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The geodynamics of oceanic core complexes: would subduction occur at ridge-transform intersections?

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Abstract

Oceanic core complexes are lithological assemblages of peridotites and serpentinites, embedded in the basaltic oceanic crust at active or dormant intersections of several slow-spreading oceanic accreting rifts with fracture zones. These occurrences are presumed to derive from the upper mantle, emplaced by low-angle and large-throw normal detachment faults. The abundant serpentinites are attributed to alteration of the ultramafic peridotites during its long ascent from the upper mantle. However the absence of both high-pressure lithologies in the oceanic core complexes and the rareness of earthquakes generated by low-angle normal faulting cast doubt on the validity of this conventional model. Alternately, analog tectonic experiments showed that subduction is a probable process for the generation of oceanic core complexes, because it could develop between two juxtaposed tectonic slabs if their density contrast will exceed 200 kg/m3 with no lateral converging pressure, if the friction between the slabs were low. Indeed oceanic core complexes occur in unique oceanic domains where two basaltic slabs of contrasting densities are juxtaposed across a weakness zone of low friction. Density of fresh basalt at the accreting ridge is approximately 2700 kg/m3 and that of the older basalts, juxtaposed across the fracture zone, is ca. 2900 kg/m3. Slow spreading rates of some ridges would set slabs of significant density contrast across the fracture zone even if the transform offsets are not large. Furthermore, the thermal gradient under the ridge is some 1300/km, enabling the metamorphism of the oceanic basalts either to serpentinites or to peridotites at similar P-T constraints, depending on the availability of water. Therefore, it seems that the serpentinites are not secondary products of source-rock alteration, but genetic equivalents to the peridotites. It is presumed therefore that the pliable serpentinite would ascend diapirically through cracks in the over-riding basaltic slab and reach the seafloor, carrying along large blocks of peridotite to produce the serpentinite-peridotite petrology, that lithological association of oceanic core complexes.

Introduction

Oceanic core complexes are lithological assemblages of variegated lithologies, predominated by peridotites and serpentinites, embedded in the basaltic oceanic crust at active or dormant intersections of several slow-spreading oceanic accreting rifts with fracture zones. The oceanic core complexes are presumed to derive from the upper mantle, emplaced by low-angle and large-throw normal detachment faults (e.g. McCaig et al., 2010). The occurrence of the abundant serpentinites is attributed to alteration of the ultramafic peridotites during the long ascent from the upper mantle, following Wernicke's (1995) simple shear concept.

