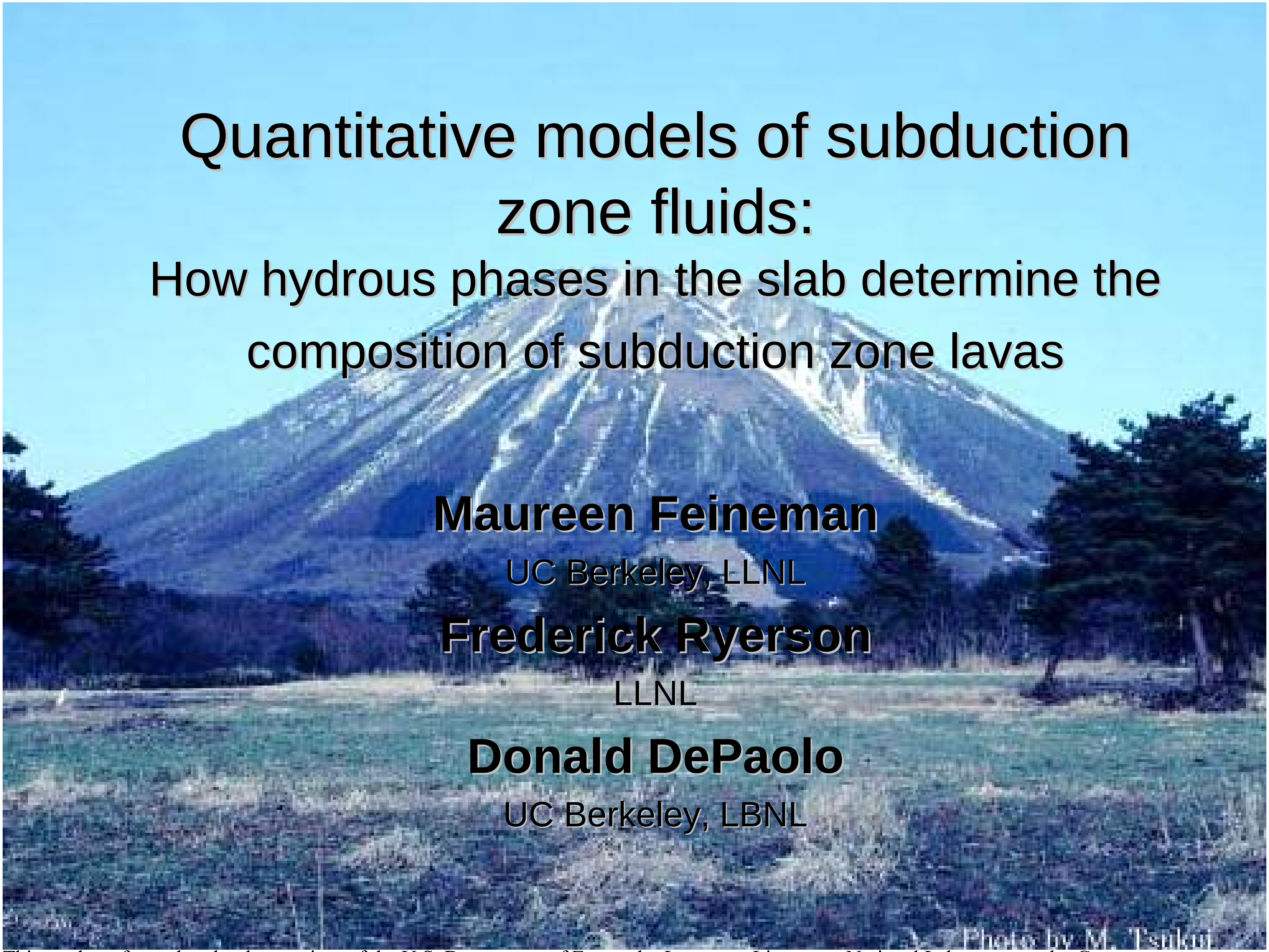

Quantitative models of subduction zone fluids:

How hydrous phases in the slab determine the composition of subduction zone lavas

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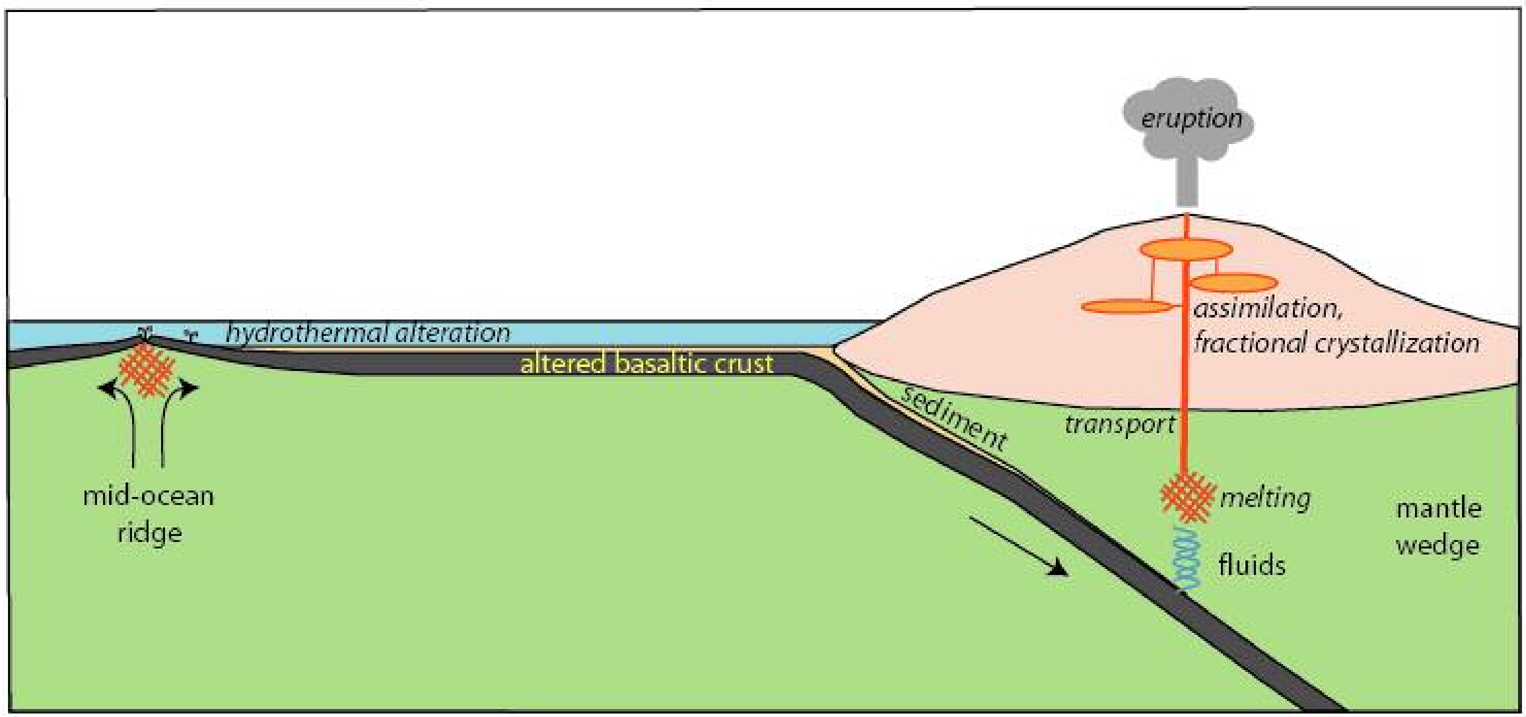
Outstanding questions:

