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Thermal Structure, Water Transport, and Melt Propagation at Subduction Zones

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It can be shown from geodynamic models that corner flow is required in the mantle wedge of subduction zones for the generation of magmatism. Models without corner flow continuously cool, and become ever less fertile with time such that no magmatism would be expected. It is likely that the subducting plate, and the negative buoyancy of the cooled wedge mantle drive the corner flow. Given such a flow, and the geometry of the subducting plate and overriding lithosphere one can produce numerical and analytic thermal models whose basic character is robust (1,2). We expect the shape of the overriding lithosphere to be changed by the induced flow, such that it is thinner in the arc region (3). The absolute temperature values are somewhat uncertain given our lack of constraints on possible localised heat sources; e.g. shear heating, and on the general mantle temperature. What is clear though is that the subducting slab is generally cool, and that the mantle will generally only melt if it has volatiles added to it.

Measurements of the dihedral angle of water with olivine suggest that the equilibrium texture of static mantle would only allow water to migrate by porous flow at temperatures above 850ºC at around 3GPa (100km depth) (4-Mibe et al., 1999). If similar temperatures apply to a deforming oceanic crust (yet to be demonstrated), then the water in most cases would be unable to leave the subducting slab to reach the mantle wedge by porous flow to produce magmatism, since the subducting crust is so cold. Intermediate depth earthquakes should not occur since at such depths the high normal stress should inhibit brittle failure. It has been suggested that the water released from the continuous dehydration of the subducting oceanic plate (5-Poli & Schmidt, 1995), would lead to high pore pressure, since it would be unable to escape (6). This high pore pressure would lower the effective normal stress allowing brittle failure. Following failure the water would be interconnected along the fault plane, and could lead to the pressure at its tip exceeding the minimum compressive stress. This would lead to the formation of a hydrofracture (6). The propagation distance of the hydrofracture would depend upon the volume of water contained.

It is expected that small fractures would stop in the sediment, possibly leading to water saturated melting if the temperatures are sufficiently high. If the fractures are larger they might reach the cold mantle, where they would react to produce hydrous minerals. These would be carried deeper, but most would ultimately dehydrate and the resulting water could migrate vertically upwards until it reached mantle with which it would react again, or lead to melting (1). Finally very large fractures might possibly be able to go as far as reach the hot part of the mantle wedge and lead directly to melting. The direction of propagation of the hydrofractures would be perpendicular to the least compressive stress, which for a wedge corner flow is up and out into the centre of the mantle wedge. If the melting occurring in the mantle wedge produced magma fractures then they would also propagate perpendicular to the least compressive wedge, and since they are in the upper half of the mantle wedge they can be shown to focus towards (though not to) the mantle wedge corner (1). The figure shows the overall geometry envisaged (6).

Such a mechanism allows one to have a range of timescales and interactions for the transport of volatiles from the slab to the mantle wedge. This potentially allows one to satisfy uranium disequilibrium data, including data suggesting comparatively short timescales. The mechanism is also consistent with the sharp decline in magmatism behind the volcanic front and the exponential decline of seismicity with depth down to around 300km depth. There are also claims of reflectors in the slab beneath Japan that have been interpreted as being due to 'pools' of water less than 0.5km in radius (Sacks and Obara, personal communication). This might be water collected on recently active faults, which was not sufficient to generate a hydrofracture. Isotopic evidence and fluid inclusion work has also pointed towards focussed intermittent fluid flow being important in subducted oceanic crust (6).

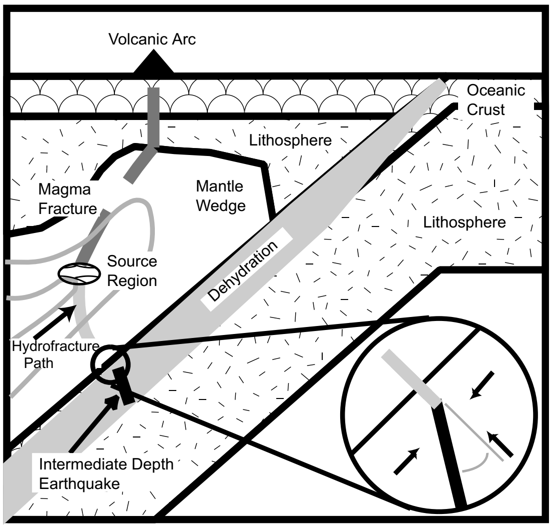

Figure 1. Diagram of proposed hypothesis. The grey region represents the location of dehydration processes. The curved dashed line represents the path of a hydrofracture and the curved dotted line the path of a magma fracture. Here the hydrofracture has been shown reaching the hottest part of the mantle wedge where it generates rapid melting, leading to a fracture driven by mamga. Hydrofractures could also stop in the cold regions of the wedge initiating a lateral transport mechanism 4. The direction of propagation of both fractures is controlled by the local stress field and is not vertical. This predicts that the ephemeral source region is horizontally further away from the trench than is the volcanic front. The thin continuous lines represent hot isotherms in the mantle wedge. The inset is a magnified view of the oceanic crust, showing the possible relationship between the trace of the earthquake fault plane (thick black bar) and the hydrofracture direction. The direction of the greatest (s1) and least (s3) principal compressive stresses are assumed to be as shown, for the propagation directions presented.

Figure 1: Envisaged possible geometry of water transport and magma migration

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