3D Numerical Modeling of the Alaska and Central America Subduction Zones: Implications for Plate-Mantle Decoupling

Margarete A. Jadamec[1,2,*], Magali I. Billen[1], and Karen M. Fischer[2]
[1] University of California, Davis, CA, [2] Brown University, Providence, RI, *Margarete_Jadamec@Brown.edu

Theme 2: Understanding Mantle Wedge Dynamics.
GeoPRISMS Primary Site: Alaska Subduction Zone.
MARGINS Primary Site: Central America Subduction Zone.

Plate-Mantle Decoupling in Subduction Zones. Away from subduction zones, the surface motion of oceanic plates is well correlated with mantle flow direction, as inferred from seismic anisotropy (*Conrad et al.*, 2007). However, this correlation breaks down in subduction zones where shear wave splitting studies suggest the mantle flow direction, both in the mantle wedge and beneath the slab, is spatially variable and commonly non-parallel to plate motions (*Long and Silver*, 2008). This implies local decoupling of the lithosphere from the mantle, yet the magnitude of this decoupling is poorly constrained.

Regional 3D Modeling Examples. Regional 3D numerical models, constrained by subduction zone geometry and observations of seismic anisotropy, can be used to further explore this decoupling of mantle flow from surface plate motion, in terms of both direction and magnitude (Figure 1). A set of 3D

