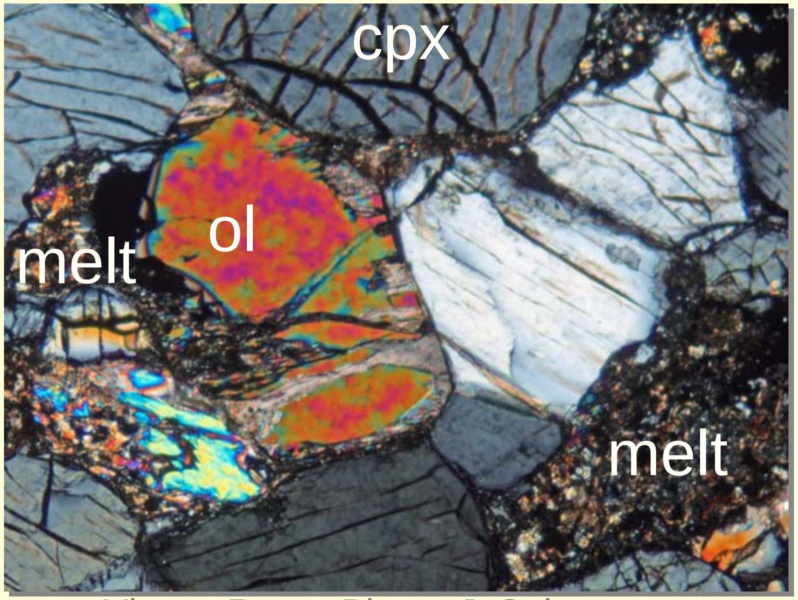
# Scientific and computational challenges in simulating fluid-rock interaction and its role in the long-term tectonics of continental lithosphere




*View ~ 5 mm; Photo: J. Selverstone*

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# General challenges in models of continental lithosphere

1. Heterogeneity - at many scales
2. Anisotropy
   - Intrinsic: anisotropic minerals, e.g., olivine
   - Due to spatial distribution of small-scale anisotropic heterogeneity (Backus, 1962)
3. Multi-phase, multi-physics, non-linear
4. Strain localization
5. What to do about the (open) basal boundary?

…

# Effective rheology: diversity of approaches

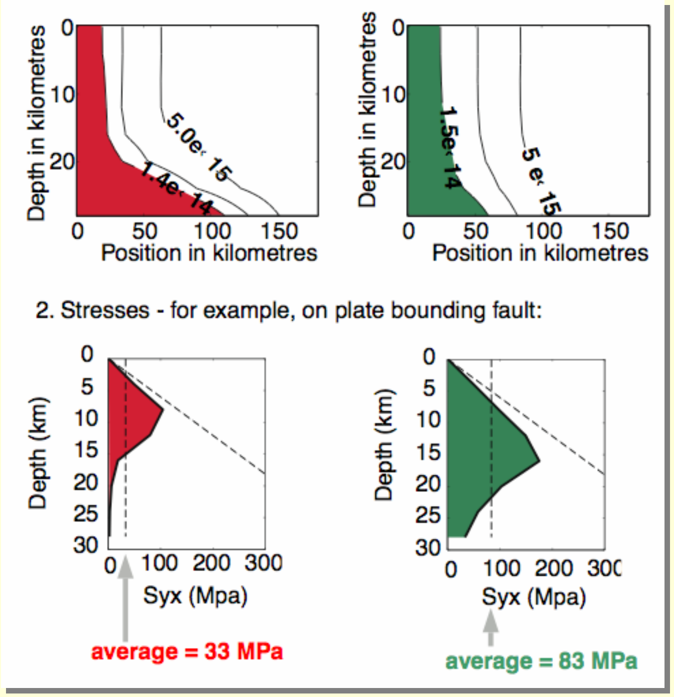
Continuum mechanics

- elastic, thin-viscous sheet, elastic-visco plastic, viscoelastic, rigid-plastic, etc; with and without emergent strain localization at faults/shear zones

*See also overview by S. Willett at 2005 CIG-Long-term crustal dynamics workshop*