- What is the nature and composition of the slab-derived fluids?
- What features of arc volcanism and geochemistry are acquired from fluids?
- How do fluids and melts move through the mantle after being released from the slab?
- What are the timescales of fluid and melt generation/migration in the slab and mantle?



Overview: experiments and models

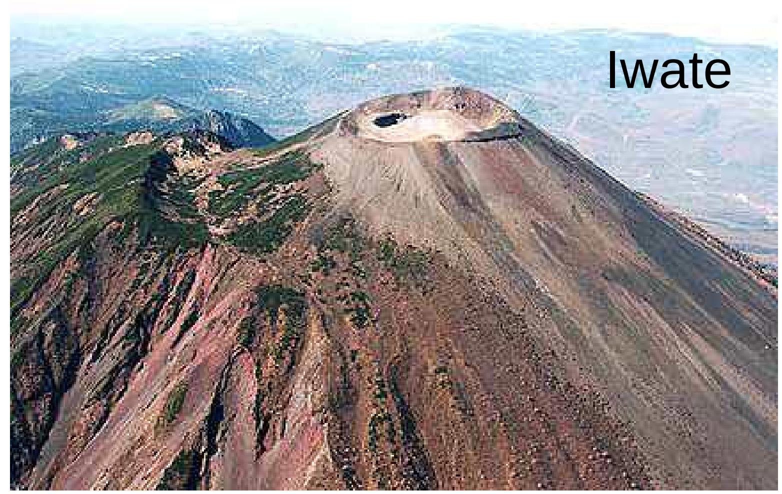
- General characteristics of arc lavas
- Mineral/fluid trace element partitioning experiments
- Bulk rock/fluid partitioning for warm vs. cold slabs
- Geochemical characteristics of the Northeast and Southwest Japan Arcs
- Questions concerning fluid migration in the mantle wedge

Trace element variations in arc basalts from Northeast and Southwest Japan

Enriched in LILE

Depleted in HFSE

Depleted in REE

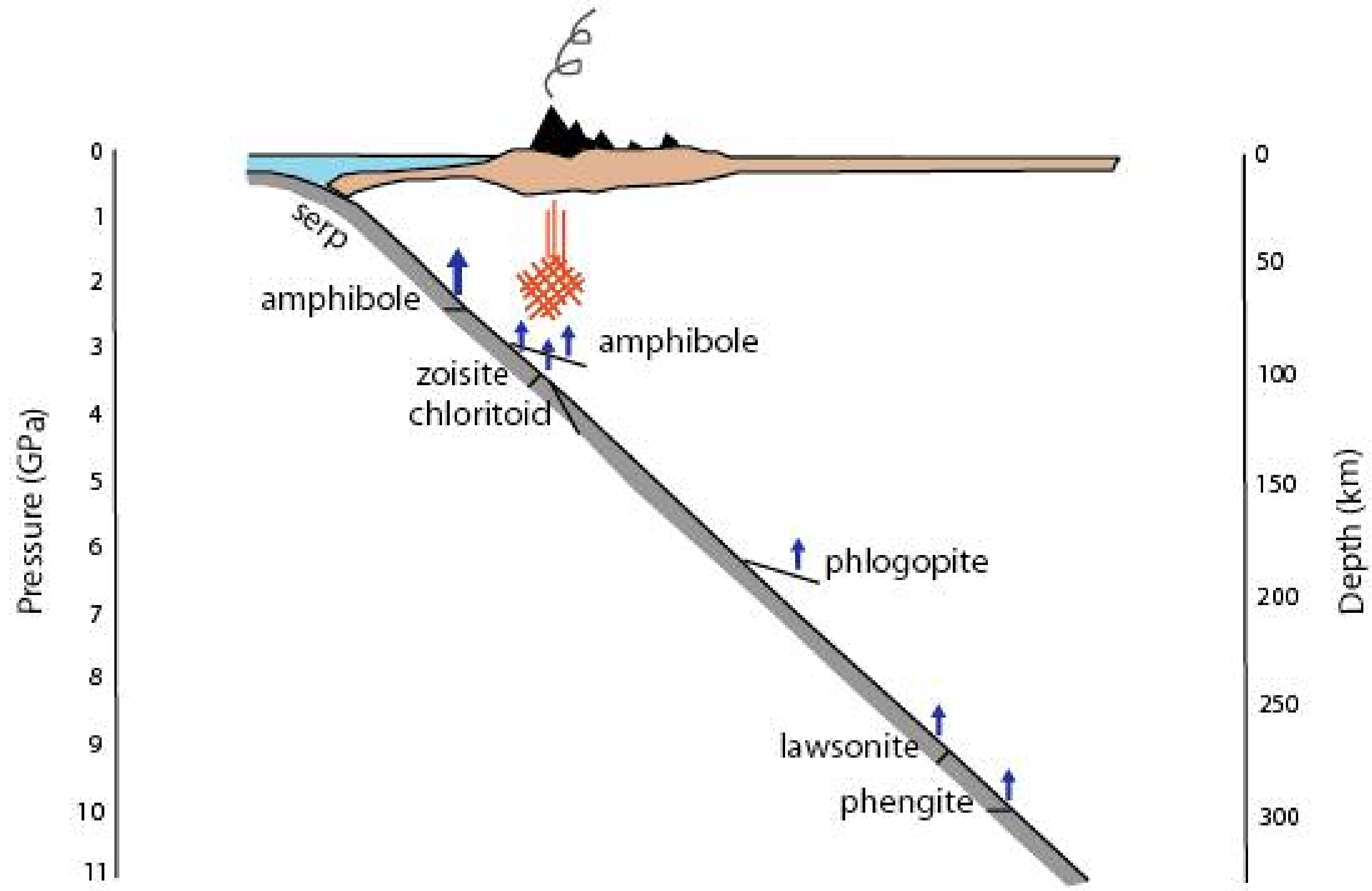


Enriched in LILE

RELATIVELY depleted in HFSE, LREE

Depleted in HREE

Water leaves slab in continuous reaction series as hydrous minerals break down in descending slab

