Interrelations between intermediate-depth earthquakes and fluid flow in subducting oceanic plates

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Hydrous fluid escape from the downgoing slab is widely believed to be the trigger that induces partial melting in the overlying mantle wedge, thereby producing the magmas erupted in arc volcanoes. Arc magmatism has a distinct chemical signature due to the addition of elements carried by initially hydrous slab-derived fluids. What is yet to be established are the mechanisms which are responsible for hydrous fluid flow from sources within the slab into the overlying wedge, and furthermore whether and how this fluid flow is linked to possible reactivation of normal faults and intermediate-depth earthquakes (70-300km). Two main but rival hypotheses have been proposed to explain intraslab seismicity; one, currently more in favor, suggests that high fluid pressures lead to dehydration embrittlement that triggers earthquakes, the other suggests that melt shear instabilities trigger seismic slip and may thereby produce permeabilities. Until now, testing these hypotheses has been restricted to theoretical investigations, lab experiments, and interpretations of seismic data. Unlike these more indirect approaches, we are able to directly investigate former slab rocks that experienced an earthquake during their burial in a subduction zone. We present so far unique field evidence indicating that intermediate-depth earthquakes produce frictional melts in subducting slabs and that the seismic failure was subsequently followed, not preceded, by infiltration of external fluid. We describe pseudotachylytes (quenched frictional melts) in eclogites from a fossil subduction slab in Zambia. Shortly after pseudotachylyte formation an external hydrous fluid infiltrated the rocks. Subsequent fluid flow leads to continuous vein formation during ongoing burial. The passing fluids mobilize those trace elements from the eclogites, which are characteristic of a ‘hydrous slab component’ in arc magmas. Since the fluids released by dehydrating slabs are believed to be the primary trigger for arc magmatism, we propose that intermediate-depth earthquakes have the potential to produce fluid-pathways within and out of the slab.

Mélange zones as a better source for the “slab” signature in arcs

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Common models for mass transfer from subducted slabs to arc sources generally hold that little modification of “slab” signatures occurs during transit into the mantle. However, developing data for metamorphic systems along the slab-mantle interface indicate that important mediation of fluid/melt chemistries occurs following their liberation from the slab and prior to their modification of arc mantle sources. Therefore, while “slab” signatures in arc volcanics certainly exist, it is questionable whether the last chemical reservoir equilibrated with these fluids/melts was actually the slab itself. One of the most likely sites for re-equilibration of the “slab” signature is within mélange zones formed along the slab-mantle interface.

The juxtaposition of the crustal lithologies of subducted slabs beneath the mantle wedge produces a dramatic contrast in chemical potentials for almost all elemental species, and these contrasts are resolved by a combination of mechanical and metasomatic mixing processes to form mélange. These hybridized rocks form a compositional gradient to chemically bridge the slab-mantle interface. Analytical data for exhumed tracts of mélange matrix from the Catalina Schist, CA, are remarkable in that they preserve the mixing processes and chemical gradients of the slab-mantle interface, but that pervasive fluid flow in mélange dominates some isotopic compositions. Sr and Nd isotopic data are heterogeneous in mélange and reflect a range in compositions expected for mixing between crustal and depleted mantle compositions. In contrast, Pb isotopic compositions for mélange are indistinguishable for a range of bulk compositions, are strongly radiogenic, and define an end-member composition that is predicted by a linear correlation of Pb data through modern arc volcanics from mantle compositions. Mélange B isotope data at a range of metamorphic temperatures agrees extremely well with models for B fractionation derived from arc volcanics, suggesting they are an ideal source for arc B. In summary, mélange isotopic compositions can explain numerous aspects of the “slab” signature observed from arcs, but are preferable to slab sources in that mélange integrates additional aspects of the physical and chemical processes occurring during subduction.