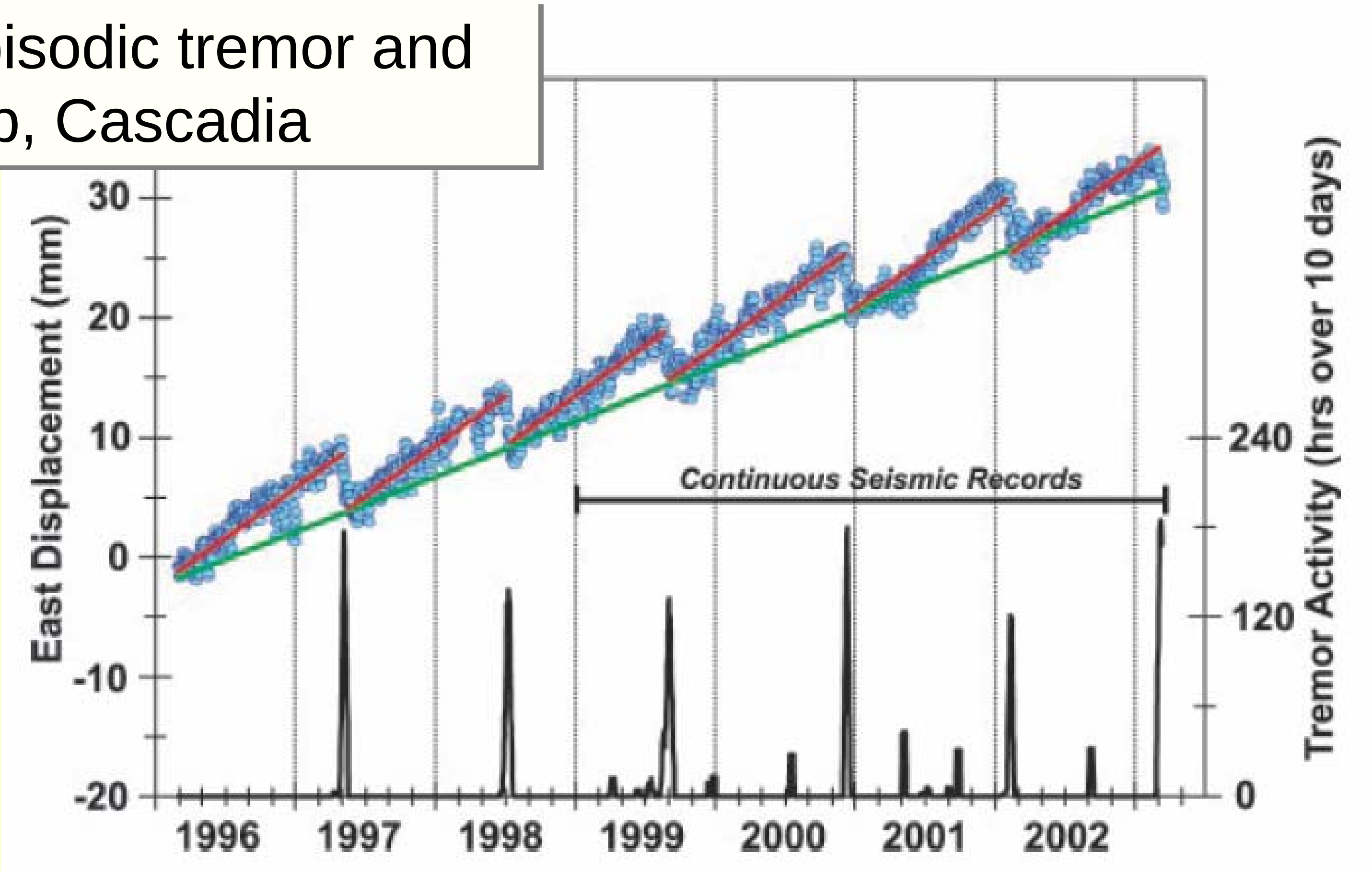
Damage theory

General problem: degeneracy
e.g. in surface strain-rate patterns



# Observations demand multi-physics

Episodic tremor and slip, Cascadia

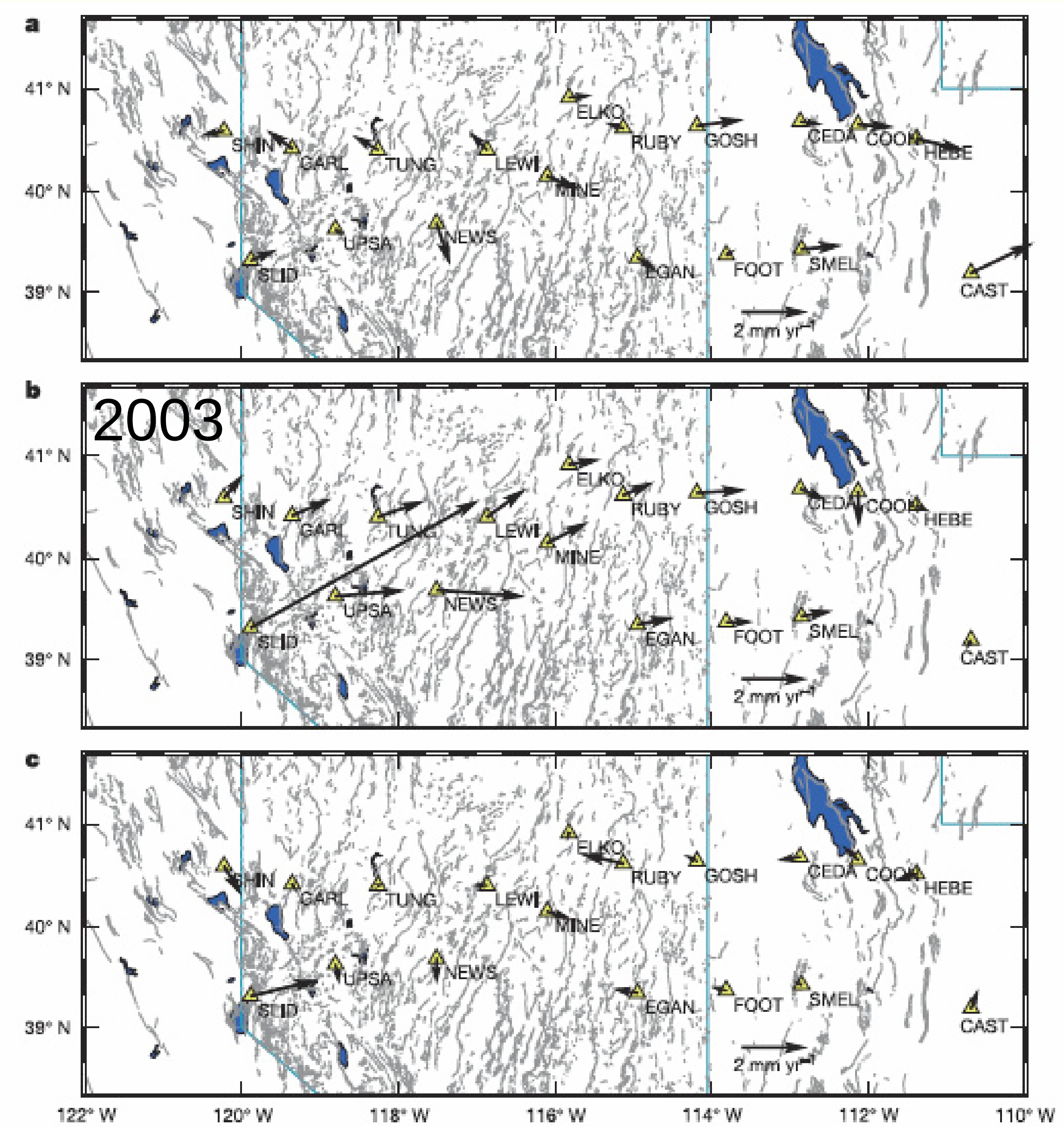



*Rogers and Dragert, 2003*

- Short time scale (<$10^1$ yrs)
- Long spatial scales  ($10^1$ to $10^2$ km)

Fluid-related?

