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TWO BREEDS OF OPHIOLITE - COLD-EMPLACED (CEO) AND HOT-EMPLACED (HEO): DOES EITHER TRULY REPRESENT WHAT IS GOING ON AT MORs?

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Enthusiasm for investigating ophiolites owes much to the general belief (e.g. Peters et al. 1991*) that they represent on-land opportunities to study what goes on at mid-ocean ridges (MORs), all being thought to have attained their supracrustal positions by some variant of the subduction process. Osmaston (1980*) argued that hot-emplaced ophiolites (HEOs - which include most of the best-preserved ones) present special problems of generation and emplacement and should be seen as a separate breed from those structurally emplaced cold (CEOs) like the Coast Range Ophiolite (CRO) of California.

HEOs are characteristically dominated by a major thickness (e.g. 5km) and sometimes huge extent (400 x 80km in Oman) of mantle tectonite below the crustal section, emplaced supracrustally at over 1000°C, presenting the severe problem of how subduction could gouge out sheets of such plastic material from near the crest of an ocean ridge. This difficulty has been emphasized by the results of the author's subsequent study (Osmaston 1992, 1994*) of the subduction downbend process and of the associated tectonic undercutting of margins and their subsequent imbrication, leading him to conclude that transfer of material from the subducting plate to the hanging wall is limited to upper crustal material, most transfer being at the buried plate downbend and in the opposite direction. So CEO slices now at the rear of accretionary complexes (e.g. CRO, Nicoya Complex of Costa Rica, rear slices in the Makran) are seen as ocean-crusted former forearc that has been subduction-undercut and then imbricated.

Another big difficulty with HEOs is that the mantle tectonites and metamorphic soles of many of them exhibit HP/HT features (composition, mineralogy, metamorphism) indicating very rapid rise, without re-equilibration, from depths far in excess of the no more than 8km actual slice thickness commonly present between the metamorphic sole and the pristine pillow lavas at the top of the crustal section (Spray 1984, Osmaston 1990a). This means that the tectonite must have been juxtaposed at high temperature beneath the crustal section after very rapid ascent (much faster than subduction can do) from much greater depth, a fact borne out by widespread evidence of tectonite flow and lower crustal dislocation.

A few examples of the pressure-depths involved in various HEOs follow.

Bay of Islands: centimetre-thick picritic melt veins in mantle tectonite, derived (without further re-equilibration) from spinel lherzolite at beyond 60km depth (Malpas 1978). Bay of Islands and Hare Bay (St Anthony Complex): 25km metamorphic sole pressure in garnet amphibolites (McCaig 1983; Jamieson 1986). Ballantrae, SW Scotland: 45km+ for mafic granulite blocks in underlying melange and for metre-thick lensoid garnet clinopyroxenite bodies within mantle harzburgite (Treloar et al. 1980; Smellie & Stone 1984, P. Stone, pers. com. 1995). Semail Ophiolite, Oman: 17km for garnet amphibolite sole (Searle & Malpas 1980). East Sulawesi Ophiolite in central Sulawesi: 20km pressure in upper amphibolite sole (Parkinson 1991) and 60km+ for garnet lherzolite retrieved from close to the sole contact (C.D.Parkinson, pers. com. 1990; D.A.Carswell, pers. com. 1994). Two Jurassic ophiolites, with substantially unmetamorphosed crustal sections present, in Tibet: 100km+(?) for diamonds and graphite pseudomorphs after diamond in mantle tectonites (Davies et al. 1995). Note that the metamorphic sole pressures are typically less than that preserved within the related mantle tectonite.

The model proposed (Osmaston 1980, 1990a, 1990b) for the generation and initial supracrustal emplacement of HEOs has nothing to do with subduction. Consider a mature deep-floored (3km?) small ocean basin in which separation has long ceased and the lithosphere has thickened. Now let fresh splitting at a medium or fast oceanic rate occur. The high heat content of the resulting mantle diapir, drawn up into the steep-sided "mantle crack" (see later), will inhibit normal faulting at the top edges of the crack and will support an embryo MOR crustal construction that stands high above the basin floor on either side.

After up to a few tens of kilometres of separation this topographic relief is quite likely to make the ridge burst its side (or end, at a transform offset) at the level of the magma chamber, with the consequence of rapid (or even catastrophic) breakout and continued upwelling of slightly melted mantle from a number of places beneath the embryo MOR. This mantle material will already have been parental to the MOR superstructure. The spreading out of this "mantle laccolith" over the sediment floor of the basin, carrying some of the MOR superstructure on its back, will add metamorphic layers to the sole and infuse water into the hot tectonite, lowering its solidus and sweating out further melt but, this time, of an H_2O controlled calc-alkaline affinity (a characteristic seen in many HEOs). Related dykes, seen in Oman, have orientations that may represent the spreading of the underlying laccolith. Wide-spread intrusions of wehrlite across the tectonite-crust transition are attributed to this stage.

In this model the upwelling and out-turning mantle tectonite flow, well documented in Oman, **occurs at supracrustal level** (relative to the old basin floor) and is **not** relevant to what is going on beneath MORs. Moreover, it is now clear (Osmaston 1995, and in prep.) that a deep, narrow mantle crack beneath active MORs, with its width maintained by restite/cumulate accretion to the walls, much as in the above HEO model, offers a probably unique explanation of their axial straightness, orthogonal segmentation and very narrow neovolcanic zone.

Consider the earlier evolution of the mantle tectonite/laccolith material. At the start of mantle intrusion into the lithosphere crack, during genesis of the embryo MOR, the crack walls will be cool and the levels of melting achieved lower, so the wall-accreted mantle may still be lherzolitic, and the produced basalts may have alkalic affinity. Sample crude calculation suggests that after a few hundred metres of wall accretion at upwards of several cm/yr this extra cooling effect on the axial upwelling temperature will have faded, resulting in MORB for the new crust, harzburgite for wall accretion and the retention of major diapiric capability within the column.

This harzburgite, although "accreted", may well preserve some interstitial melt so that, when rapid burst-out upwelling of much of the young filling of the lithosphere-crack occurs, shear-induced segregation of melt is to be expected, particularly near the relatively strong original mantle crack walls. It is argued that the invariably mafic, higher-pressure part of the metamorphic soles represent segregated melt that froze against the cooler walls as it was dragged up with the tectonite, that the garnet-clinopyroxenite lenses at Ballantrae are similar and that chromite bodies within mantle tectonites are residual (after the sweating-out stage) from such segregations.

Observations of HEOs show the mantle tectonite to be intermittently (often spinel-) lherzolitic both next to the sole and (less often) just below the crust, as would be expected if these locations correspond to the early accretion to the two sides of the mantle crack. Now-residual dunite banding is also widely present in these two locations. These may have been melt segregations analogous to the mafic metamorphic sole but which were in hotter positions than the continuously chilled sole during the spreading out over the basin floor, making them susceptible to partial remelting in the presence of water from below. In some cases, this may have obliterated higher pressure components of the sole, especially in Oman.

It is noted that the general HEO model outlined above would also apply, with little modification, to the high-temperature lherzolite bodies of Lherz, Ronda and Beni Bousera.

It is concluded

(a) that the crustal sections of HEOs are produced under special thermal and topographic contrast conditions of ocean ridge initiation not present at mature MORs,

(b) that the mantle tectonites of HEOs have nothing to do with MOR processes but

(c) that some CEOs may truly represent MOR activity if the crust formed far enough from sources of sedimentation to escape the major modification seen in the N Gulf of California.

*The following list of references was made available at the meeting.

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