NSF Site Visit to the Computational Infrastructure for Geodynamics

Future Directions: Modeling & Understanding Complex Coupled Systems

The Dynamics of Magmatic Plate Boundaries

Current state of CIG

- CIG has developed Computational Infrastructure for a wide range of specific communities
  - Mantle Convection - CitcomS
  - Earthquake Physics - PyLith
  - Long-Term Tectonophysics -GALE
  - Seismology - SpecFEM3D
- Each Component has significant technical challenges and explores/leverages new computational infrastructure
  - E.g. Pyre, PETSc, Sieve/Mesh,StG
- In its initial phase, CIG has provided useful tools driven by specific community needs

Looking Forward

- Nevertheless, there is important scientific questions that require integration and extension of methods/codes to make progress.
- Example: Understanding the Dynamics of Plate Boundaries
  - Complex systems that require coupling of
    - Lithospheric (Brittle) and Mantle (Ductile) deformation
    - Solid and Fluid Mechanics (Magma, Aqueous Fluids)
    - Geodynamics and Thermodynamics
    - Models and observations (Seismology, chemistry, petrology)

Plate Boundaries

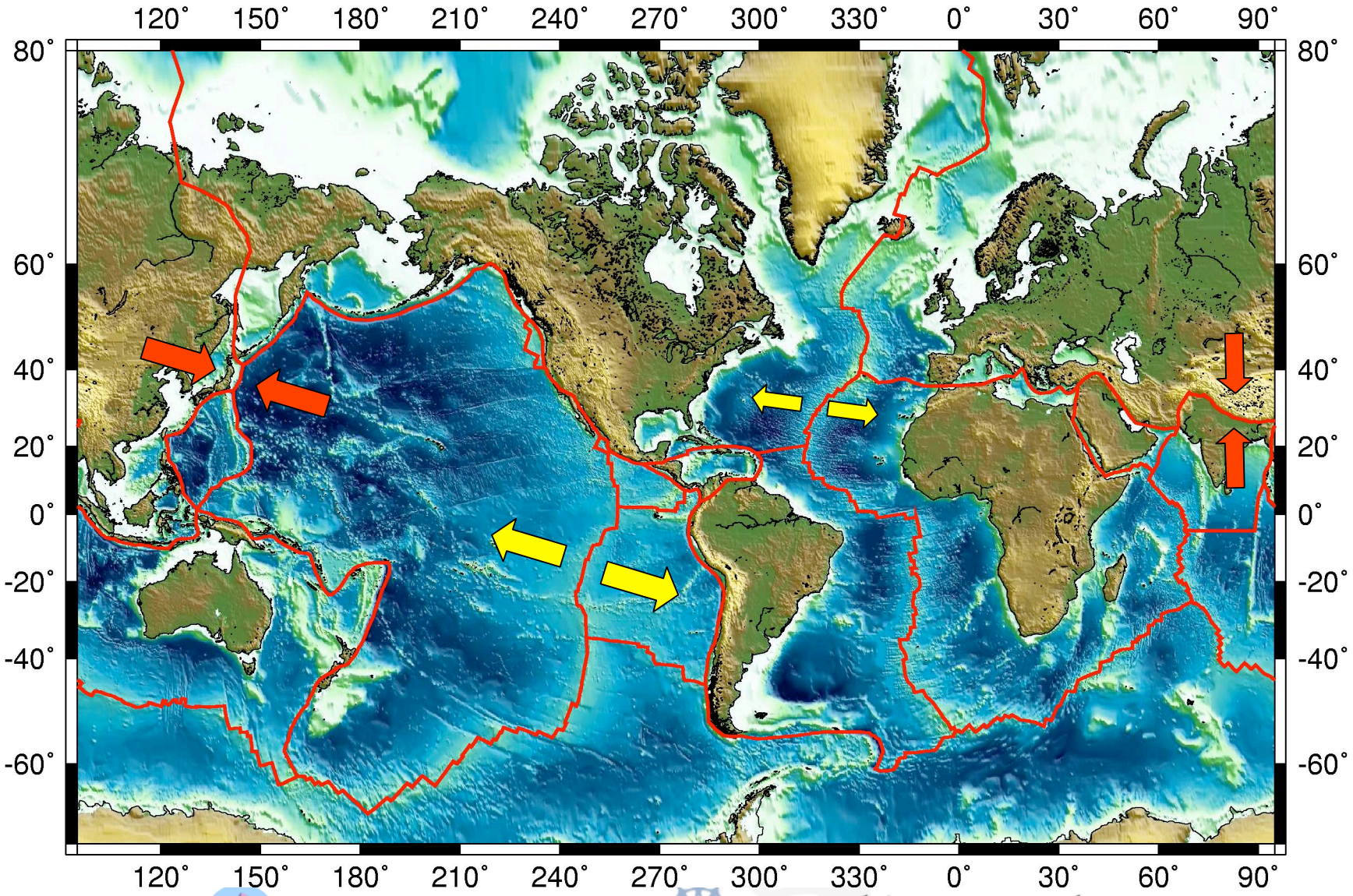
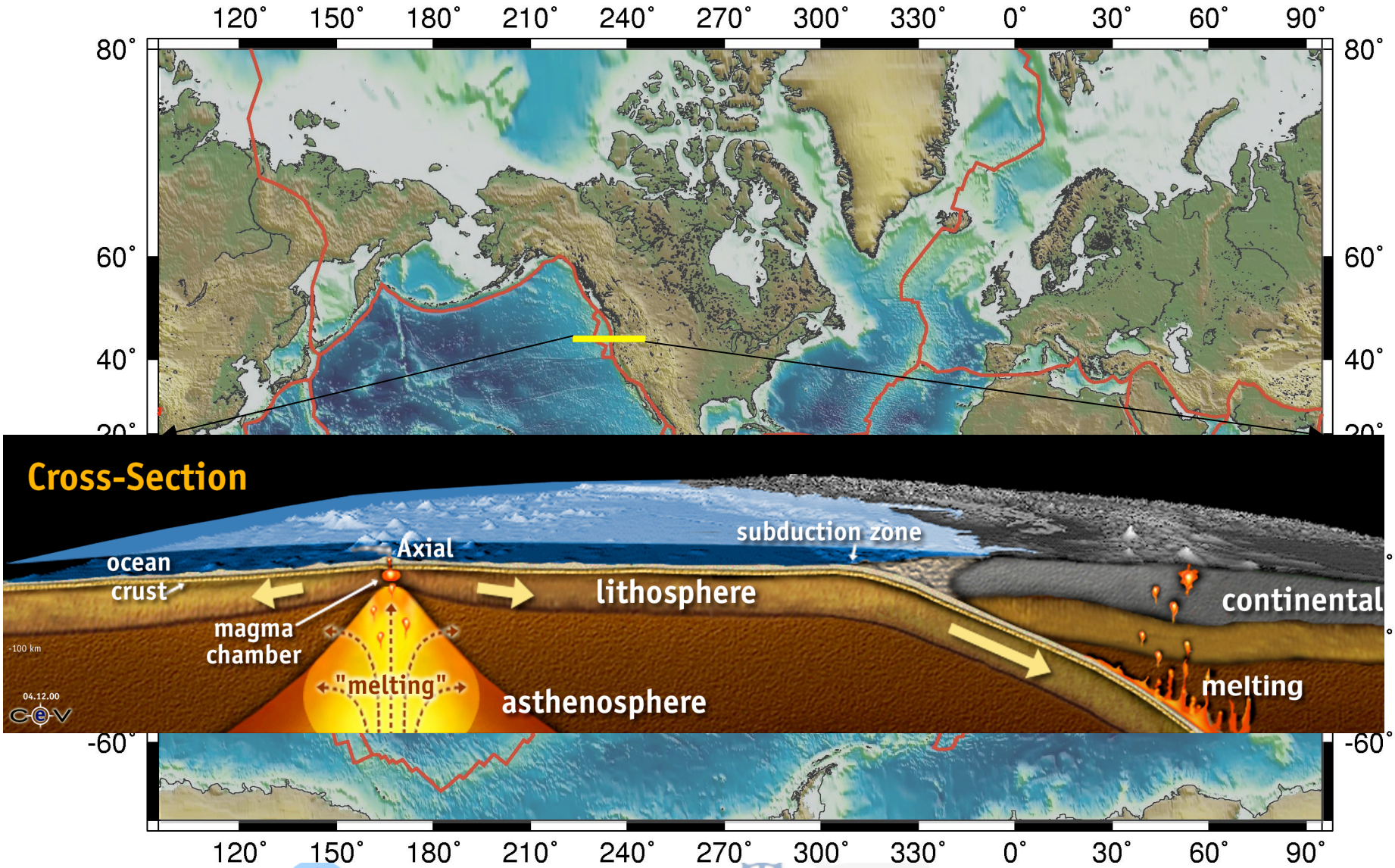