*Obara, 2002*




*Davis et al., 2006*

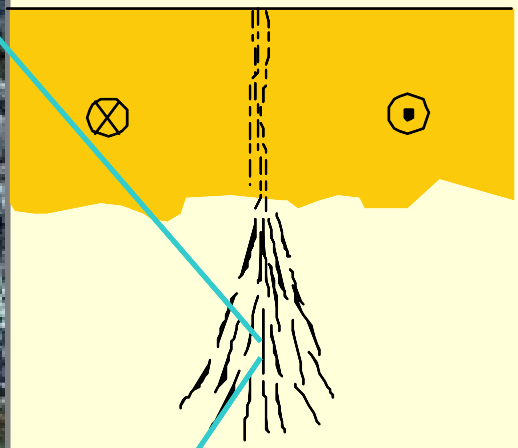
Deviations from constant velocity (estimated from the previous 2.5 years of data)

- Short time scale ($<10^0$ yrs)
- Long spatial scales ($10^2$ to $10^3$ km)

Very long-range interactions:
??
Fluids?

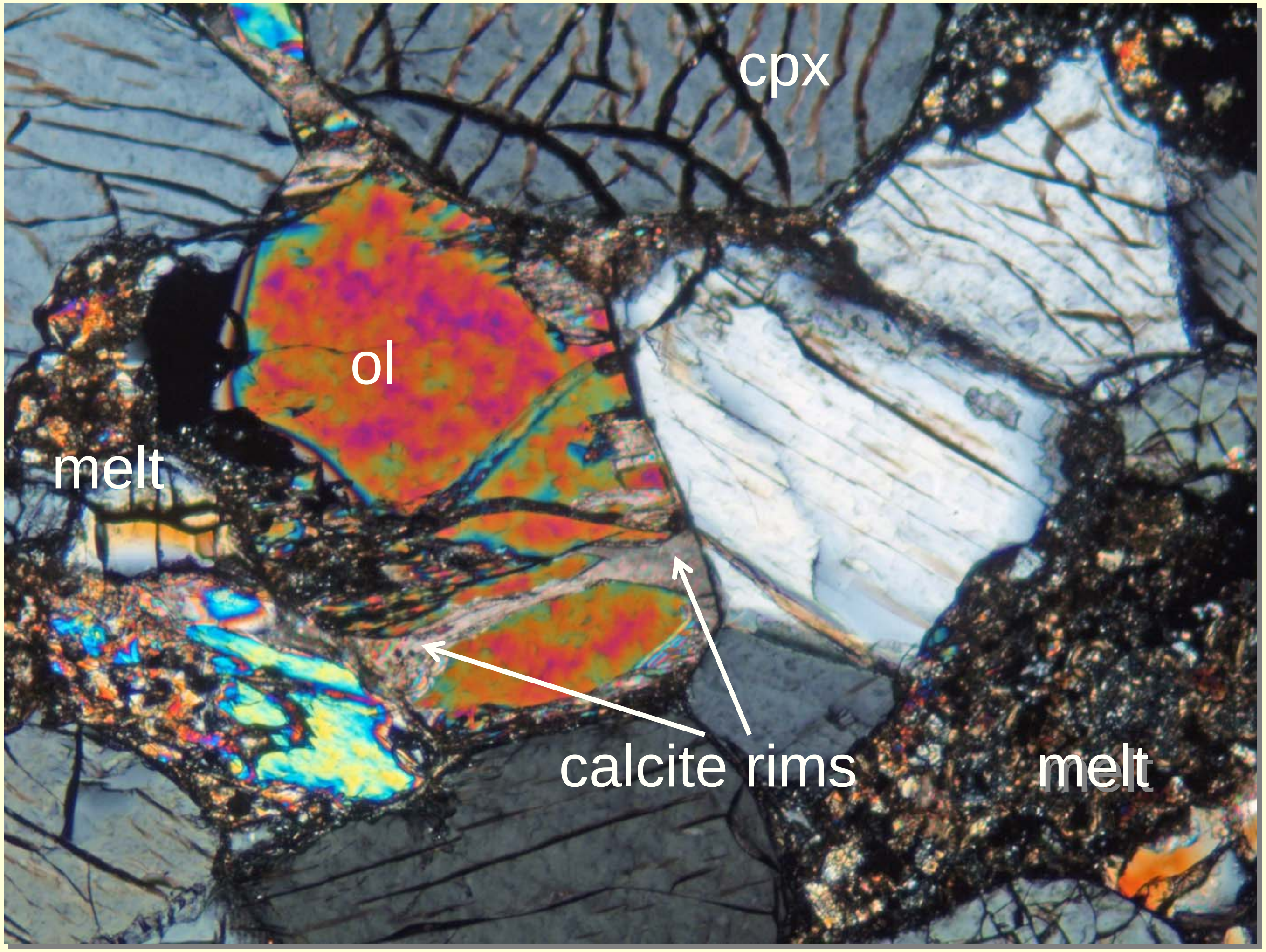
# Melt-rock interaction in continents: Strain localization and deformation

Scale: C. Manduca



Magmatic brecciation: tonalite surrounding blocks of lower crustal diorite within a lower crustal shear zone

