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)
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 significantly new behavior
- Specific Example: Magma Dynamics
Magma Dynamics

- 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
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
- 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
Lithospheric deformation

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