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Intermediate-depth earthquake generation: what hydrous minerals can tell us

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Subduction zone seismicity has commonly been causally related to the dehydration of minerals within the subducting slab(Hacker et al. 2004, Jung et al. (2004), Dobson et al. 2002, Rondenay et al. 2008). Other models for release of intermediate- and deep earthquakes include spontaneous reaction(s) affecting large rock-bodies along overstepped phase boundaries (e.g. Green and Houston, 1995) and various shear heating-localization models (e.g. Kelemen and Hirth 2007, John et al. 2009). These concepts are principally reliant on seismic and thermo-petrological modeling; both of which are indirect methods of analysis. Recent discoveries of pseudotachylytes (PST) formed under high pressure conditions (Ivrea-Verbano Zone, Italy, Western Gneiss Region, Norway and Corsica) provide the first tangible opportunity to evaluate these models (Austrheim and Andersen, 2004, Lund and Austrheim, 2003, Obata and Karato, 1995, Jin et al., 1998).
This case study focuses on observations based on ultramafic and mafic PST within the Ligurian Ophiolite of the high pressure-low temperature metamorphic (HP-LT) 'Shistes Lustres' complex in Cima di Gratera, Corsica (Andersen et al. 2008). These PST have been preserved in pristine lenses of peridotite and gabbro surrounded by schistose serpentinites. The PST range in thickness from 1mm to 25 cm (Andersen and Austrheim, 2006). Petrography and geochemistry on PST from the peridotite and gabbro samples indicates that total/near-total fusion of the local host rock mineral assemblage occurred; bringing up the temperature of shear zone from 350º C to 1400 - 1700º C; depending on the host rock (Andersen and Austrheim, 2006). The composition of the PST is highly variable, even at the thin section scale and this has been attributed to the coarse-grained nature of the host rock, its small scale inhomogeneity and poor mixing of the fusion melt. Almost all the bulk analyses of the PST are hydrous; the peridotitic PST is always hydrous (H_2O content from 3.8 to 14 wt %) but the gabbro is not (H_2O content from 0 to 2.6 wt%). The hydrous nature of the PST is due to the preferential melting of hydrous minerals (chlorite and serpentine – peridotite, glaucophane, epidote, Mg-hornblende - gabbro) in the host rock, rather than later hydration associated with exhumation (greenschist facies metamorphism and later alteration). However, in the case of the gabbro, the melt can be hydrous, but is not always. Anhydrous, glassy PST is formed in association with hydrous PST in the gabbro host rock. The gabbroic PST nucleate at the boundary between a coarse-grained pegmatoidal gabbro and a fine-grained gabbro, whereas the exclusively hydrous peridotite-hosted PST only nucleate along pre-existing hydrated fractures. These facts are significant when considering the mechanism of formation of the pseudotachylyte; which is commonly thought to be associated with the preferential melting of hydrous minerals. An anhydrous melt in proximity to other hydrous melts formed contemporaneously must have formed by the same mechanism; one which can exploit more than just one rheological characteristic in the rock vis. hydrous mineralogy AND grain size changes. Furthermore the presence of anhydrous PST suggests that little or no fluid ingress occurred prior to or during PST generation.
Hydrous crystallisation products in the gabbro such as glaucophane and edenite indicate that whole-sale melting of the wallrock amphiboles (glaucophane, edenite, actinolite) took place to produce a melt with dissolved H_2O, out of which such blue amphiboles were able to crystallise. It is important to note that in order for amphiboles to crystallise out of a melt, H_2O is required but necessarily to an under-saturated degree. i.e. it cannot be 'free' water occurring as a separate phase in the melt (Carmen and Gilbert, 1983 and Koons, 1982). It is unlikely therefore that the water in the gabbro-derived fusion melt was the result of solid-state dehydration of the wallrock amphiboles.

Microtextural observations of sheared out, kinked, twinned, prolate wallrock grains millimetres from vein boundaries and thermally rounded clasts, similarly deformed, entrained into the melt suggest that the process initiating fusion melting and seismic failure is spatially and temporally related to a high temperature ductile process rather than a brittle one.

Together, the microtextural and geochemical observations provide ample support for a ductile thermal run-away process to initiate high pressure PST development and seismic failure and preclude dehydration embrittlement.