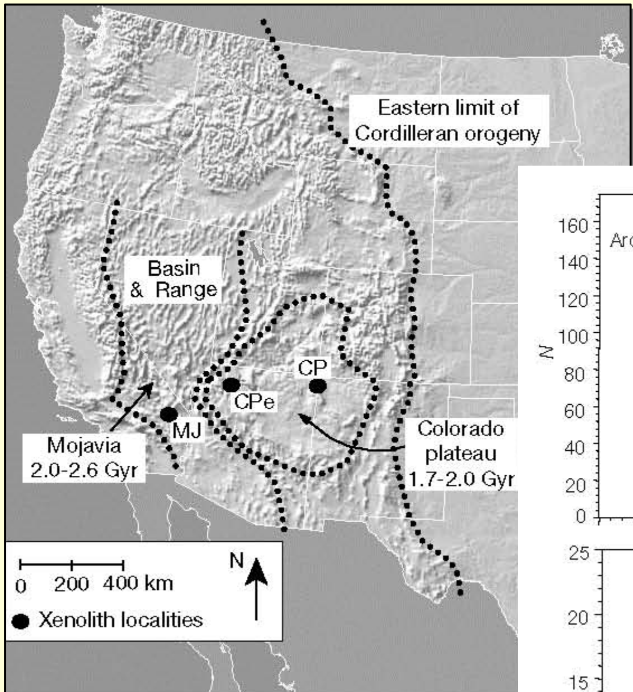
# Melt-rock interaction in continents: Metasomatism




*View ~ 5 mm; Photo: J. Selverstone*

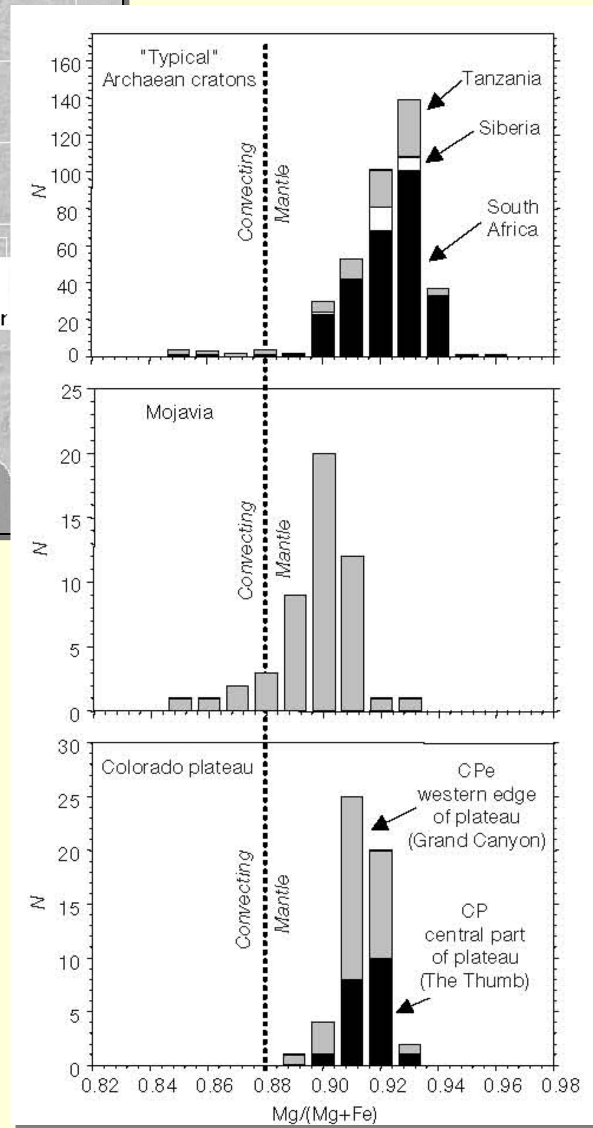
Wholesale transformation of lherzolite into carbonate-bearing pyroxenite (Rio Puerco volcanic field, NM)

Olivine reaction with carbonatitic melts to form calcite



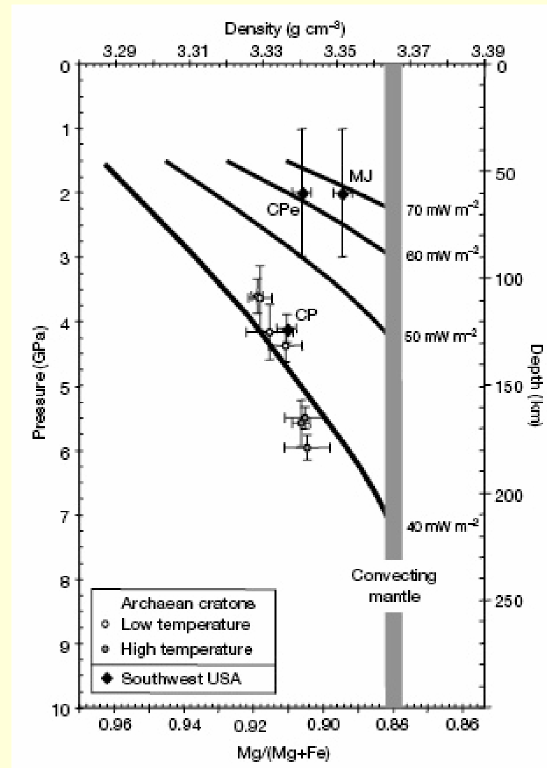

see: [Alibert, 1990; Ehrenberg, 1982; Lee et al., 2001; Roden, et al., 1990; Smith, 2000]

Enigmatic lithospheric stability of CP correlates with Mg# not age




e.g., *Lee et al., 2001*

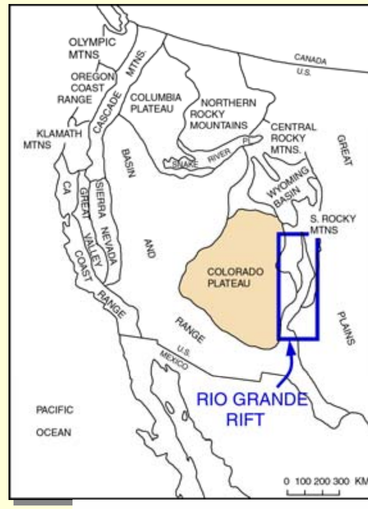
- CP more depleted in basaltic components removed by partial melting (higher Mg#) than Mojavia