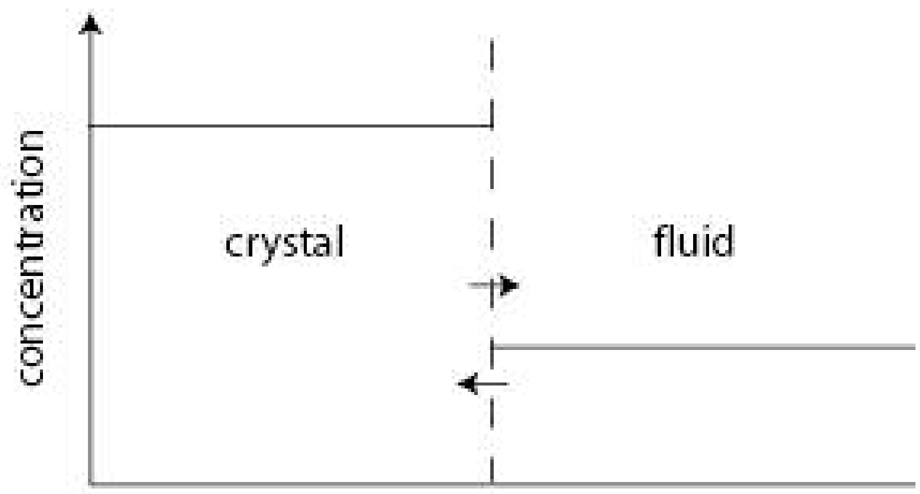


after Schmidt and Poli 1998

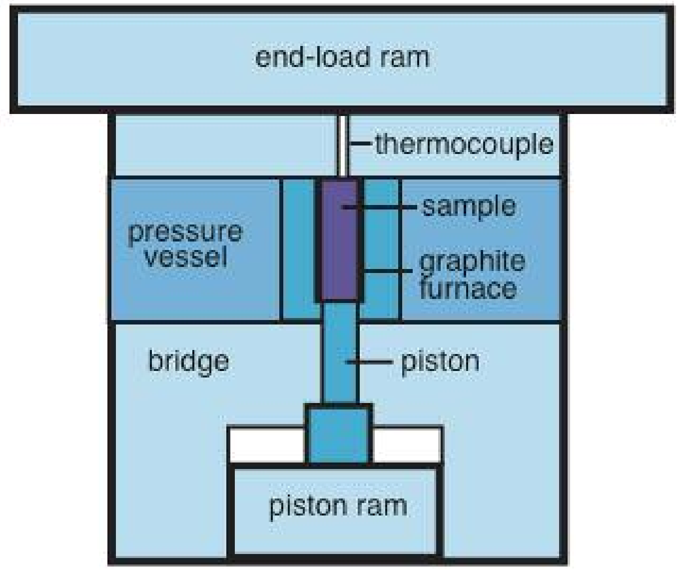
Mineral/fluid equilibrium partition coefficient

$$\text{mineral} \leftrightarrow \text{fluid}$$

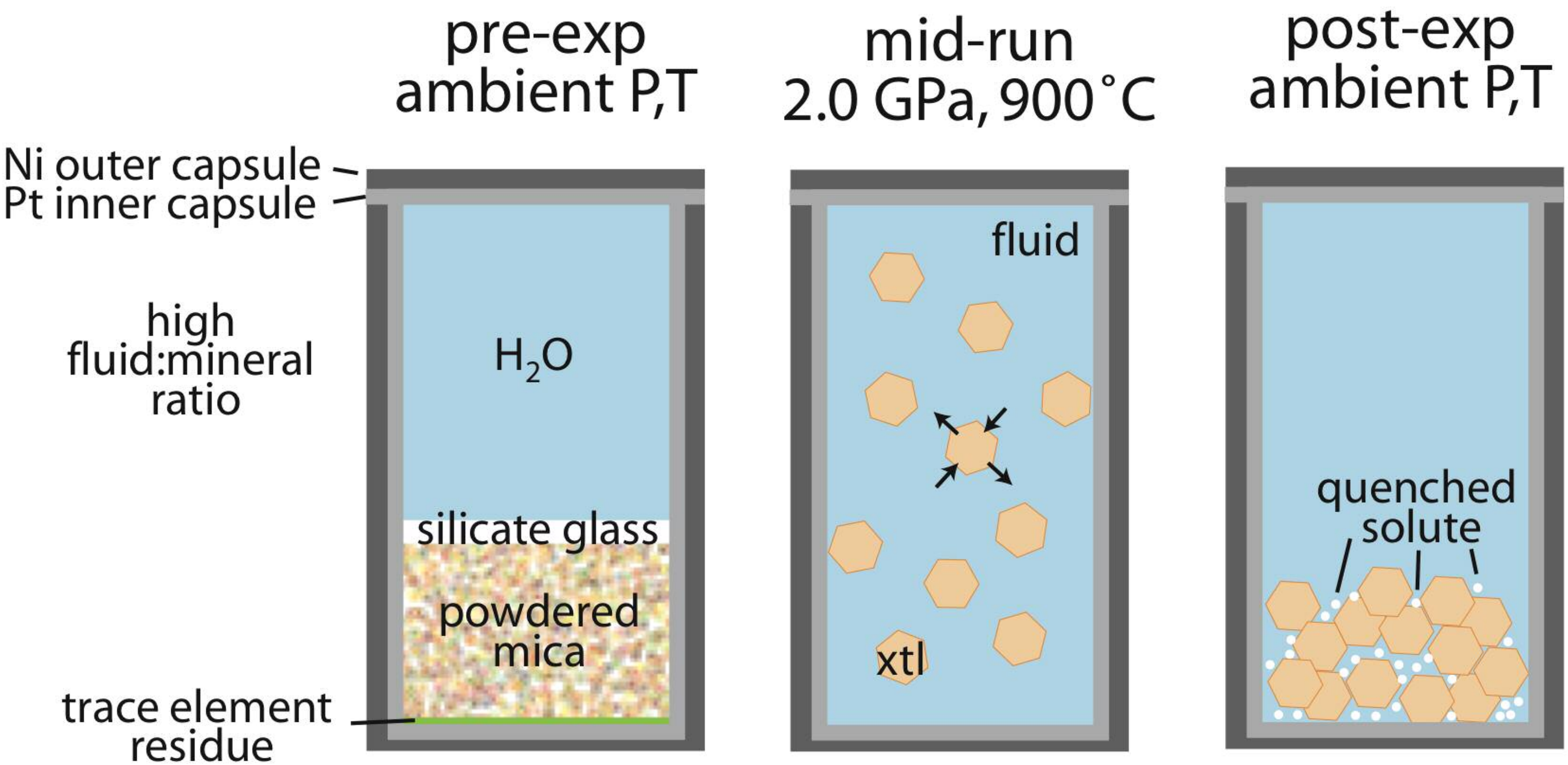
$$D^{\text{mineral/fluid}} = \frac{C^{\text{mineral}}}{C^{\text{fluid}}}$$