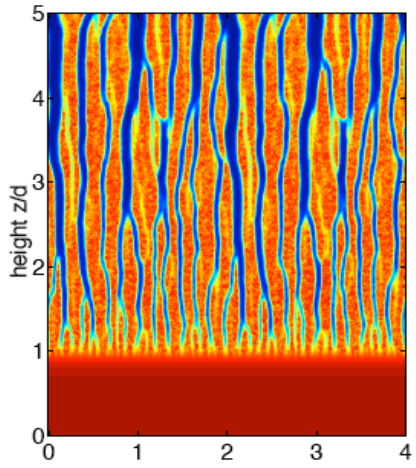
Plate Boundaries

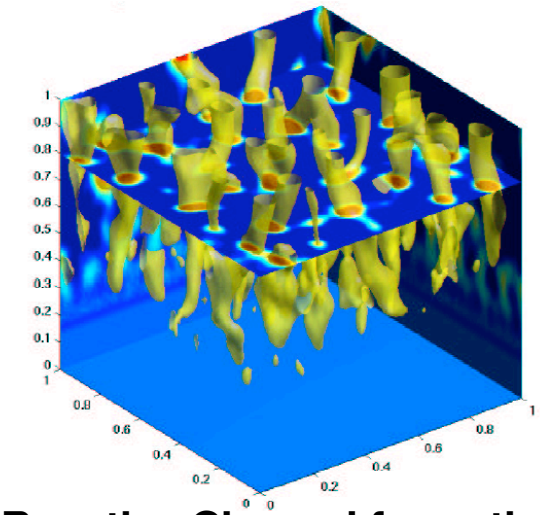


Computational Issues

- Code integration & interoperability
- Interfaces to Data/ Thermodynamic models
- Modeling of Multi-physics Multi-scale problems
  - Important point: coupling of even two well-understood problems (through feedbacks or constitutive relations) can lead to signficantly new behavior
- Specific Example: Magma Dynamics

Magma Dynamics



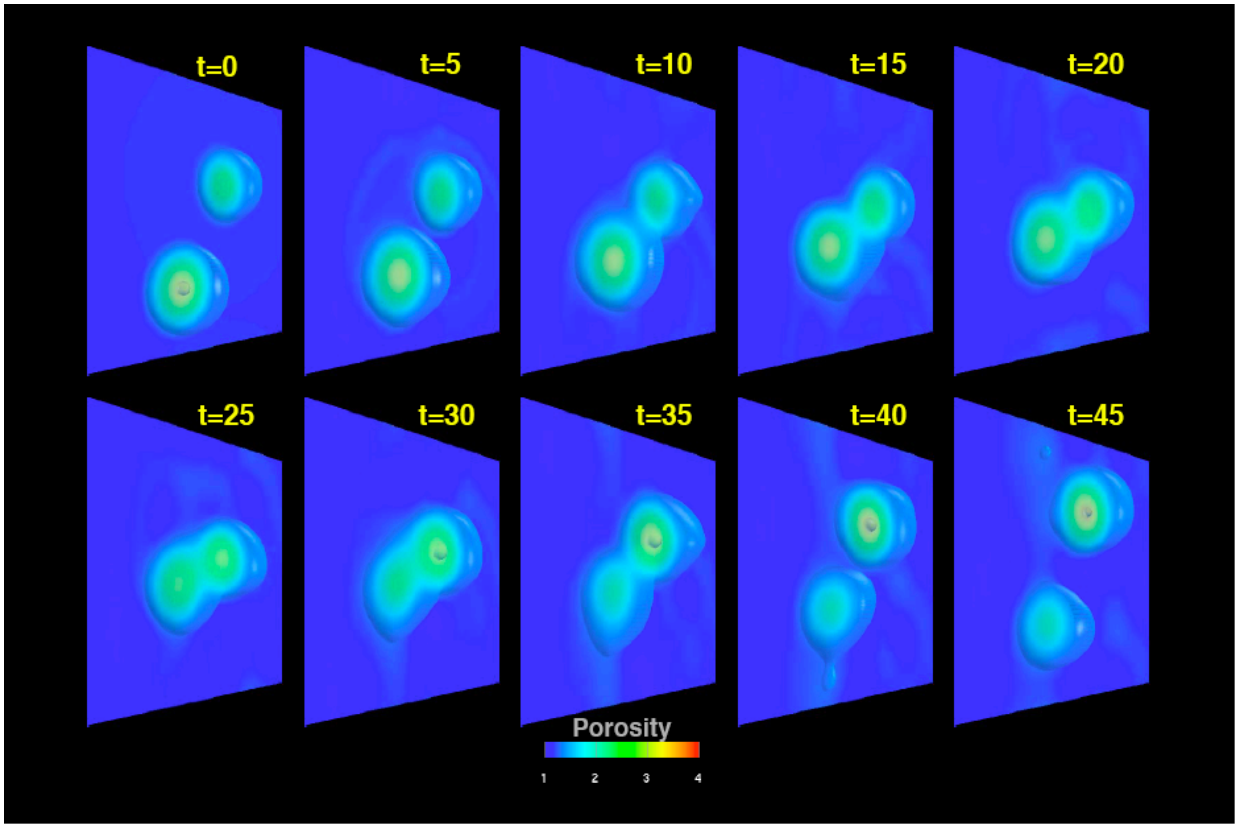


Reactive Channel formation
(Spiegelman et al, 2001)