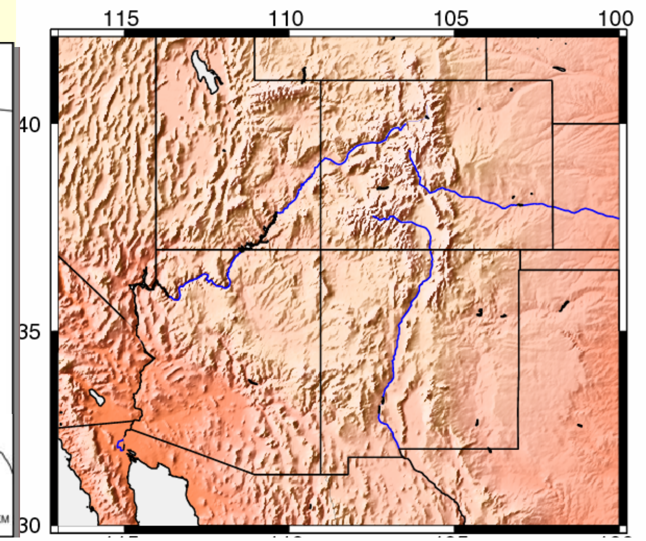


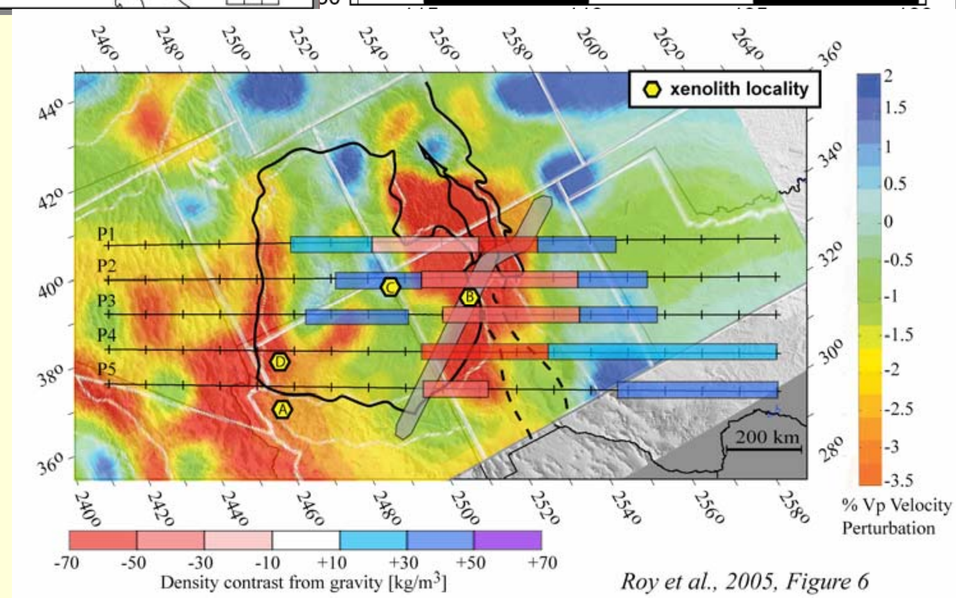
# Goal: Coupled deformation and magmatism models for long-term tectonics

- Subduction zones
  *GyPSM-S: Baker et al., AGU, 2005*
- Intra-plate setting
  - Colorado Plateau, western US

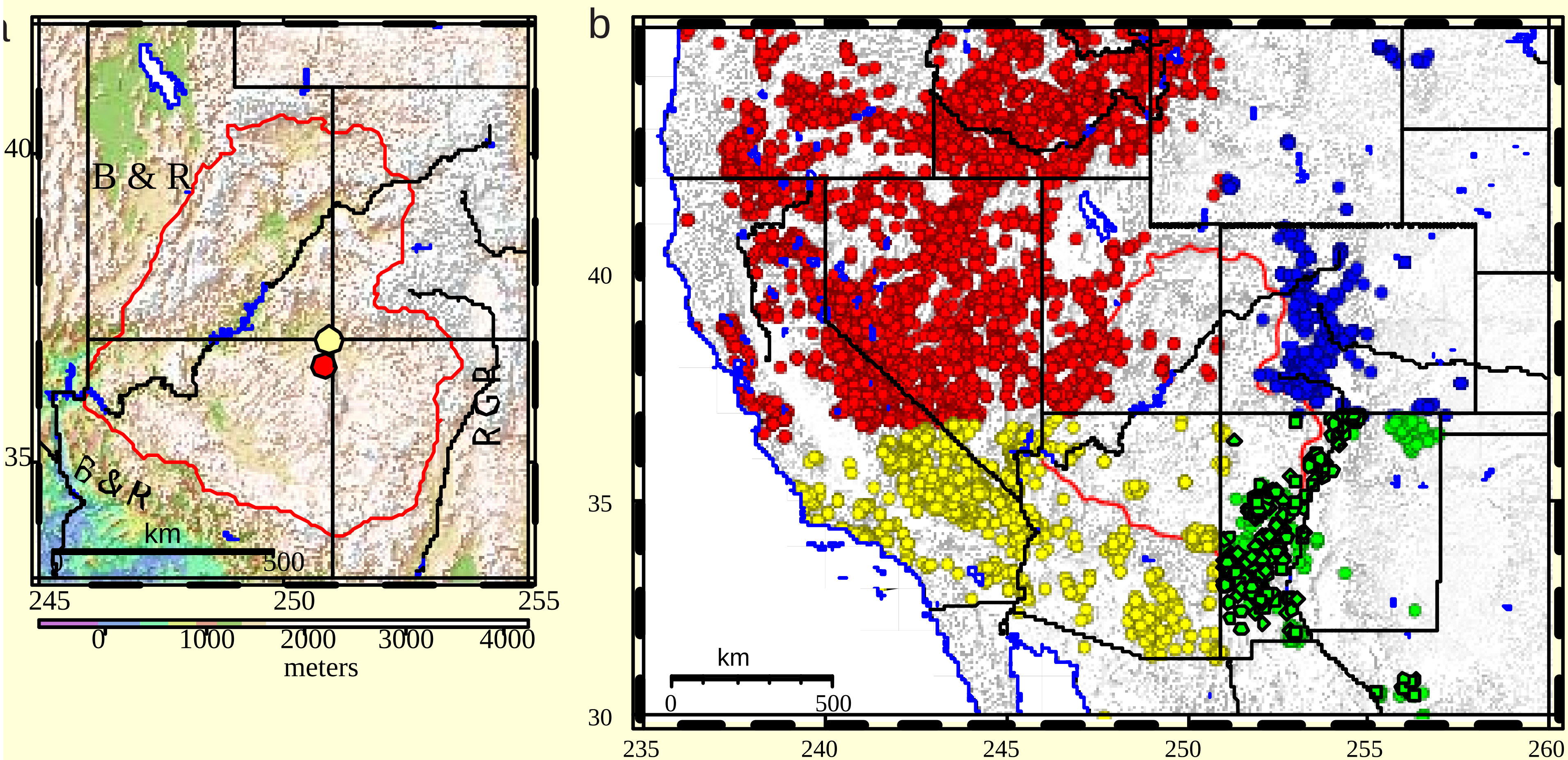
*Roy and Jordan, in review, 2006;*
*Callahan, Roy, and Jordan, in prep.*