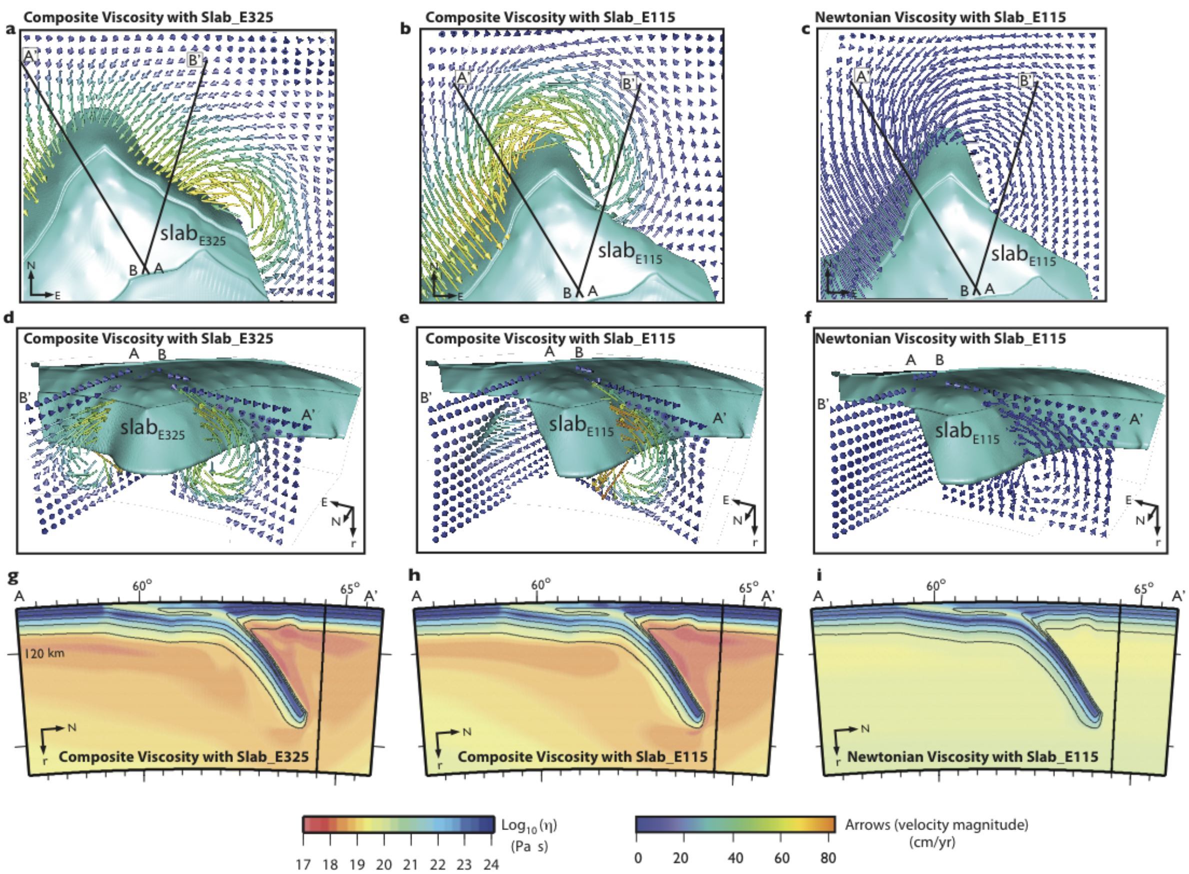

Figure 1: Map view (a-c) and cross sections (d-f) from three models of the Alaska subduction zone that vary the slab shape and the rheology (*Jadamec and Billen*, In Review). The slab is colored by viscosity and mantle velocity vectors are colored by velocity magnitude. Upper plate not shown. Cross section AA' of viscosity (g-i) for the three models. In models using a composite viscosity, a low viscosity region ($< 10^{18}$ Pa s) emerges in the mantle surrounding the slab and allows for rapid mantle velocities (> 80 cm/yr) within 500 km of the slab (*Jadamec and Billen*, 2010).

regional numerical models of the eastern Alaska subduction-transform plate boundary system showed that, in models using the composite viscosity, a laterally variable mantle viscosity emerges surrounding the slab as a consequence of the lateral variations in the mantle flow field and strain-rate (*Jadamec and Billen*, 2010) and (*Jadamec and Billen*, In Review) (Figures 1 and 2). In this region of low viscosity, mantle velocity magnitudes can be up to 80 cm/yr. The same models that produce the rapid mantle flow, predict surface plate motions of less than 10 cm/yr, comparable to observed plate motions, and predict toroidal mantle flow around the slab edge consistent with observations from seismic anisotropy (*Jadamec and Billen*, 2010) (Figure 2). These results show a power law rheology, i.e., one that includes the effects of the dislocation creep deformation mechanism, can explain both observations of seismic anisotropy and decoupling of mantle flow from surface motion. This suggests that partial decoupling of the surface plate motion from the underlying mantle flow field, in terms of both direction and magnitude, may be common in subduction zones. We expect that short slabs are more likely to induce localized rapid flow in the mantle at subduction zones, as these slabs are not supported by the higher viscosity lower mantle and therefore are more free to move in response to the local forces. We will further test this hypothesis with 3D geodynamic models of the Costa Rica-Nicaragua subduction zone (Jadamec NSF-EAR Postdoc Fellowship), a region where previous geochemical studies (*Hoernle et al.*, 2008) and observations of seismic anisotropy (*Abt et al.*, 2010) have predicted rapid trench parallel mantle flow in the mantle wedge.

