Geodynamic setting and origin of the Oman/UAE ophiolite

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The ~500km-long mid-Cretaceous Semail nappe of the Sultanate of Oman and UAE (henceforth referred to as the Oman ophiolite) is the largest and best-preserved ophiolite complex known. It is of particular importance because it is generally believed to have an internal structure and composition closely comparable to that of crust formed at the present-day East Pacific Rise (EPR), making it our only known on-land analogue for ocean lithosphere formed at a fast spreading rate. On the basis of this assumption Oman has long played a pivotal role in guiding our conceptual understanding of fast-spreading ridge processes, as modern fast-spread ocean crust is largely inaccessible.

There remains doubt, however, about how appropriate the analogy with modern fast-spreading ridges actually is in detail. Arguments as to the geodynamic environment within which the Oman ophiolite formed, and the mechanisms by which it was obducted, have been continuing for three decades and remain heated.

In contrast to most ophiolites, the axial ('Geotimes') volcanic suite and associated sheeted dyke complex in Oman have compositions similar to typical mid-ocean ridge basalt (MORB), leading some workers therefore to assume an open-ocean mid-ocean ridge origin for the ophiolite. However, in northern Oman, where the extrusive sequence is best developed, later lava sequences (the 'Lasail' and 'Alley' Units) and associated plutonics succeed the Geotimes. These have clear hydrous signatures; some, indeed, are boninitic: rare rocks that are only otherwise found in intra-oceanic forearcs. To some authors these characteristics are consistent with the entire ophiolite being formed above a subduction zone rather than open-ocean setting – perhaps in some kind of 'pre-arc' marginal basin rather than open-ocean setting – a conclusion supported by the observation of contemporaneous high-pressure rocks in the underlying metamorphic sole. Other workers, however, have instead maintained or assumed that the Oman formed at a true open-ocean mid-ocean ridge and have sought alternative explanations for the source of the water in the Lasail/Alley lavas: either a residue from ancient subduction, derived from descending near-axis hydrothermal fluids, or as a consequence of overthrusting at the initiation of obduction (which is thereby constrained to have started between the Geotimes and Lasail volcanic episodes).

We here show from the geochemistry of the Geotimes lavas and sheeted dykes that, although 'MORB-like', they differ subtly but significantly from true open-ocean MORB as found at, for example, the EPR. Specifically, we show that the observed liquid lines of descent for 870 Oman Geotimes samples require fractionation in the presence of water at levels significantly higher than those of any mid-ocean ridge MORB source. This is supported by consistently elevated fluid-mobile trace elements contents (e.g. Th) in Geotimes lavas/dykes, and high calculated oxygen fugacities in related gabbros. We demonstrate that water was pervasive, therefore, in the mantle source of the Oman system in all parts of the ophiolite, and for its entire history. The Geotimes-Lasail-Alley sequence can be explained by a progressive increase in water content with time and (in present coordinates) from north to south. The whole of the ophiolite, therefore, formed in a hydrous setting, allowing us to robustly discount the 'open-ocean' models.

Combining geochemical, structural and geochronological evidence we here develop a variant of the supra-subduction models in which the entire Oman ophiolite formed by a short-lived phase of 'infant arc' spreading immediately after the initiation of intra-oceanic subduction, in a manner comparable to that proposed for the Izu-Bonin-Mariana and Tonga forearcs in the Eocene. Following Stern (2004 EPSL v.226, p.275-292) we propose that foundering of a dense slab at a point, probably at a large-offset ridge-transform intersection, was followed immediately by unzipping and lengthening of the proto-trench. Rollback induced the production of (slightly wet) melts from the original MORB source and generation of the Geotimes crust by a phase of rapid but unstable seafloor spreading. Progressively increasing water contamination in the mantle and convection induced by the growing slab led to the subsequent production of boninites and 'conventional' arc tholeiites. Vertical-axis rotations of blocks of the newly formed crust in the young extending over-riding plate induced by differential rollback were accommodated by propagation of new spreading segments, resulting a complex spreading and rotation history in the preserved, obducted portion of the ophiolite.