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Thermal models of subduction zones: How slab - mantle wedge decoupling affects metamorphism, volcanism, and earthquakes

K Wang (1) and I Wada (2)

(1) Geological Survey of Canada, Pacific Geoscience Centre, Sidney, BC, Canada (kwang@nrcan.gc.ca, 1-250-363-6565), (2) School of Earth and Ocean Sciences, University of Victoria, Victoria, BC, Canada (ikukow@uvic.ca)

To the first order, the thermal regime of subduction zones is controlled primarily by the age of the subducting slab and the pattern of viscous mantle wedge flow. A younger slab brings in more heat from the trench side, and a more vigorous wedge flow brings in more heat from the arc side. In general younger and warmer slabs dehydrate at shallower depths, leading to shallower termination of intraslab earthquake and less active arc volcanism. However, regardless of its age, the depth of the dipping slab is about 100 km beneath the volcanic arc. This surprisingly uniform configuration must reflect a common pattern of mantle wedge flow. In this study, we use numerical thermal models of 17 subduction zones to demonstrate that their process diversity and configuration uniformity can be reconciled if the slab and mantle wedge are decoupled to a common depth of around 70-80 km. Where there are adequate surface heat flow constraints, such at Cascadia, NE Japan, and Kamchatka, we find that such a common depth best explains the heat flow data. The abruptness of the decoupling-coupling transition due to the temperature- and stress-dependent rheology gives rise to a sharp transition in the flow and thermal regimes of the mantle wedge. Overlying the shallow, decoupled part of the interface in the forearc, the mantle wedge is stagnant and cold. Overlying the deeper, coupled part of the interface, the wedge flows at full speed, resulting in high temperatures for magma generation provided there is sufficient fluid supply from the dehydrating slab to trigger melting. The diversity of subduction processes is due to the different age-dependent thermal states of the slab, but the uniformity of their configuration is due to the common depth of decoupling.