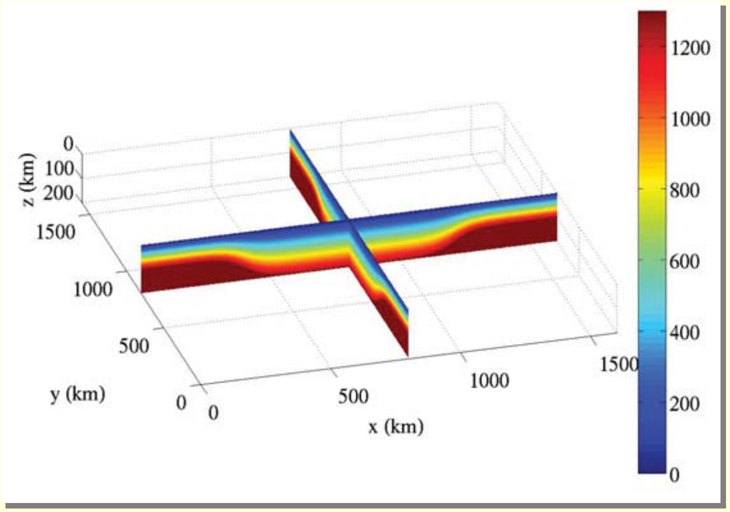



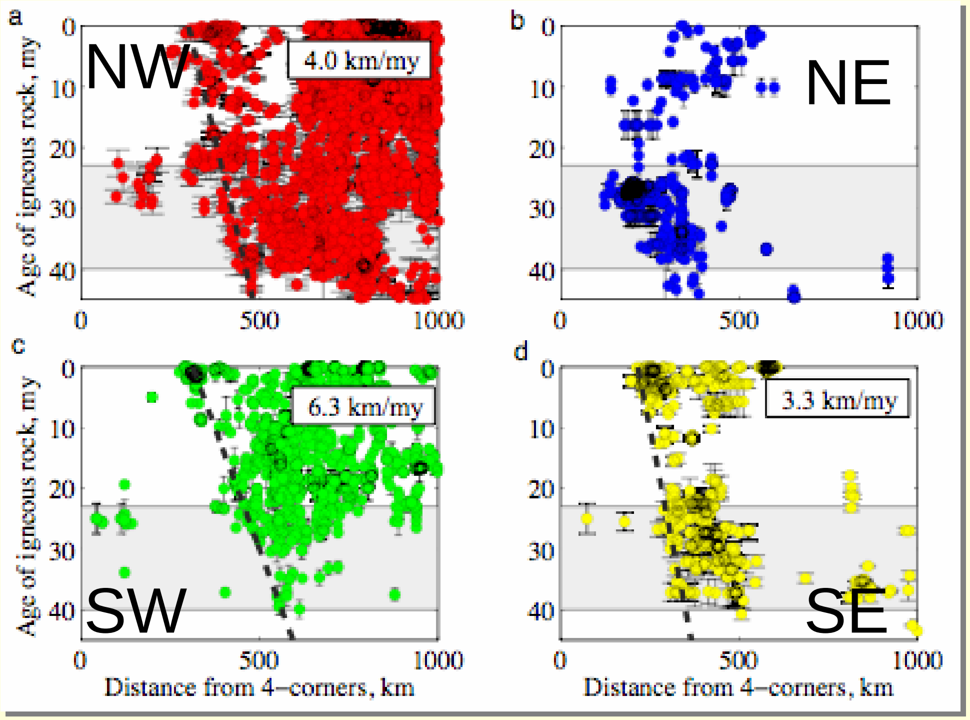

*Roy, MacCarthy, and Selverstone, 2005*

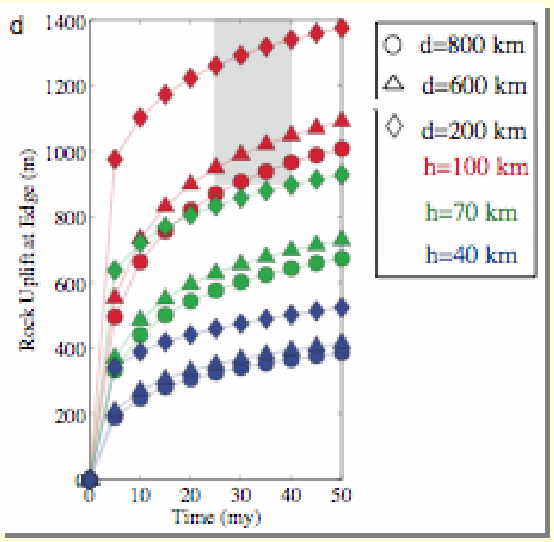


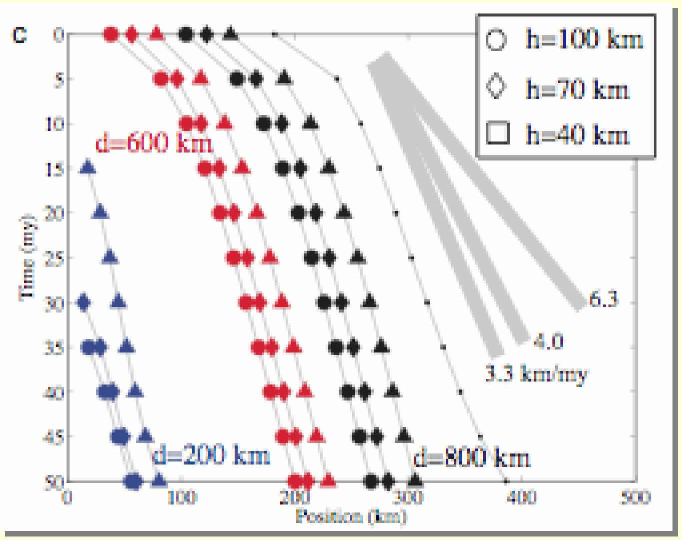

*Roy and Jordan, in review, 2006*

# Cenozoic magmatic pattern and rock uplift



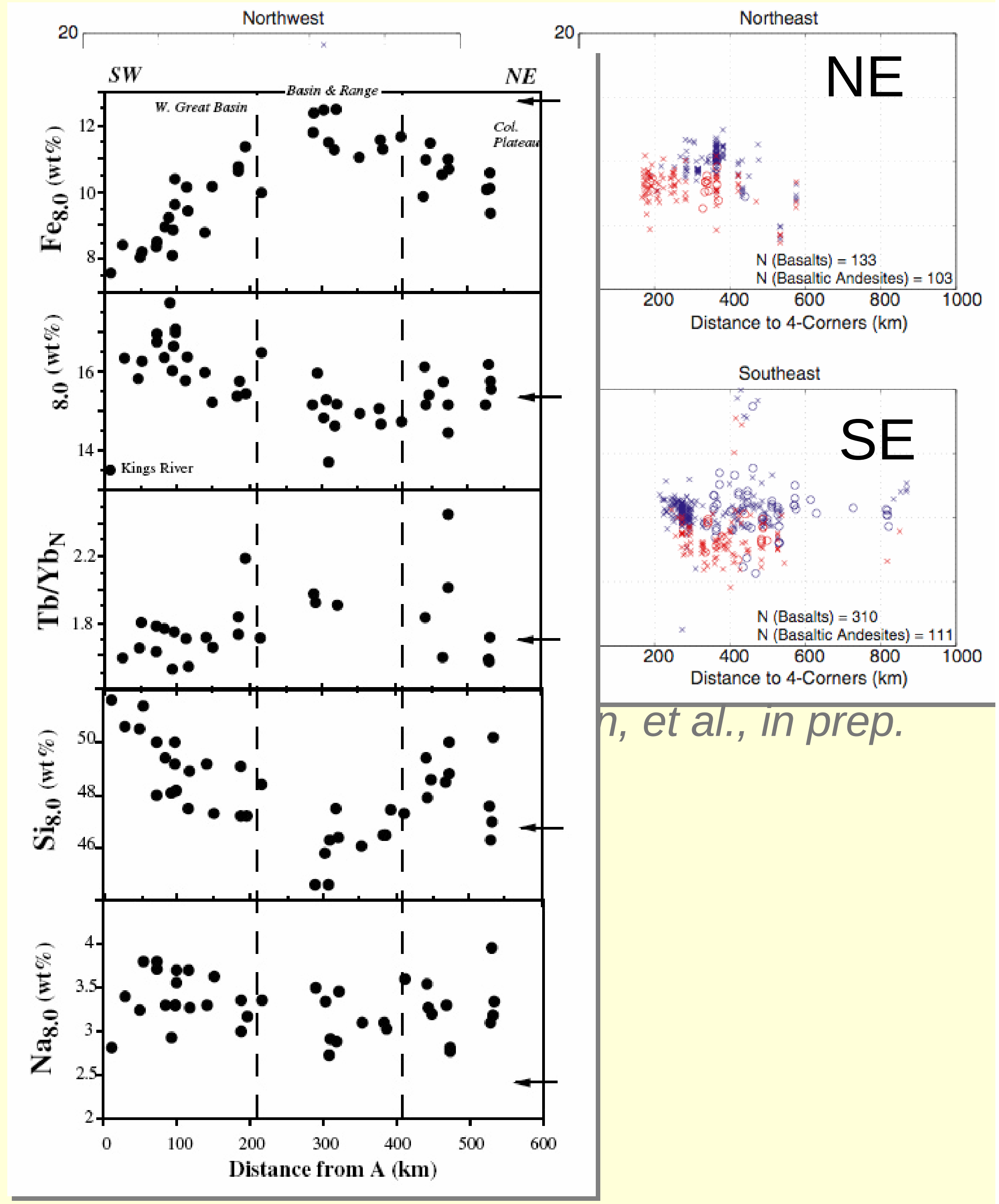




*Roy and Jordan, in review, 2006*

# Coupled chemical, thermal, rheologic evolution

- Intra-plate deformation (mainly buoyancy-driven vertical motion)
- Chemistry: couple thermodynamic phase relations using pMELTS and pHMELTs on the same grid as the thermal/deformation calcs




n, et al., in prep.