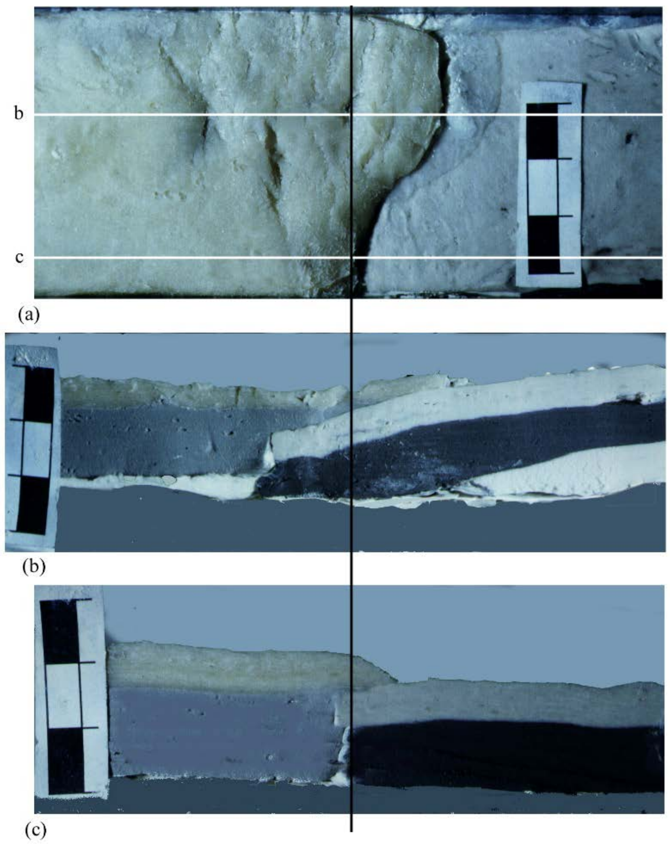

Figure 1. Centrifuge deformed 3-layers and 5 components model of incipient subduction, where no lateral pressure was applied. Friction along the contact zone was not uniform; therefore an arcuate subduction front was produced. (a) top view of the experiment after 7 minutes of deformation at acceleration of 1000 g. (b) The denser slab was driven underneath the lighter one where friction was low, and the overthrust slab stretched and extended by thinning and faulting. (c) Compression and minor underthrusting prevailed where the friction between the slabs was high. After Mart et al., (2005).

However the absence of eclogite and other high-pressure lithologies in the oceanic core complexes, and the rareness of earthquakes generated by low-angle normal faulting (Scholz, 2002) cast doubt on the validity of this conventional model. Alternately, centrifuge-driven analog tectonic experiments showed that subduction could develop between two juxtaposed tectonic slabs with no lateral converging pressure, if their density contrast will exceed 200 kg/m^3 (Figure 1), and if the friction between the slabs was low (Mart et al., 2005; Goren et al., 2008). Numeric models used this concept in their suggestion for the initiation of subduction (Nikolaeva et al., 2010). The models used the model to account for subduction between land and sea, but already

Casey and Dewey (1984) the density contrast between lithospheric slabs, which could occur across transform faults and fracture zones, to account for ocean-ocean subduction. The present concept suggests to extend it to the application of the density contrast to account for the evolution of oceanic core complexes (Mart, 2020)

Methods and results

Oceanic core complexes occur, mostly, in a unique oceanic domain, bounded by one active and one dormant major faults. Their active faulted boundary is the normal fault that bounds the accretion rift of a slow-spreading Mid-Ocean Ridge and their inactive, faulted border is the head of the fracture zone, which is tectonically inactive, but close to the edge of the active transform fault (Figure 2). Such occurrences abound in the equatorial segment of the North Atlantic Ocean, and also in the SW Indian Ocean, and in a few locations elsewhere, where two basaltic slabs of contrasting densities are juxtaposed across a weakness zone.