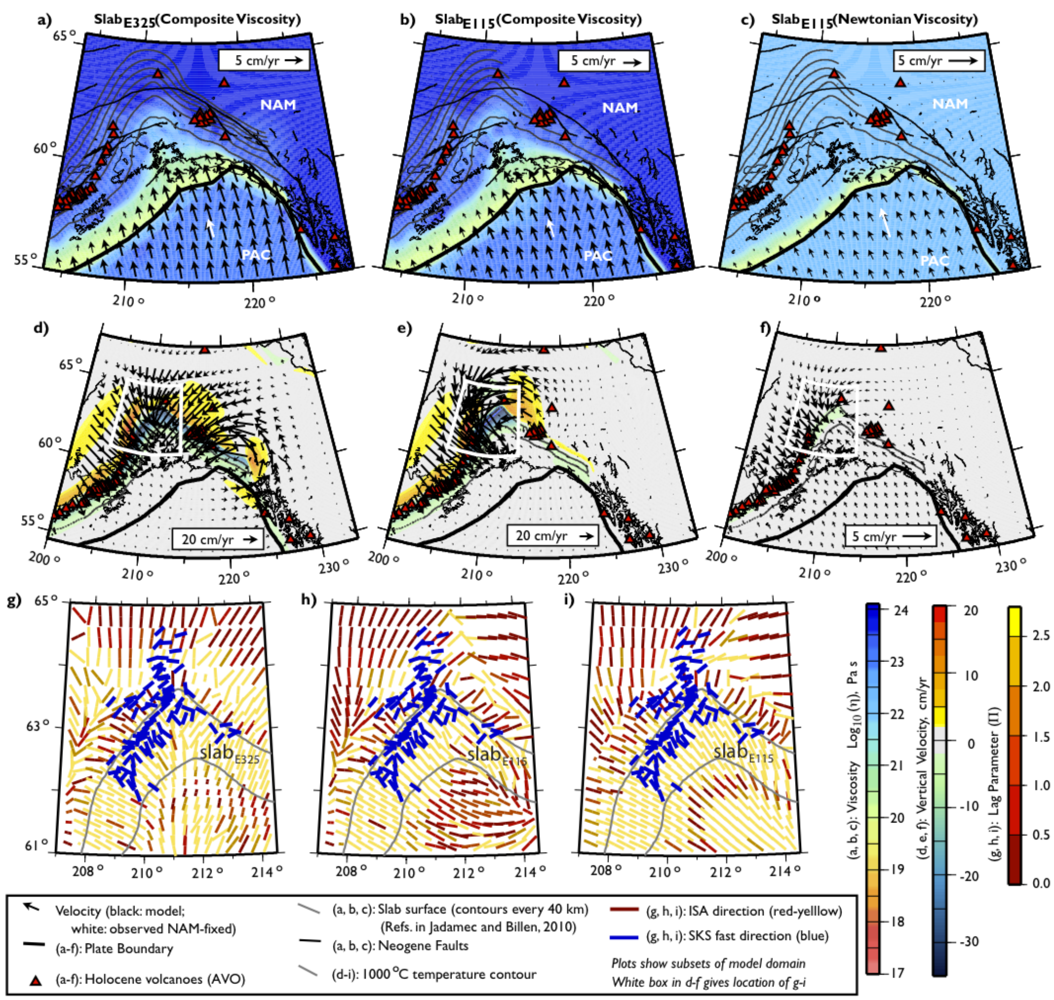

Figure 2: Model predicted surface velocity (a-c) and velocity at 100 km depth (d-f) for three models in Figure 1 (Modified from *Jadamec and Billen* (2010)). Model predicted infinite strain axis (ISA) orientation (g-i) for region outlined by white box in (d-f) (Modified from *Jadamec and Billen* (2010)). Observed SKS fast directions projected at 100 km depth from *Christensen and Abers* (2010). Plate boundary from *Bird* (2003). Faults from *Plafker et al.* (1994).

3D Modeling For Thematic Studies and Local Tectonic Questions. A value of using regional 3D models to investigate a thematic question, such as what is driving mantle wedge dynamics, is that local geologic and geophysical observations can be used to independently constrain model input and output. In addition, these models can provide insights to tectonic questions particular to the region being studied. For the Alaska tectonic boundary, we have shown here 3D geodynamic models that include both an overriding plate and slab, and where the negative buoyancy of the slab drives the flow, result in rapid mantle flow and significant local plate-mantle decoupling in models using a non-linear rheology. The prediction of rapid mantle wedge velocities (*Jadamec and Billen*, 2010) will be tested in the central America subduction zone, in particular the role of rheology, water and melt will be investigated. Thus, comparison of results from regional models of a MARGINS and GeoPRISMS primary site can provide insights to the nature of flow in the mantle wedge.

In the 3D models of Alaska, the fit between the anisotropy and the ISA directions suggests a two-tiered slab beneath south central Alaska with a deeper slab edge at approximately 212° longitude and a shorter edge farther east (*Jadamec and Billen*, 2010). The numerical models show that the relative depth of the slab tip and base of the overriding lithosphere influences whether there will be flow induced in the mantle (*Jadamec and Billen*, In Review). The models showed that a two-tiered slab shape, with the slab beneath the Wrangell volcanics only extending to 115 km, induces toroidal and poloidal flow around the Aleutian slab edge located west of the Wrangell volcanics, matching observations of seismic anisotropy, but that the eastern part of the slab was too short to induce toroidal or poloidal flow east of the Wrangell volcanics. However, anisotropy data were lacking east of the Wrangell volcanics to test whether toroidal or poloidal flow should be induced there. Additional seismic anisotropy observations that could be collected from the EarthScope and GeoPRISMS initiatives in Alaska can better constrain the slab geometry east of the Wrangell volcanics.

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