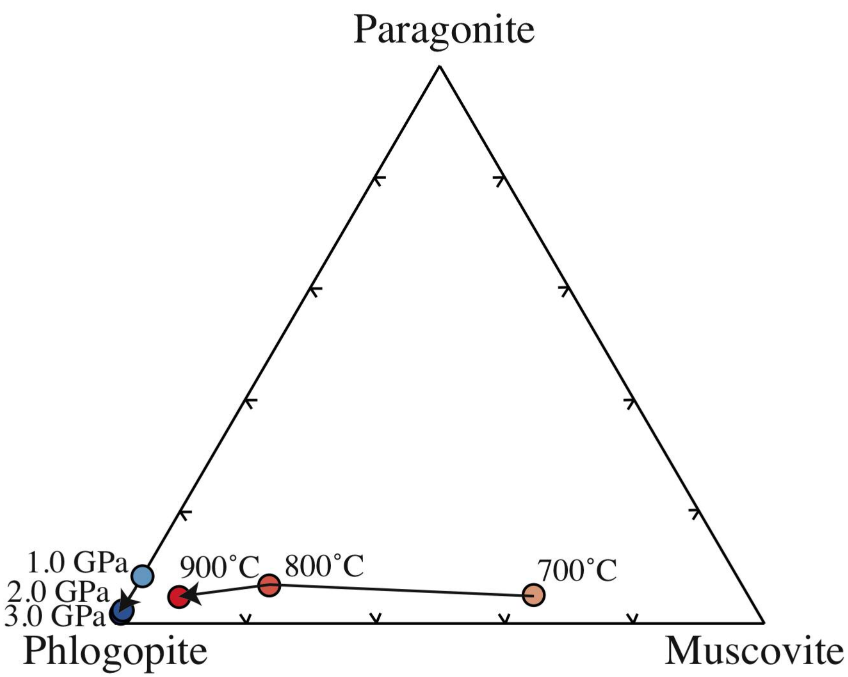
End-loaded piston cylinder apparatus: can achieve upper mantle pressures (<4GPa)

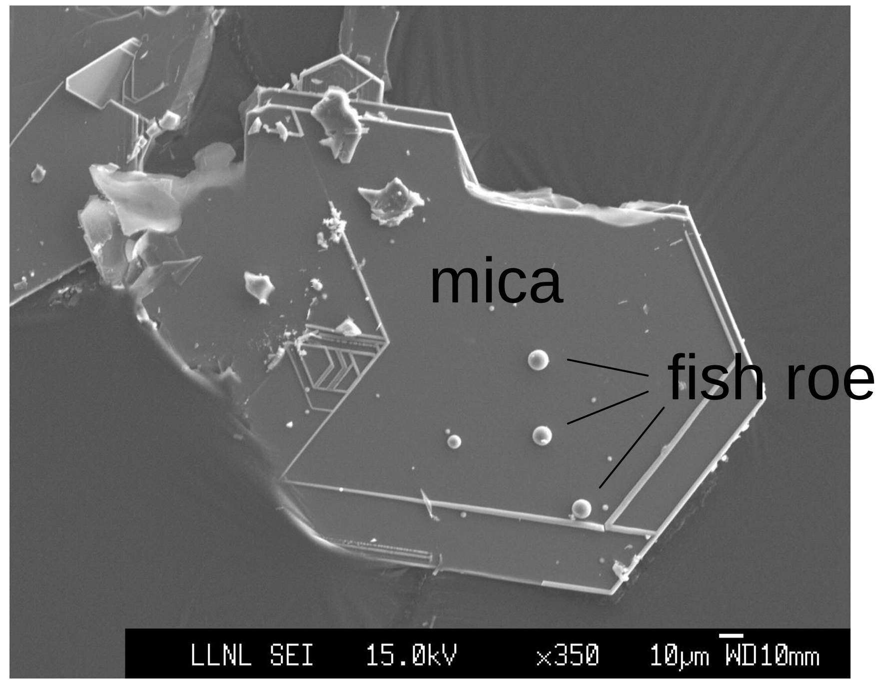


Partitioning experiments: 700-900˚C, 1.0-3.0 GPa



Experimental run products: crystals and quenched solute





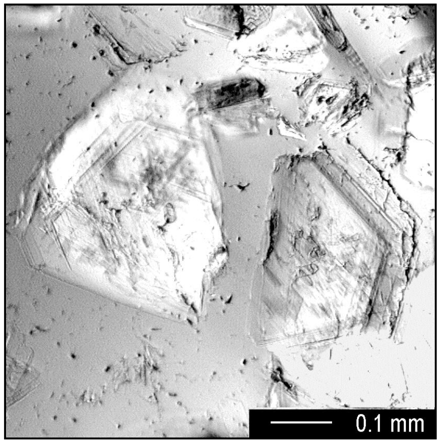
Mica/solute ratio calculated by K, Na mass balance

$$M_{SM} \cdot \%K_{SM} = M_{mica} \cdot \%K_{mica} + M_{solute} \cdot \%K_{solute}$$

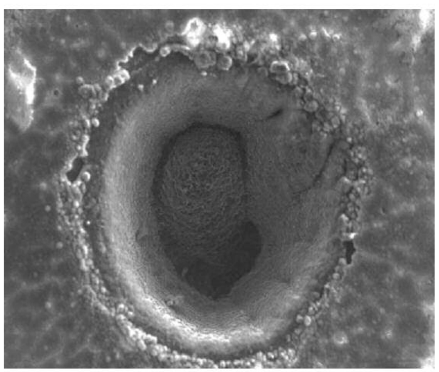
$$M_{SM} \cdot \%Na_{SM} = M_{mica} \cdot \%Na_{mica} + M_{solute} \cdot \%Na_{solute}$$