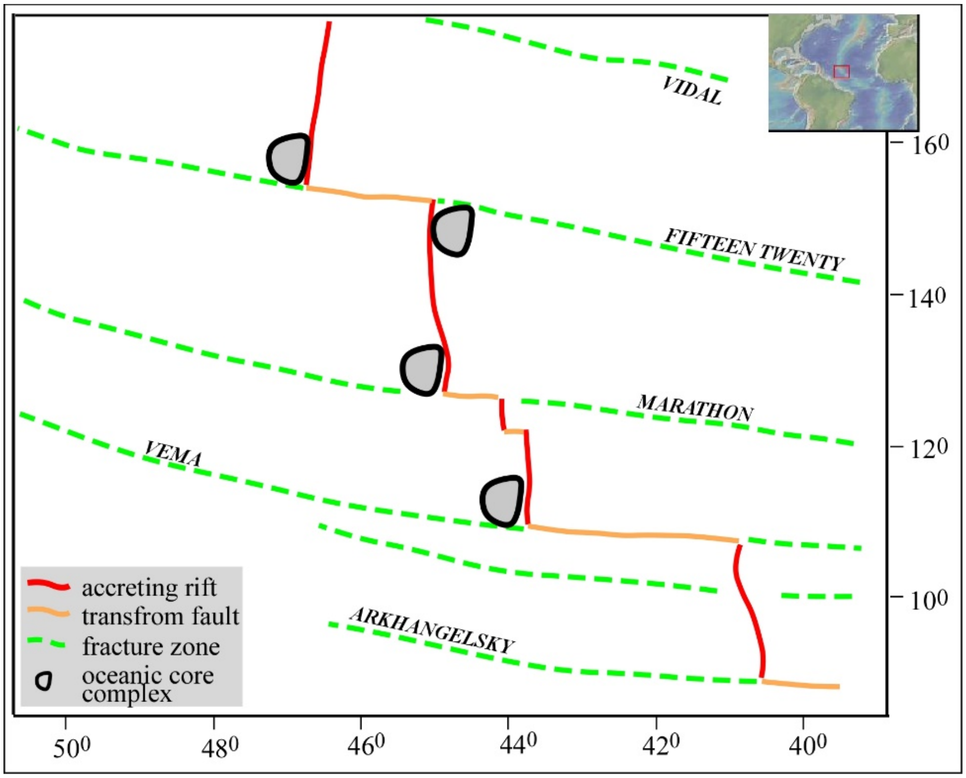

Figure 2. Schematic distribution of oceanic core complexes at the equatorial North Atlantic Ocean shows that the complexes are located at the junction of the Mid-Ocean Rift and a fracture zone, where the density contrast between the juxtaposed slabs is significant. Inserts, location chart (top right) and legend (bottom left). Based on maps of www.geomapapp.org.

In the oceanic domain, requirements of density contrast of some 200 kg/m^3 are met at the edge of the accretion rift at the crest or a slow spreading Mid-Ocean Ridge. The density of fresh basalt at the accreting rift is approximately 2700 kg/m^3 and that of the older basalts, juxtaposed across the fracture zone, is ca. 2900 kg/m^3 (Schubert and Turcotte, 2002?), if the spreading rates are low and the older basalts cools down by the time it is juxtaposed against the fresh basalt. Furthermore, the thermal gradient under the accreting rift is some 130^0/km, enabling the alteration of the oceanic basalts either to serpentinites or to peridotites at similar P-T constraints (Kessel et al., 2005), depending on the availability of water (Figure 3). Therefore, it seems plausible that the serpentinites are not secondary products of source-rock alteration, but genetic equivalents to the peridotites. It is presumed further that the pliable serpentinite would ascend diapirically through cracks in the over-riding basaltic slab and reach the seafloor, carrying along large blocks of peridotite to produce the serpentinite-peridotite petrology, that lithological association of oceanic core complexes. Thick layer of rubble, commonly found to overlay the top of the rocks of the oceanic core complexes could be attributed to the high friction generated by the ascending diapir secreted from the subducting slab (Figure 4).