- Theory describes reactive fluid flow in deformable permeable media
- Consistent coupling of Darcy and Stoke's Flow (porous media and mantle convection)
- Coupled system shows much richer behavior than either end-member
- Generates emergent, coherent structures at a wide range of scales (~1-10^4 m)

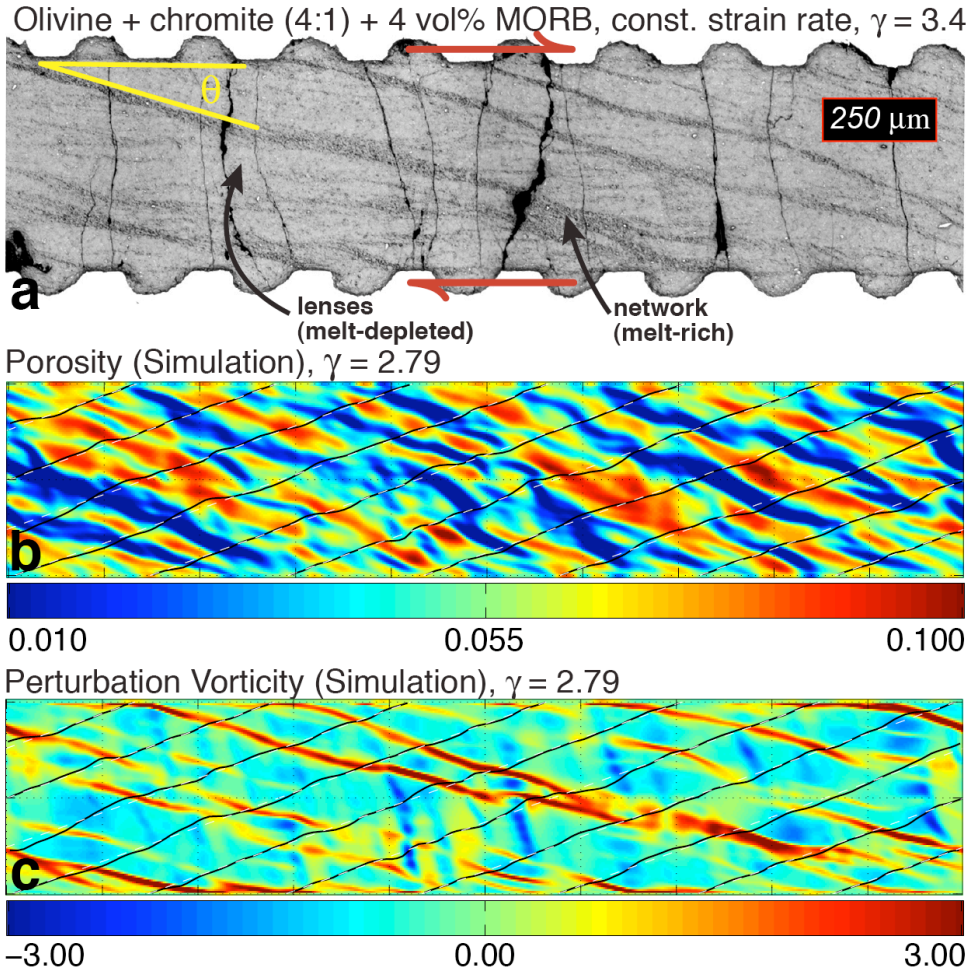
Magma Dynamics Examples
(non-linear magma waves ~1-10km)

- **Spontaneous generation of time dependent non-linear porosity waves**
- **Arise from non-linearity in permeability/porosity relationship and compressible Stokes flow**
- **Imply magma dynamics inherently time dependent**



Magma Dynamics Examples
(Mechanical Melt Channelization Instabilities)

- **Spontaneous generation of high-porosity, weak melt-rich bands seen in experiment and simulation.**
- **Could lead to both Seismic and flow anisotropy**
- **Unknown effects on bulk rheology and large scale mantle flow**

