Geophysical Research Abstracts
Vol. 14, EGU2012-6801-1, 2012
EGU General Assembly 2012

Nature of the slab-mantle wedge interface: Clues from geophysical observations and thermal and petrologic modeling

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Mantle wedge flow in subduction zones is driven largely by viscous coupling between the subducting slab and the overriding mantle. The flow brings hot mantle material from the back-arc region into the forearc and arc regions, providing the necessary thermal condition for melt generation beneath the arc. However, geophysical observations, such as surface heat flow and seismic attenuation, indicate that the mantle wedge corner is cold and decoupled from the subducting slab. The primary factor that controls slab-mantle (de)coupling is the strength contrast between the interface and the overlying mantle: Decoupling occurs where the interface is weaker than the overlying mantle, and coupling occurs where the interface is as strong as or stronger than the overlying mantle. Our 2-D steady-state thermal models that satisfy observed surface heat flow patterns, seismic attenuation structures, and petrologically and geochemically inferred sub-arc mantle temperatures, predict that the maximum depth of decoupling (MDD) is $70-80$ km for most subduction zones. Near the MDD, temperature along the plate interface is predicted to increase rapidly down-dip by $200-300^{\circ}$C due to the heating effect of the flowing mantle down-dip of the MDD, and thus the MDD has a strong influence not only on the mantle wedge thermal structure but also on the interface temperature condition. One of the outstanding questions is what causes the strength contrast to disappear at 70-80 km depth. The important clue is the relatively uniform MDD, which indicates that some self-regulating mechanism characterized by an inherent scale length is at work. Here, using thermal and petrologic modeling results, we qualitatively assess the role of metamorphic reactions, fluids and melts, and temperature-dependence of the rheologies of the interface material and the overlying mantle in controlling the strength contrast and the MDD. These mechanisms depend strongly on the thermal condition, which in turn depends on mantle wedge flow and the MDD. This interdependence between the mechanisms and the MDD is expected to result in positive feedback that causes a runaway effect, making it difficult to explain the MDD of 70-80 km. The amount of heat brought into the arc and forearc regions by wedge flow depends on the back-arc thermal state. Back-arc heat flows for most subduction zones are about 80 mW/m2, and the relatively hot state of the back-arcs is likely to be governed by a common process of small-scale convection, which may regulate the MDD through uniform thermal weakening of the mantle wedge among different subduction zones. Compositional buoyancy of the serpentinized interface material may cause return flow in the subduction channel and/or cold plumes in the mantle wedge, mechanically controlling the distribution of weak serpentinites along the interface and thus the down-dip change in the interface-mantle strength contrast.