Trace element analysis by LA-ICP-MS

Run-product mica



SEM Image of a 185 micron laser crater



200 microns

Analyses run on VG ExCell at Boston University

Mica by LA-ICP-MS

Fluid by mass balance

$$C_{SM} = X_{mica} \cdot C_{mica} + X_{fluid} \cdot C_{fluid}$$

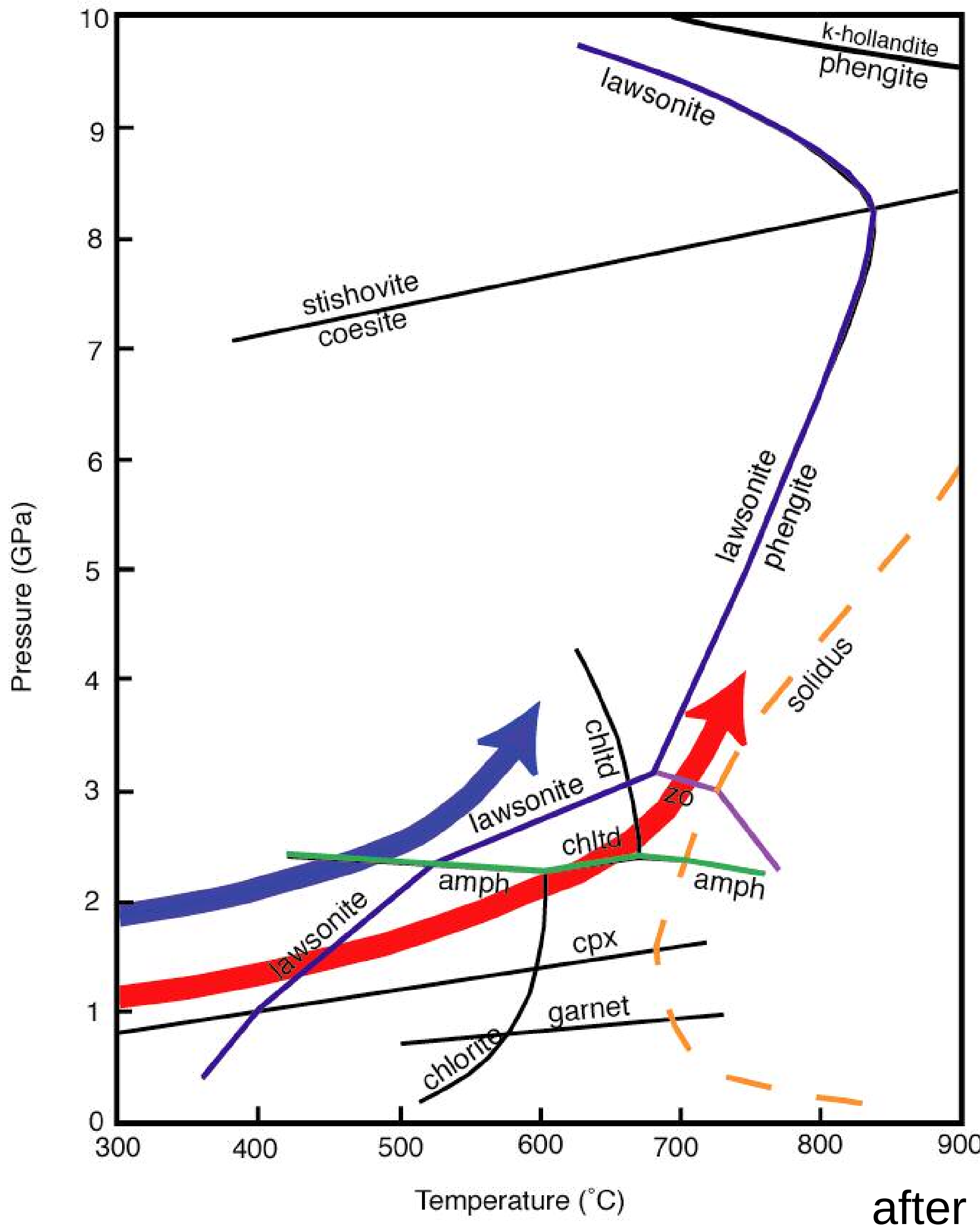
Mineral/fluid partition coefficients

Mineral-fluid partitioning review

- Th more compatible in cpx, U more compatible in garnet
- Many trace elements incompatible in cpx, garnet
- Most trace elements, especially LILE (Ba, Sr), compatible in hydrous minerals
- Y compatible in all major slab minerals