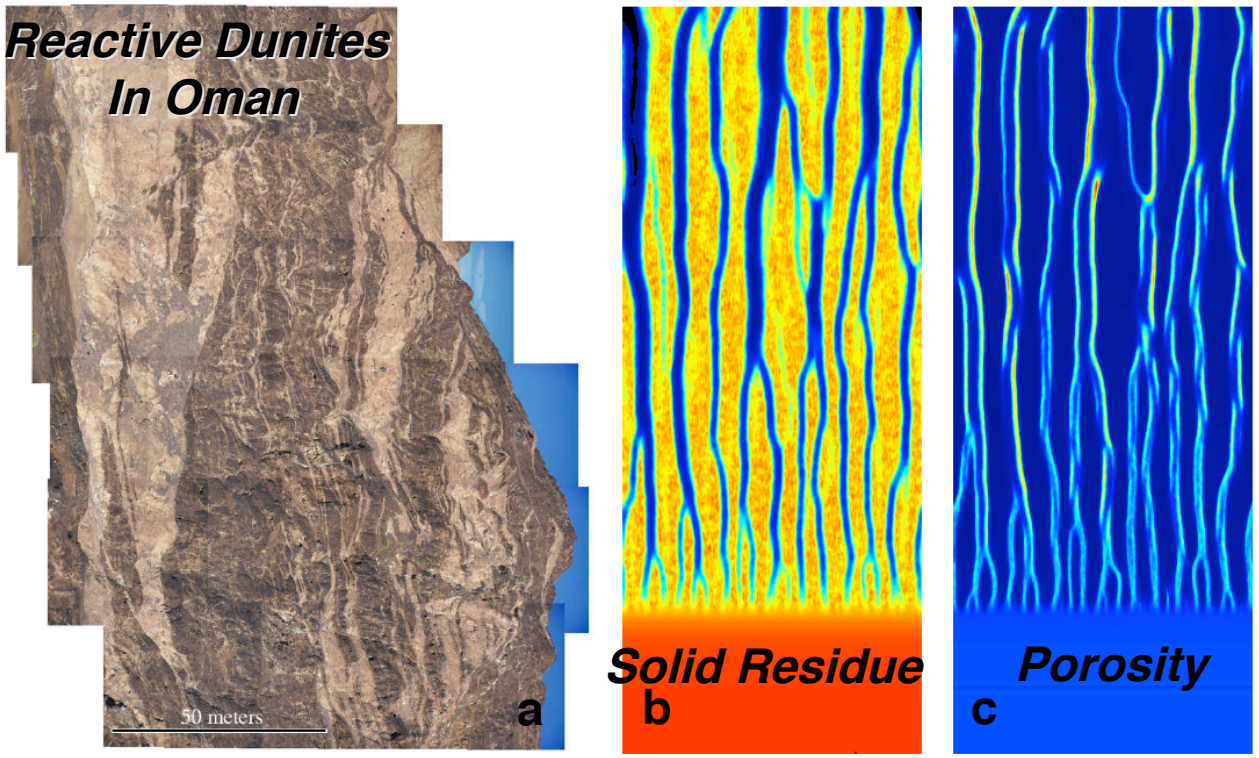


Experiments and models of magmatic shear-bands

(Katz et al. Nature, 2006)

Magma Dynamics Examples
(Reactive Melt Channelization Instabilities)

- **Spontaneous generation of high-porosity, weak melt-rich bands seen in experiment and simulation.**
- **Could lead to both Seismic and flow anisotropy**
- **Unknown effects on bulk rheology and large scale mantle flow**
- **Demonstrated ability to radically change variability of magma chemistry**