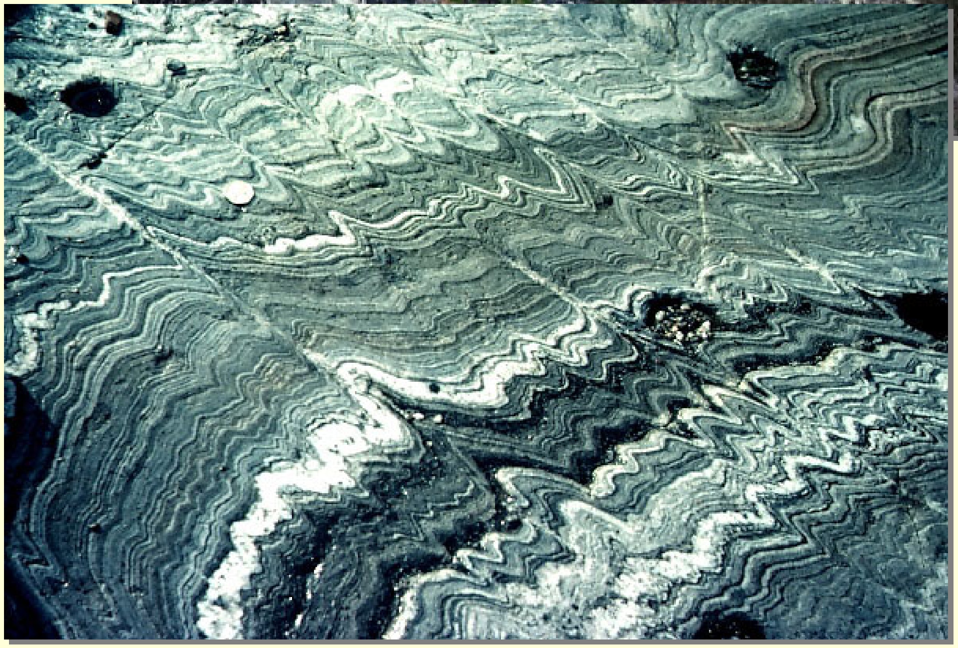
Wang, et al., 2002

# Magmatism and long-term tectonic deformation

- Long-term effect on rheology: “inherited” weakness
  - Planar zones of weakness
  - Volumetric inheritance
    - Responsible for large-scale compositional and rheologic heterogeneity within continents
    - Relationships between deformation during mountain building and crustal melting (anatexis)
- Mechanisms/processes:
  - Chemical effects of metasomatism (melt/fluid reactions - transform the dominant mineralogy and affect energy balance)
  - Removal of Fe leaves a less dense and rigid residue (particularly if Gt consumed)
  - Advective heating
  - Phase changes

# Software Challenges - 1

- Magma-deformation feedback on short timescales (<$10^{2\text{-}3}$ yrs)
- Fluid flow in viscously deforming media (e.g., McKenzie, 1984) -- details of this may not be necessary for models of long-term deformation?



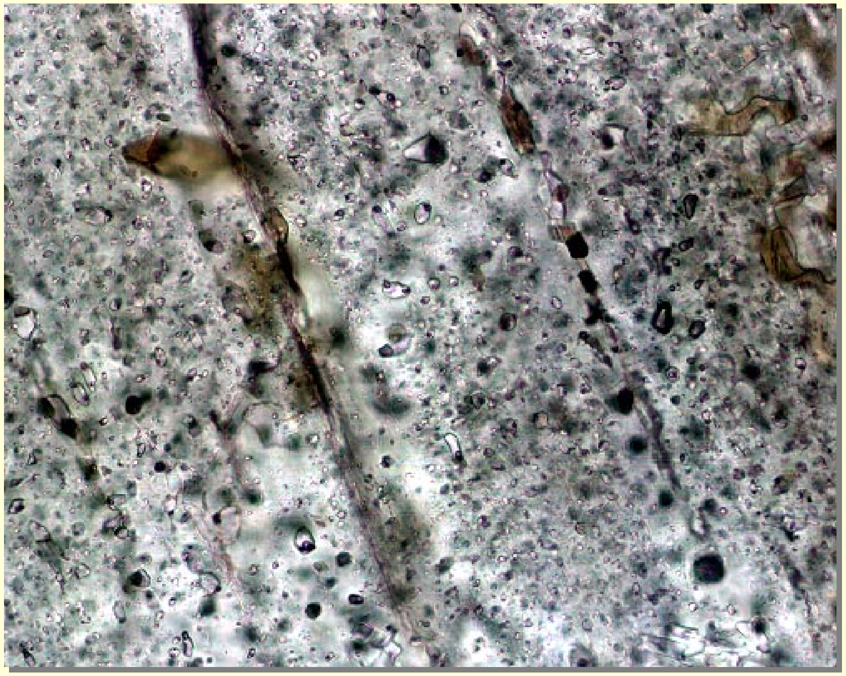
# Software Challenges - 2

- Coupled PDE's for deformation, chemistry, and rheology solved on coincident grids for thermodynamics and deformation
- Particle histories (proxy for species segregation between melt and residuum) for major and trace elements
- Modular implementation (turn magma migration/chemistry on/off?)

→ PDE-based multi-physics (FEMLab approach?)

# Challenges for petrologic models

- Continental mantle lithosphere is not a simple residue of melting (we have no melting models for hydrated, previously metasomatized upper mantle)
- Kinetics are important in chemical evolution but are ignored



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