Research report for "A Multi-disciplinary Model of the Pacific Upper Mantle"

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During my visit at ERI, I was hosted by Profs. Kawakatsu and Honda and worked with them and their respective students. Our joint research focused mainly on three projects, all related to upper mantle convection, the nature of the lithosphere, and how to address its dynamics using seismological constraints and geodynamic modeling. Work is still ongoing on all three of these efforts, and we expect two publications to be submitted before the end of this year.

1. **The role of mechanical anisotropy for plate-scale flow as applied to the Pacific**.

   Recent observations of an age, and hence temperature, dependent depth of the lithosphere-asthenosphere boundary (LAB) of oceanic plates by Prof. Kawakatsu have motivated the study of partial melt as the origin of the LAB as well as the origin of the strong radial seismic anisotropy that is observed underneath oceanic plates. This is an alternative model to the more common hypothesis of the alignment of intrinsically anisotropic olivine crystals under mantle shear (lattice preferred orientation, or LPO). The predictions of both models for seismic (*P* and *S* wave propagation) and mechanical (viscosity) properties differ, motivating our study of both effects. Shape preferred orientation (SPO) of melt pockets can, in particular, be expected to lead to strongly mechanically anisotropic flow behavior, making shear in a horizontal plane much (factors of 1/100 to 1/1000, perhaps) easier than shear perpendicular to it.

   During my stay at ERI, I implemented a general, transversely isotropic (radially anisotropic) viscosity constitutive law into the regional and global versions of the finite element, mantle convection code CitcomCU/CitcomS. Based on these numerical improvements, I conducted a range of instantaneous flow tests, showing the differences in asthenospheric flow for isotropic and anisotropic viscosity reduction in the uppermost ~400 km of the sub-oceanic mantle. As it turns out, there are quite strong differences in the details of flow, but surface observables, such as plate motions and dynamic topography are very similar to isotropic models, if the average viscosities are adjusted properly. Similar results are found for global flow, e.g. when evaluating the geoid predictions with and without anistropic viscosity. This implies an unfortunate ambiguity, making mechanical anisotropy hard to distinguish from an isotropically weak asthenosphere. It also implies that SPO models with large partial melt content are dynamically permissible. Results from this study are about to be written up into a manuscript for submission later this year.

   Besides the instantaneous flow computations, I also ran several dynamically evolving convection computations, confirming the earlier 2D results by Prof. Honda; convective wavelengths are indeed larger with anisotropic viscosity than without, and convection for visco-plastic rheologies appears more platelike with an SPO layer of lubricating melt. We will explore the implications of anisotropic viscosity for time-variable convection and changes in plate motions in the future.

2. **Distinguishing between shape and lattice preferred orientation origins of uppermost mantle anisotropy in oceanic plates.**

   This project was led by Prof. Kawakatsu's student who is analyzing Love and Rayleigh wave fundamental mode observations from an ocean bottom seismometer deployment on the Pacific plate. Such inversions for mantle velocity structure typically assume scaling relationships between *S* and *P* velocity anomalies, as well as the respective radially anisotropic (Love) parameters. I assisted the student in exploring different scaling relationships for LPO anisotropy based on petrology and geodynamic modeling. SPO and LPO models lead to different predictions for the relative behavior of *S* and *P* anisotropy, and it appears that the data might just be sensitive enough to make inferences on the likelihood of the different suggested models. This project is ongoing during Prof. Kawakatsu's student's PhD project.

3. **The flow field around subducting slabs and its interpretation with seismic anisotropy observations, in particular shear wave splitting**.

   The flow field around subducting oceanic lithosphere is strongly diagnostic of key kinematic parameters such as trench rollback, and dynamic parameters such as slab strength. In particular the amount of toroidal flow around slabs may yield constraints on slab viscosity, and this had been explored with regional geodynamic models by Prof. Honda's and my own group. In discussions, Prof. Honda and I explored the role of the overriding plate and mechanical boundary conditions on inferred flow fields. I also assisted Prof. Honda's student in using the mineral physics software DREX and extensions to it which I had worked on earlier for the prediction of shear wave splitting from the anisotropy inferred from mantle flow.

   Motivated by findings of a global correlation of the amplitude of the sub-slab shear wave splitting with the amount of inferred trench rollback (in an absolute plate motion reference frame with respect to the lower mantle), we also started to work on global subduction zone flow modeling. This work is being continued by my graduate student, and we hope to work on a joint manuscript by the end of this year.

I had a fantastic time at ERI and would like to take this moment to thank again my scientific hosts Profs. Kawakatsu and Honda, as well as the students, and the support staff including Ms. Watanabe. I hope that the visit will be only the beginning of a long-term collaboration, and very much appreciate the generous support I have received through ERI's outstanding international visitor program.