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Metamorphic soles and flip flops: rheology of the plate interface during early subduction stages

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Metamorphic soles underlie most extensive ophiolites worldwide (i.e. ∼several 100 km long, non metamorphosed obducted pieces of oceanic lithosphere). These metamorphic soles (MS) are tectonic slices dragged along and welded to the ophiolite and generally comprise m to ∼500 m thick (strongly deformed and thus partly thinned) high-T granulite to amphibolite facies mafic protoliths, together with subordinate metaradiolarites. There is wide recognition that these HT MS formed during subduction initiation (ie., < 1-2 My after inception) at the expense of the upper part of the oceanic crust, atop the incipiently underthrusting lower plate.

This sole observation implies a spectacular yet unaccounted for jump of the lower contact of the ophiolite thrust during early subduction stages, from above to below the MS. Besides, the review of recent P-T determinations constraining the formation of high-T MS evidences a fairly narrow range between 1±0.2 GPa, 700-850°C. This is, consistently, significantly warmer than the later subduction regime, during which (a) lower T amphibolite to greenschist facies units from the top of the oceanic crust, yet with comparatively greater amounts of metasediments, become accreted below the high-T MS, (b) later, non metamorphosed and/or HP-LT units derived from uppermost crustal material are underthrust beneath the metamorphic sole s.l., as in W. Turkey or Oman.

This contribution tentatively explains how metamorphic soles get attached to the upper plate ophiolite by a simple conceptual model of the plate interface rheology during early subduction stages. This model draws on the existence of a major flip, in terms of mechanical behaviour, as the plate interface progressively cools:

(1) rheological data suggest that the mechanical resistance of the upper plate mantle is initially greater than that of the lower plate (variably hydrothermalized) oceanic crust;

(2) as the system cools, and even more so once the upper plate mantle gets incipiently serpentinized (i.e. at ∼700-750°C), the effective resistance of both lithologies/domains will progressively converge. I propose that this particular P-T window corresponds to the transient, optimal period during which similar effective rheology on both sides maximizes interplate mechanical coupling: deformation gets distributed over a larger band (on the 500 m to km scale), which allows the high-T MS to be transfered from the downgoing plate to the upper plate.

(3) at decreasing, lower T, the lower plate oceanic crust becomes stronger than the upper plate mantle (this crust also gets efficiently eclogitized at depths and thus rarely returned with respect to subduction duration). The plate interface becomes highly localized again and later underthrusting and tectonic slicing at the toe of the upper plate detaches progressively shallower parts of the incoming material. Flip flops are firmly tied to the ophiolite by then...

This interpretation of the plate interface rheology during progressive cooling is consistent with reports of low-temperature obduction-related deformation (i.e. 700-900°C) at the base of the ophiolite mantle itself. It may also provide constraints on the long-term mechanical properties of both basalt and peridotite.