Geophysical Research Abstracts
Vol. 18, EGU2016-3527-1, 2016
EGU General Assembly 2016

Subduction on long time scales: Tighter constraints on mantle rheologies require cross-disciplinary engagement with subduction histories.

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Two observational records constrain subduction on long timescales: accretionary mountain belts at the surface and subducted lithosphere in the subsurface. Subducted slabs represent paleo-oceans and can be imaged by seismic tomography. Mountain belts consist of crustal slivers that were produced and aggregated near paleo-trenches but escaped subduction (arc terranes, accretionary complexes, ophiolites). They are mapped by regional geologists and further constrained by lab-based rock analysis methods.

The strength of seismic tomography consists in relatively comprehensive spatial coverage of the mantle's slab inventory, together with established methods for probing uncertainties (image resolution). Unfortunately, subsurface imaging provides no direct constraints on slabs' ages and their deformation histories from rigid oceanic plates to lumpy velocity anomalies. Convection modelling by itself cannot remedy this shortcoming because independent observational constraints on mantle rheologies are lacking.

Through dating of accretionary orogens, geology can in principle provide the subduction and slab ages that geophysics is missing. This requires a testable strategy for associating slabs with major accretionary events, and synthesis of geological inputs across vast spatial scales (1000 to 10,000 km) and time scales (10-100 million years). Orogens provide only limited spatial constraints on paleo-trenches because they record several generations of accreted terranes, usually heavily deformed, overprinted, and translated with the migrating continent. The interpretational uncertainties produced by these complexities are very nonlinear: Miss a suture in the field, and you may be missing an entire paleo-ocean – while also incorrectly attributing the associated slab.

This danger is real, as we demonstrate for North American slabs and Cordilleran geology. Prevailing paleo-geographic interpretations for the Cordillera arguably miss a Jura-Cretaceous ocean, and slab geometries in the lower mantle show that it must have been a major ocean. Individual geologists' earlier suggestions of this ocean had not gained sustained traction, but the combination with geophysical subsurface evidence provides strong predictions of where to look for its sutured remains. If correct, this scenario implies much simpler, more systematic slab sinking than the prevailing hypothesis of Farallon-only subduction.

Generalizing to subduction worldwide, geophysics tends to turn in circles when slab sinking behaviour has to be postulated because both mantle rheologies and subduction histories are insufficiently known. Convection modelling may go down erroneous paths unnoticed if subduction history is assumed more certain than it actually is. As a result, widely varying estimates of sinking behaviour stand unreconciled across a large number of regional slab interpretations, implying little generalizable process knowledge for the mantle. Examples are vastly divergent age estimates for certain slabs, differing postulates of slab 'stagnation' times on the '670', or hypothesized viscosity maxima at 1500 km or 2000 km depth.

For geophysics, the way forward is to embrace geological observations despite their messiness, which also requires serious engagement with their uncertainties – in this case, with spatio-temporal subduction histories as boundary conditions for slab interpretations. The promise is that slab sinking behaviour may turn out to be significantly more systematic than currently perceived, with correspondingly tighter constraints on mantle rheologies.