Warm vs. cold slab trajectory

Cold slab retains lawsonite, H_2O

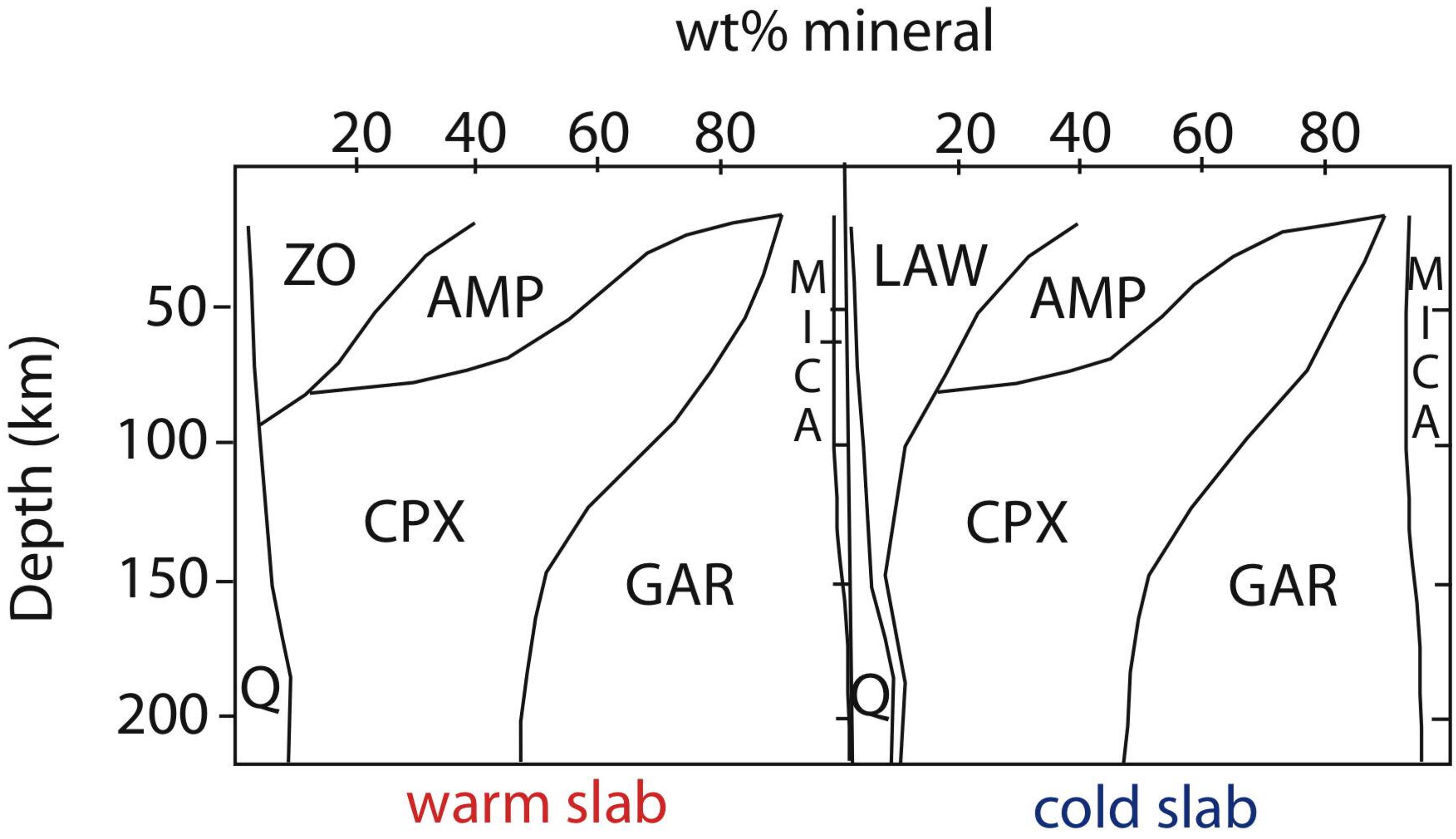


Warm slab "dries up" by ~100 km depth

after Schmidt and Poli 1998

Determining bulk partition coefficients

$$D_{bulk} = \Sigma X_i D_i$$



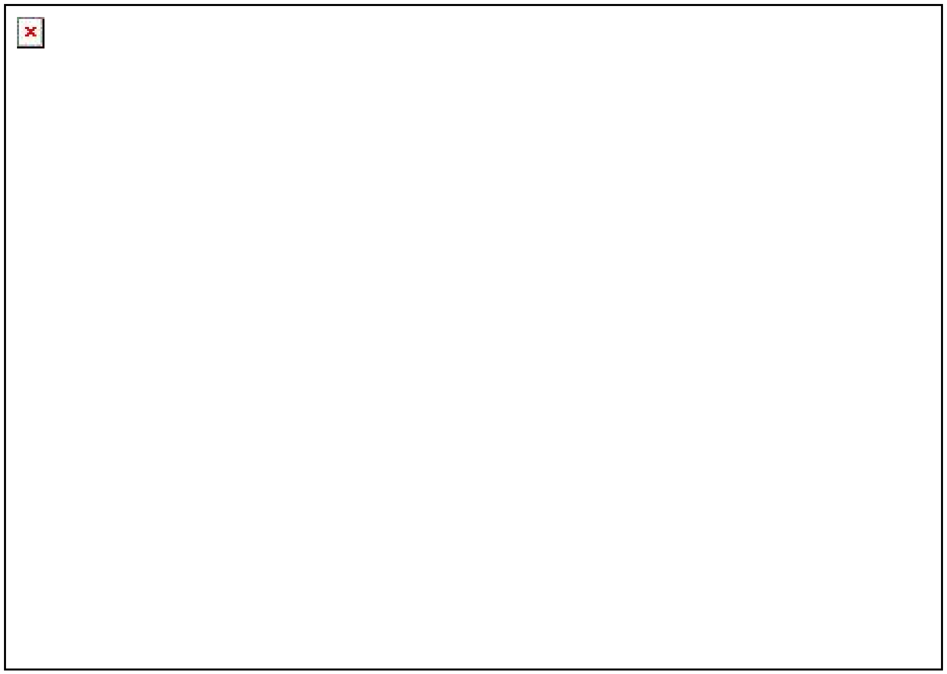
after Schmidt and Poli 1998

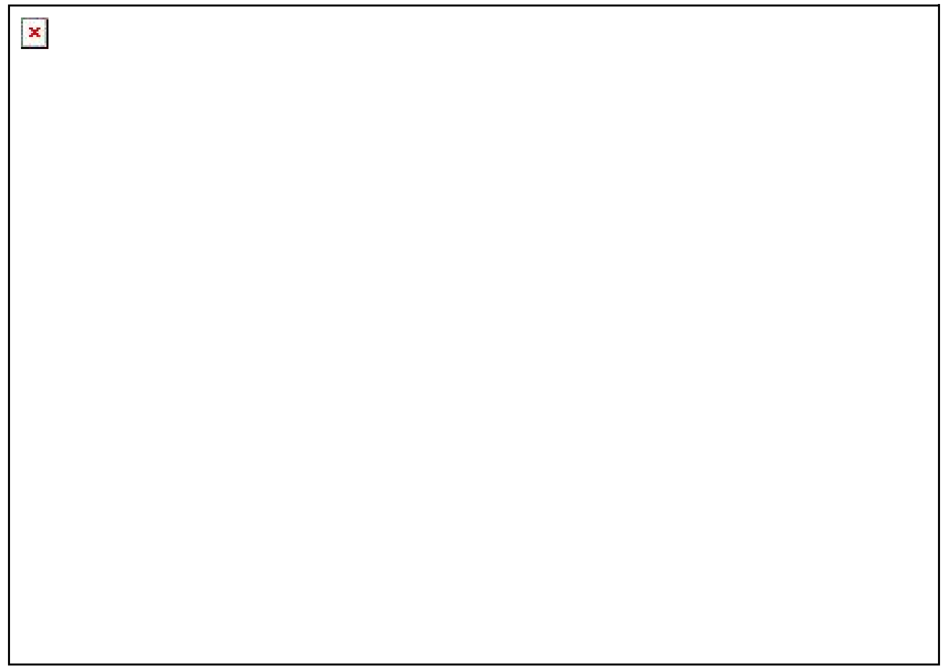
Bulk partition coefficients in slab

Not fractionated by mantle melting

Indicator of
slab melting

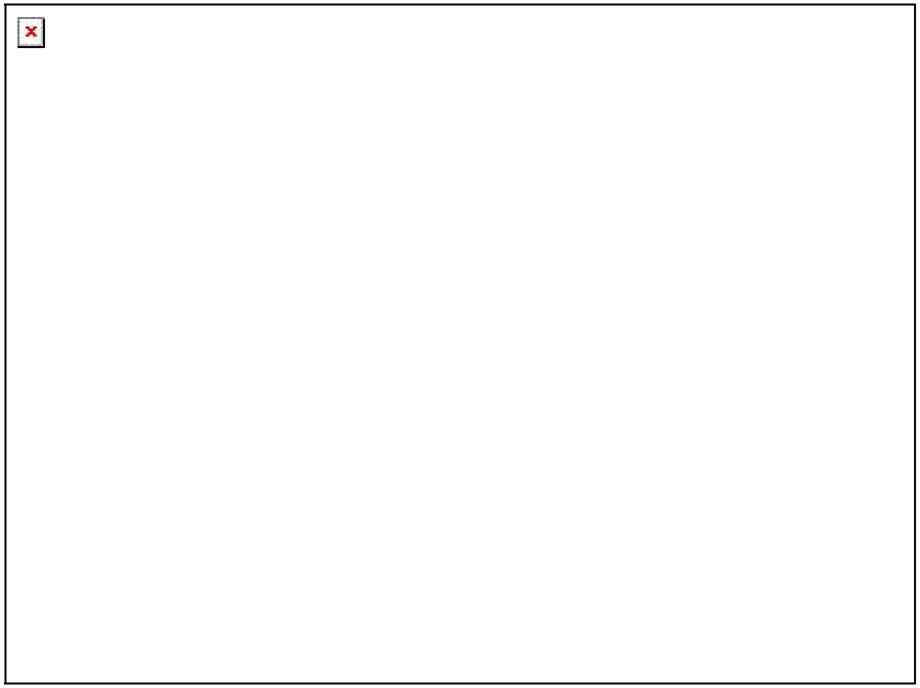
Variation in fluid released depends on evolving mineralogy

