ArcFlow: Advanced models of fluid flow in subduction zones

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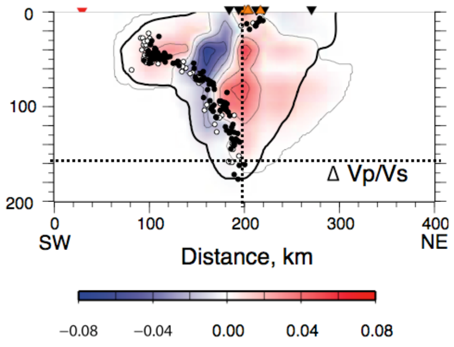
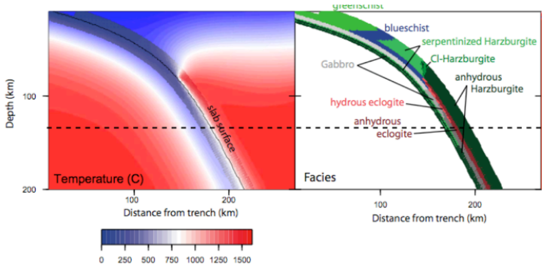
Subduction zones are one of the most critical components of global plate tectonics and mantle convection. They control the structure of the plates, are the major downwelling structures of mantle convection and control the geochemical cycling and transport between the surface and the deep interior. These systems are also perhaps the most difficult and complex geodynamic systems to model, requiring flexible multi-physics/multi-scale computations that can explore couplings between asthenosphere and lithosphere, brittle deformation, fluid-flow and magmatism. Considerable work has developed high-resolution solid flow and thermal models for subduction zones, but there has been much less modelling of the flow of hydrous fluids and magmas through the slab and wedge. Because many of the critical observations--including the position of volcanoes with respect to intermediate depth earthquakes, and variations in arc lava geochemistry--depend on the sources and pathways of fluids, considerable questions remain as how to relate these observations to the underlying dynamics.

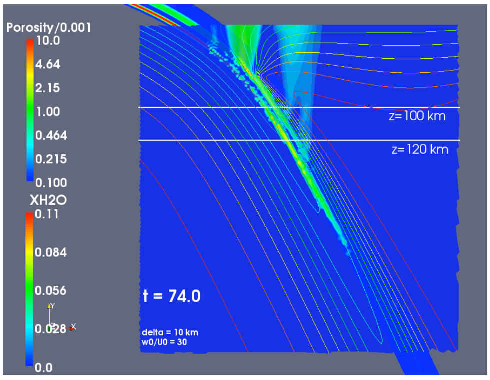
The ArcFlow project is an NSF-MARGINS funded project to develop advanced models for calculating and exploring the coupled fluid-solid dynamics of subduction zones, built on modern computational libraries (FEniCS, PETSc, Sepran, Perple_X). Key features of these models include the ability to reuse existing high-resolution thermal/solid flow models on *unstructured grids* that can be generated for specific arc geometries (van Keken using SEPRAN), together with thermodynamic calculations of phase diagrams to calculate the rate and distribution of fluid production in the slab (Hacker using Perple_X). Given these inputs, the initial models solve for the explicit flow of fluid using the magma-dynamics formulation of McKenzie (1984), implemented in a hybrid Dolfin/PETSc code that utilizes automated code generation for coupled non-linear problems (FFC/Dolfin) together with PDE-based block-preconditioners (PETSc). The first generation of models address where and at what rates fluids are generated in the slab and explore the consequences of physical parameters such as permeability and solid rheology for affecting the potential fluid-flow paths through the slab and wedge. Initial results suggest that flow paths are sensitive to mantle rheology, with the possibility of considerable up-dip slab flow if the slabs are relatively strong. Future models will explore the direct coupling of fluid flow and solid flow in the wedge. The new FEniCS/PETSc will be made available through CIG and will contribute to the next generation of magma dynamics codes.



Vp/Vs perturbations observed in Nicaragua (TUCAN experment, Syracuse et al, G-cubed, 2009), showing potential fluid-flow paths in the wedge



Left: Solid Flow/Thermal calculations for Nicaraugua calculated using SEPRAN (van Keken) on a high-resolution unstructured mesh with non-linear olivine rheology. Right: consistent water saturated facies for high-resolution submesh calculated using PERPLE_X (Hacker)



Evolving porosity field for fluids produced produced by slab-dehydration. Note, two principal dehydrating layers, a shallow layer that dehydrates rapidly supplying fluids to the “cold nose” and a deeper, serpentinized layer with considerable up-dip transport before being released into the wedge at ~120 km depth to the earthquakes. Calculations done using hybrid FEniCS/PETSc code (Spiegelman)