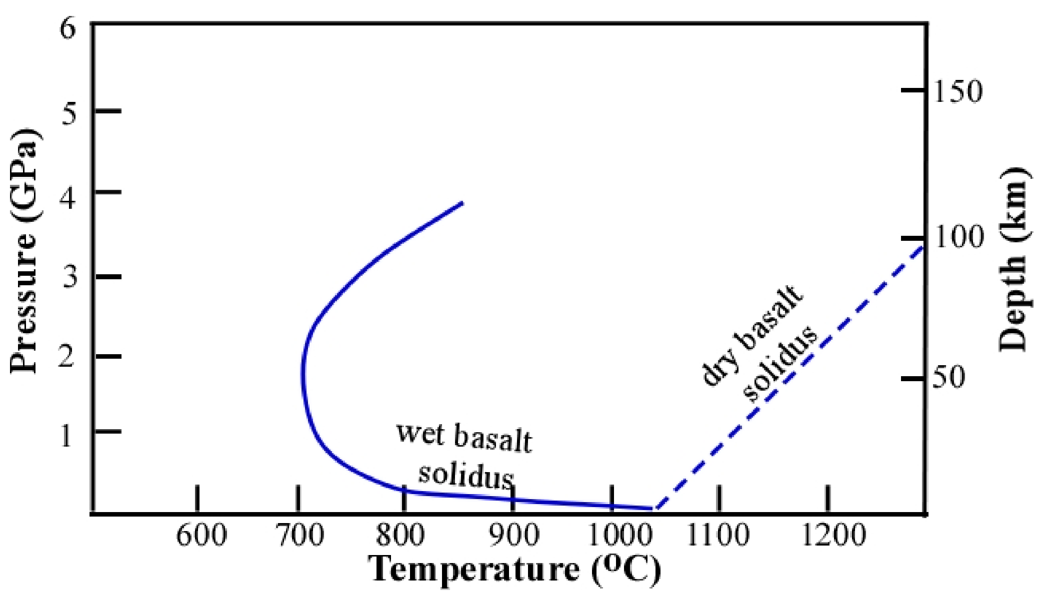

Figure 3. Presence of water in the subducting slab would lower the melting temperature of the oceanic lithosphere to 700 °C. At normal subduction zones, such temperature occurs at lithostatic pressures of ca. 2 GPa, or depth of ~50 km, but at oceanic core complexes such temperatures would occur at depth of ca. 5–7 km. Note the sharp drop of the solidus of wet basalt at temperatures circa 700 °C. After Kessel et al. (2005).

Discussion.

The distinctive characteristics of oceanic core complexes are (a) their petrology of intimate co-occurrence of metamorphic serpentinites and magmatic peridotites and (b) their location at the flank on accreting oceanic ridges. Conventionally, the location characteristic is interpreted as the products of extensional detachment faults that transect the entire lithosphere displacing and uplifting their footwalls some tens of kilometers, they are non-Andersonian and cannot be restored (e.g. McCaig et al., 2010). Already the early petrologic investigations of the Mid-Ocean ridge noticed the co-occurrence of peridotites and serpentinites in the valleys of the transform faults and the fracture zones like the findings of Ewing and Ewing (1959), Bonatti (1968), Ahrens and Schubert (1975), Francheteau et al. (1976), Dick (1989), or Cannat et al. (1992), to mention only a few. The petrological origin of the oceanic core complexes from the upper mantle and its ascent through detachment faults is rarely doubted (see Whitney et al., 2013 or Parnell-Turner et al., 2017 and references therein).