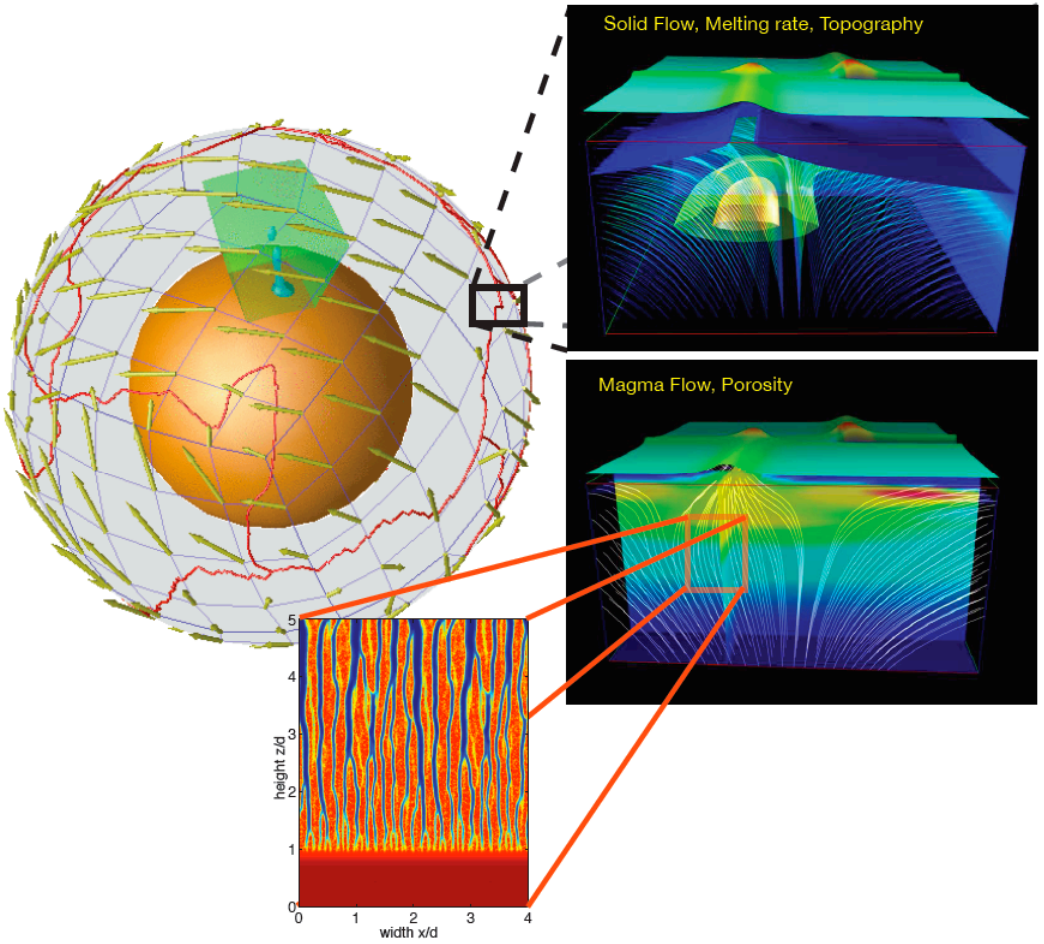


Reactive Channelization in deformable porous media
(Spiegelman et al., 2001, Spiegelman and Kelemen, 2003)

Magma Dynamics

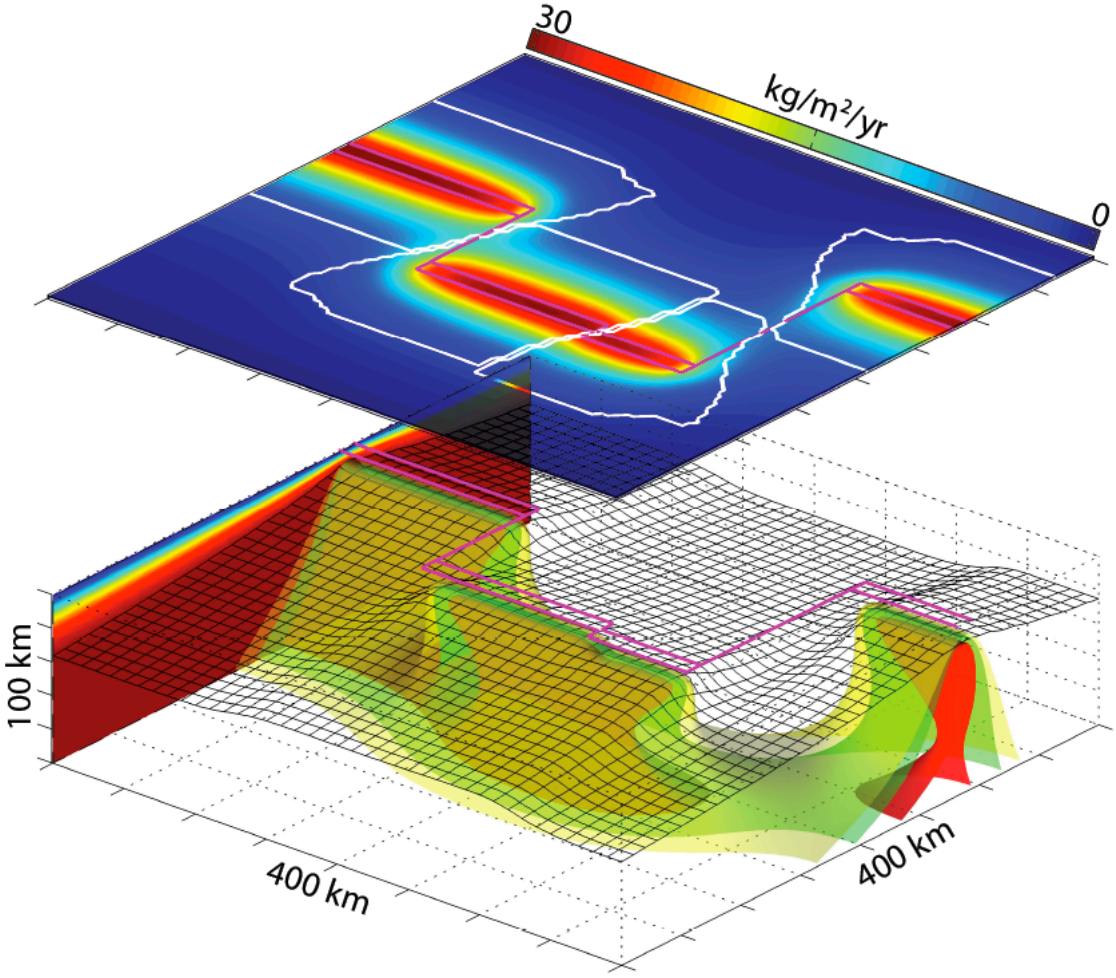
- Shares many computational components with other CIG projects (Mantle convection, Lithospheric Deformation)
- But adds new dynamics and scales.
- How to integrate?