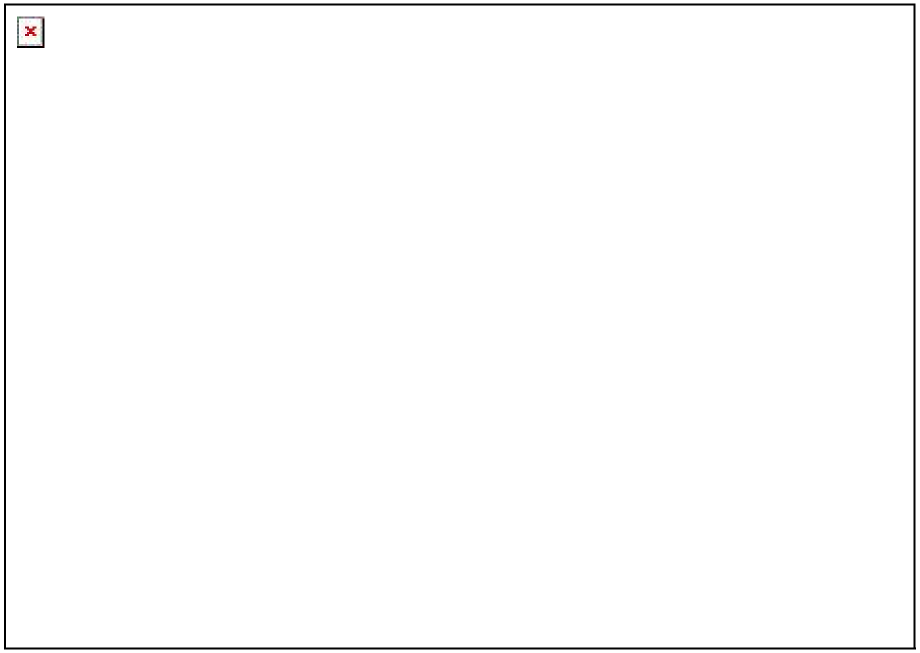




Assuming equilibrium in the slab

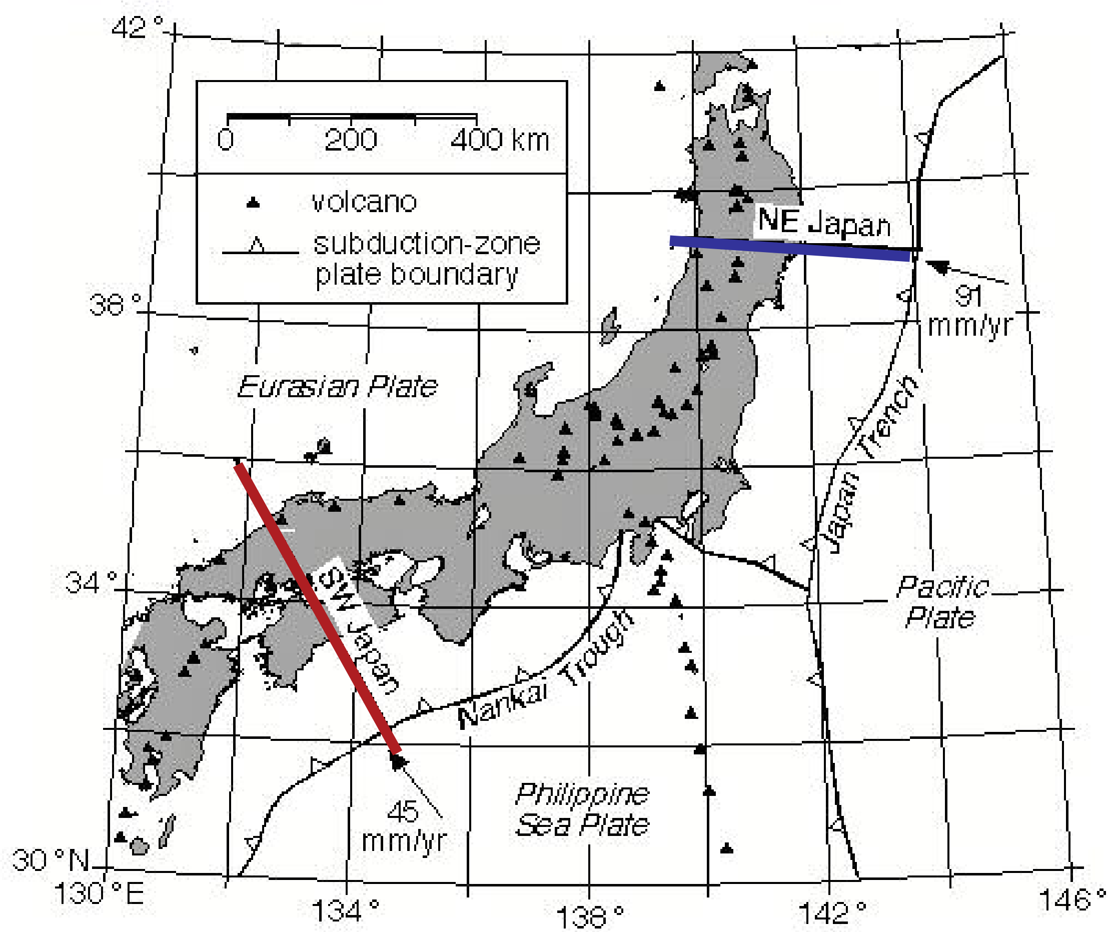
Fluid compositions





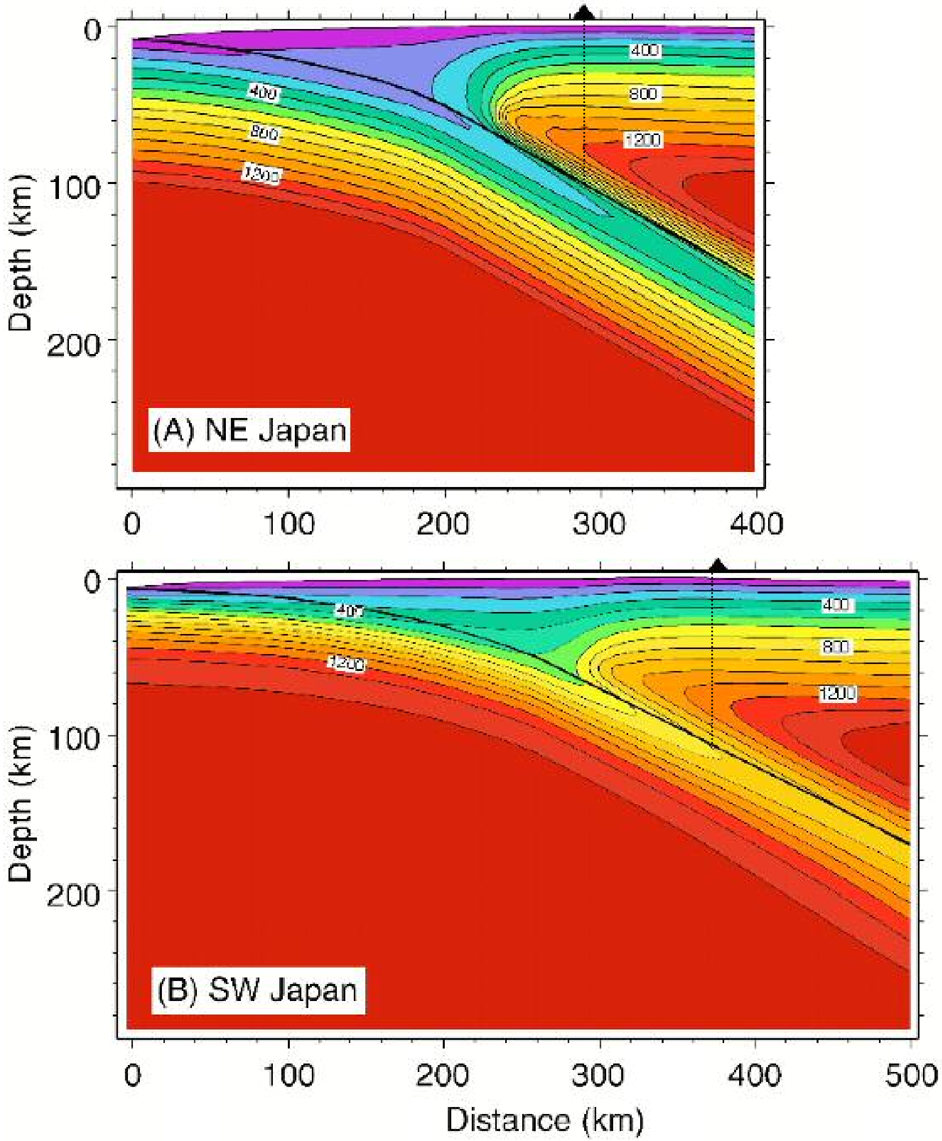
$$C^{fluid} = \frac{C_0}{F + (1 - F) \cdot D}$$

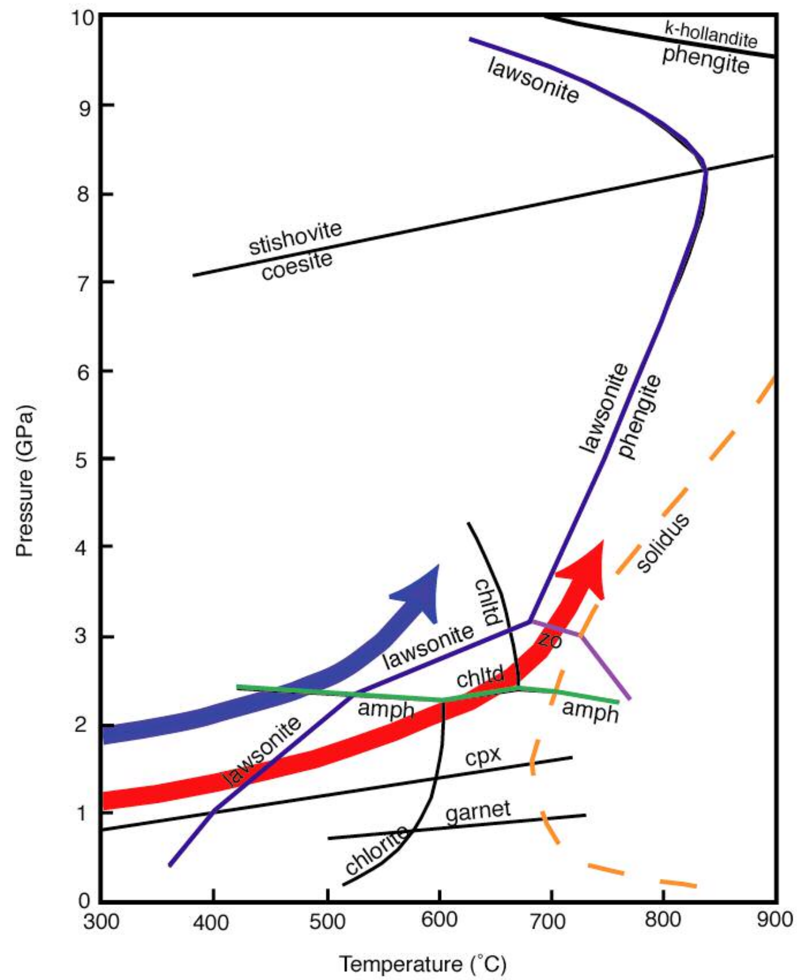
Japan Arc



Peacock and Wang
1999

Northeast (cold) vs. Southwest (warm) Japan





Peacock and Wang 1999

after Schmidt and Poli 1998

Trace element variations in the Japan Arc

Model fluid

Arc basalts

Volcanic front occurs at greater slab depth than predicted for cold slab

Arc volcanism and geochemistry review

- Fluid composition models predict trace element fractionation for certain key elemental ratios in arc basalts that cannot be explained by simple melting processes
- Appearance of volcanic front is delayed relative to model in cold arcs

Conclusions

- Arc basalt geochemistry is determined to a large extent by residual hydrous phases in the slab
- The differing mineralogy in warm and cold subducting slabs is apparent in the compositions of arc basalts
- The location of the volcanic front also appears to be related to thermal conditions in the slab