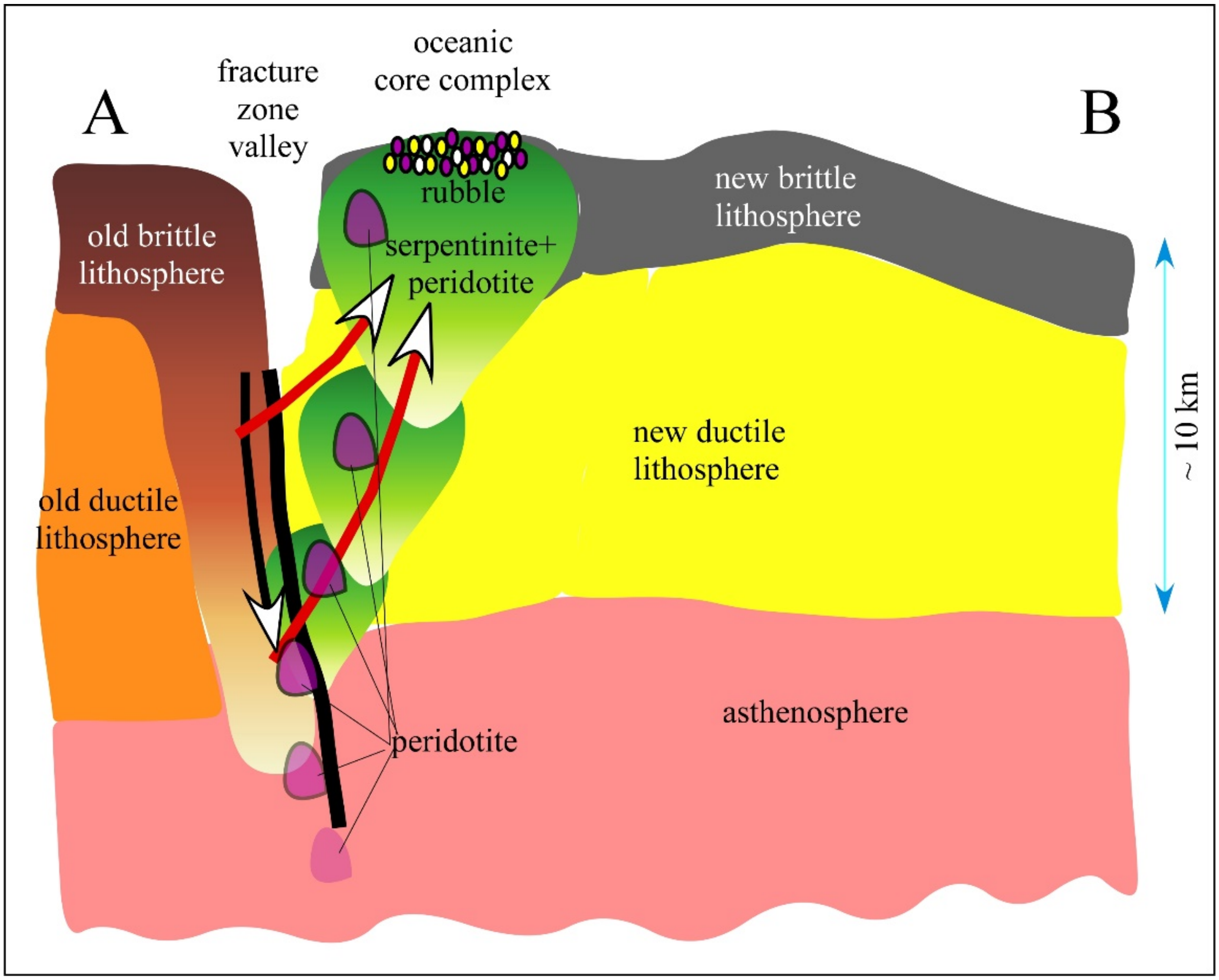

Figure 4. Conceptual section across a fracture zone very close to the accreting rift, where the brittle and ductile lithospheres are hot and light, while the juxtaposed lithosphere is denser. Analog experiments suggest that under such setting, the denser slab would subduct and petrological considerations indicate that at depth of some 4-5 km bi-modal remineralization would take place, producing concurrently peridotites and serpentinites, depending on the availability of water. The predominantly serpentinized rocks are likely to ascend diapirically to the flank of the Mid-Ocean Ridge. After Mart (2020).

However, Mevel (2003) presented evidence that the protolith, from which the serpentinites of oceanic core complexes were generated, was oceanic crust gabbro. She suggested that the occurrence of the serpentinites indicates seawater content of nearly 15 % in the source rock, and that temperatures of circa 500 °C were required for the serpentinization reaction of gabbro to take place. And Scholz (2002) doubted the existence of normal low-angle detachment faults altogether. Dannowsky et al. (2010) noticed that the depth of the Moho under the oceanic core complex is ca. 40% thinner under the core complex than its depth under the adjacent and contemporaneous normal basaltic brittle lithosphere. Diapiric ascent of oceanic core complexes and their diapiric emplacement was suggested by Cannat et al. (1992) and Guillot et al. (2015), supporting the similar presumption of Francheteau et al. (1976).

Conclusions

Analog experiments showing the critical contribution of density contrasts and reduced friction to the initiation of subduction support the concept that oceanic core complexes and their unique lithology could derive from subduction of denser oceanic lithosphere under the fresh and light lithosphere, accreted at the external flank of the Mid-Ocean Ridge. The high thermal gradient under the Ridge that could reach 130^{o}C/km and the probable occurrence of water could enhance the concurrent remineralization of peridotites and serpentinites at depth of 4-5 km from the subducting lithosphere. The suggested concept implies that where the serpentinite was abundant in the remineralized domain, diapirs of hydrous metamorphic silicates would ascend to the seafloor carrying with them blocks of ultramafic rocks (figure 4).

Acknowledgements

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