Integrated models of plate boundaries



Misc Figure for PETSc 9N Ridge model (Katz et al, PEPI, 2007)

- **4km resolution (1.5M Dof)**
- **Full non-Newtonian, temperature dependent viscosity**
- **2,**
- **Shows 80% hard scaling out to 1024 processors (BGL Argonne)**

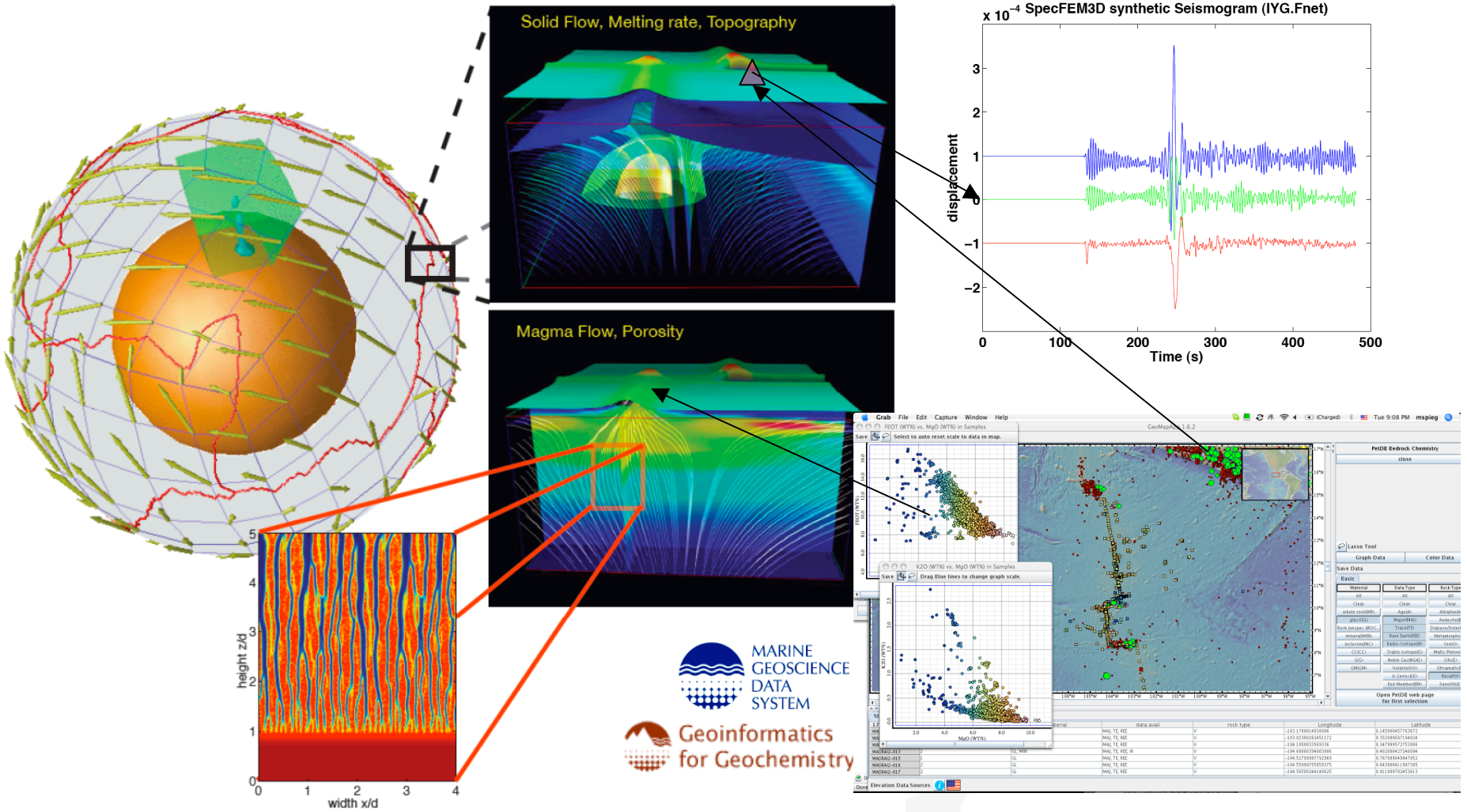


MADDs: Magma Dynamics Demonstration Suite

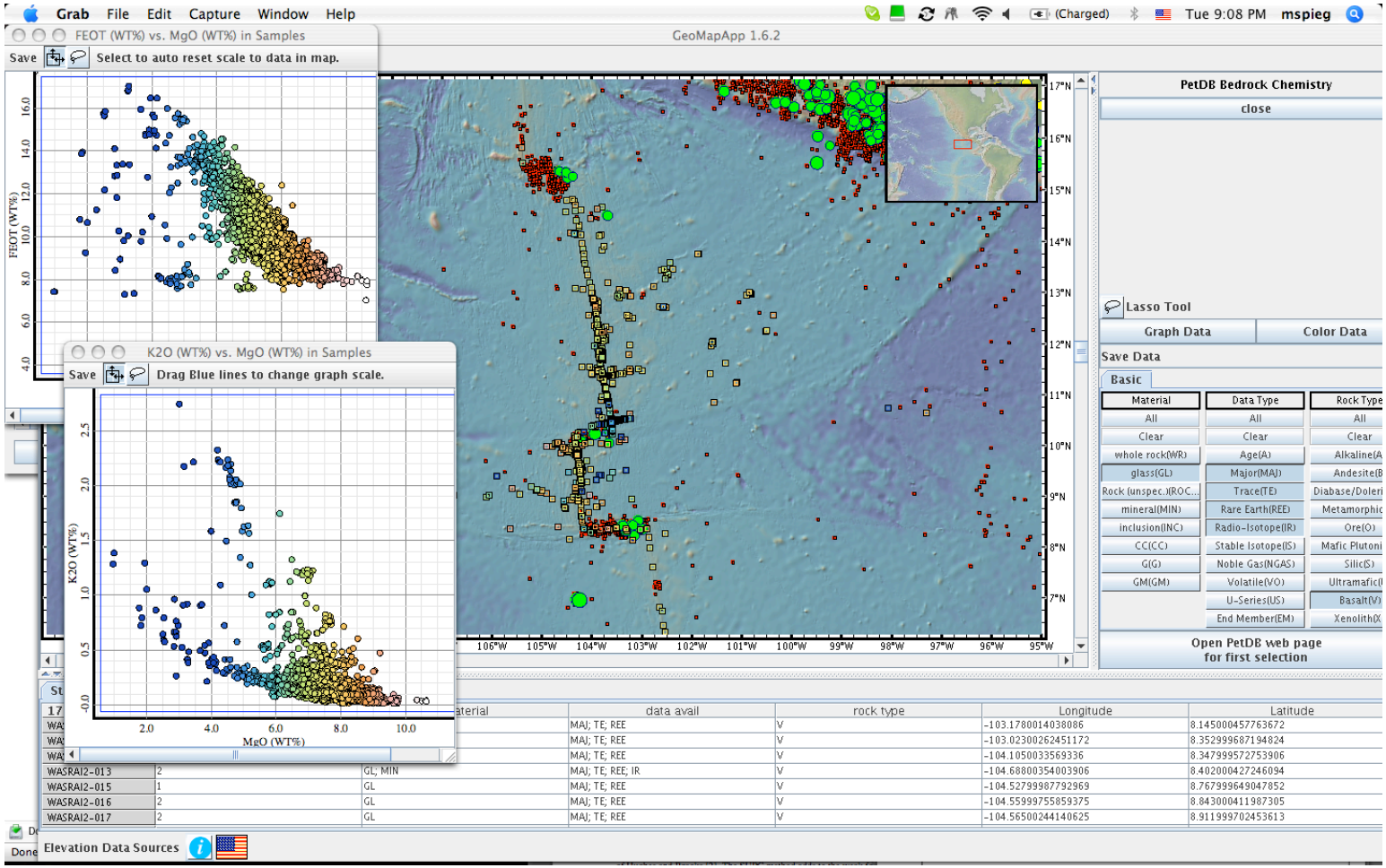
- Initial project (date?) to integrate magma dynamics into existing CIG framework
- Building on PETSc and StG frameworks (same as GALE) partnership with VPAC and ANL
- Developed Benchmark suite and first Milestones
- Further integration with AMR (Peta-Apps? Deall.II,)
- Extension to fluids in Brittle media for crustal dynamics.

Future Directions

Coupled Multi-Scale, multi-physics models



Interfacing Models with GeoData



MARINE GEOSCIENCE DATA SYSTEM

Geoinformatics for Geochemistry

Lithospheric deformation

Long-Term Tectonics: Recent results from Gale 2-D/3-D extension Benchmarks