Tectono-magmatic evolution for oceanic core complex formation

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Abstract: Oceanic core complexes are the corrugated massifs formed by the uplifting of large-offset low angle detachment faults along the mid-oceanic ridges. These large-offset low angle faults play a key role in accommodating the lithospheric separation at slow and ultra-slow spreading ridges. The published literature on oceanic core complexes and the associated detachment faulting highlighted the control of magma in the oceanic core complex formation. However, it is still unclear whether the detachment faulting is initiated in the amagmatic or fully magmatic environment. Based on published literature, this report presents a tectono-magmatic evolution for the oceanic core complex formation.

Keywords: Oceanic core complex, detachment faulting, seafloor spreading, magma injection

1. Introduction

The widely exposed gabbros and mantle peridotites at slow spreading mid-oceanic ridges are thought to be the products of large-offset low angle detachment faults (e.g. Karson and Dick, 1983; Karson, 1990). Different oceanic core complex formation models (e.g. Karson, 1990; Tucholke and Lin, 1994) have been proposed and related the genesis of these detachment faults to the amagmatic regime developed in order to accommodate the lithospheric separation at slow or ultra-slow spreading centers. These typical low angle detachment faults were first identified by Cann et al. (1997) along the Mid Atlantic Ridge (MAR). These detachments form corrugated massifs, exposing the lower crustal and upper mantle rocks on the seafloor (Cann et al., 1997; Blackman et al., 1998; Tucholke et al., 1998). The uplifted footwalls of these large-offset low angle detachment faults are termed as ‘oceanic core complexes’ (Smith et al., 2006; Escartın et al., 2008; MacLeod et al., 2002; MacLeod et al., 2009; Ildefonse et al., 2007) named after ‘metamorphic core complexes’ usually found in extensional continental tectonic regions (John, 1978). The oceanic core complexes (OCC) have been identified at mid-ocean ridges and marginal basins generally showing a spreading rate varying from 14 to 75 mm/yr (Tucholke et al., 2008). The OCC occur more widely (Smith et al., 2006, 2008) unlike the previous studies proposed that they are restricted to the extremities of the spreading ridges (e.g. Tucholke et al., 2001;

Ohara et al., 2001; Reston et al., 2002; Searle et al., 2003). The wide occurrences of oceanic core complexes are usually controlled by the large extending low angle detachment faults as they can extend from tens of kilometers to several hundred kilometers.

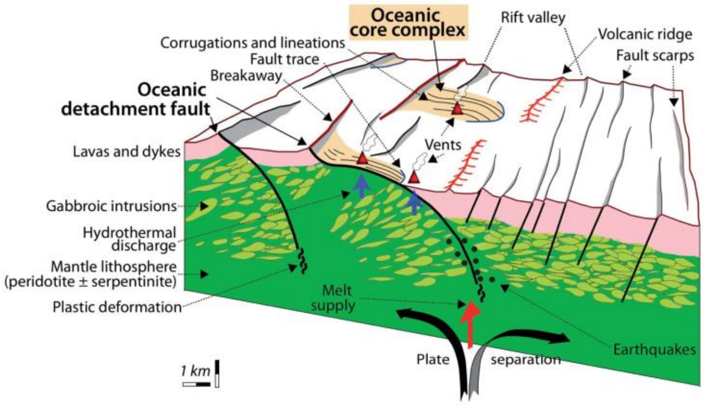

Figure 1: The ‘Chapman model’ (Escartín and Canales, 2011) of lithospheric accretion and oceanic core complex formation (Maffione et al., 2013).

2. Evolution of core complex formation by detachment faulting

Smith et al. (2006) summarize the OCC evolution and the detachment fault formation from the initiation to the extinction, into three main stages **(Fig. 2)**. These interpretations are based on the observations of a number of oceanic core complexes at different stages of their evolution. After thoroughly studying the structure, the degree of activity and the detachment nature, three main stages of the core complex formation are proposed.

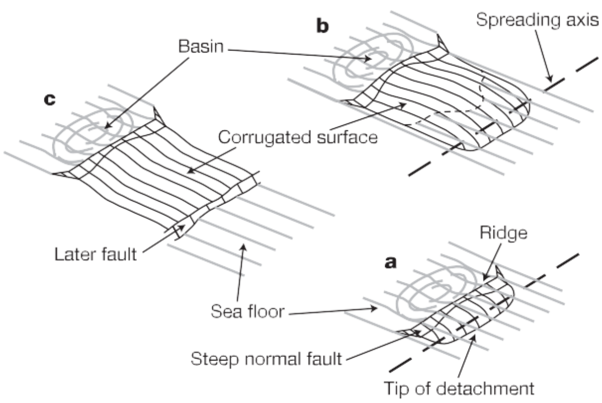

Figure 2: 3D model for oceanic core complex evolution by detachment faulting. Thick light grey lines represent ocean floor. Thin black lines showing the detachment surface and faults. The spreading axis represented by thick black dashed-line (Smith et al., 2006).

The formation of oceanic core complex starts with the subsidence of a basin accommodated by a basaltic ridge (Fig. 2a). A new basin emerges right behind the ridge, possibly formed by an outward rotation of the footwall.

The second stage of OCC evolution is followed by a dome shaped corrugation, intersecting the valley floor forming a line convex towards the spreading axis (Fig. 2b). The detachment fault may have a low angle extension but the formation of the basin might be related to a steep curve below the sea floor.

At the final stage of this cycle, a normal fault cuts the oceanic core complex off along a line of detachment leading to the core complex extinction (Fig. 2c). As a result, the corrugated surfaces become flat to the horizontal extending from tens of kilometres to several hundred kilometres along the spreading axis as a single elongated unit.

3. Role of magma in oceanic core complex formation

The evident role of magma in the formation of oceanic core complex formation is controversial over the past several years. The earlier oceanic core complex models (e.g. Tucholke and Lin, 1994; Tucholke et al., 1998) proposed an amagmatic evolution for the detachment faulting, have been replaced with the new geological evidences suggesting a continued magmatism during the active detachment faulting (Dick et al., 2000; MacLeod et al., 2002; Reston et al., 2002; Escartín et al., 2003; Blackman et al., 2006). All oceanic core complexes contain gabbro cores suggesting their development in a relatively enhanced magma supply (Ildefonse et al., 2007).

A new study (Olive et al., 2010) suggests that the development of detachment faults is likely to strongly influenced by the rate at which the magma is injected into the brittle lithosphere forming intrusive dykes. Most of the previous studies proposed a low magma injection for the development of detachment faults, suggesting only 30–50% of the total plate separation caused by magma injection into the lithosphere (Buck et al., 2005; Behn and Ito, 2008; Tucholke et al., 2008). On a contrary, field observations reported the core complex formation under a spectrum of magma injection rates, as the detachment is found to be developed from amagmatic to fully magmatic conditions (Tucholke and Lin, 1994; Xu et al., 2009; Tucholke et al., 1998; Dick et al., 2000; Blackman et al., 2002; MacLeod et al., 2002).

Olive et al. (2010) suggested that the development of oceanic core complex is controlled by the rate of magma injection into the lithosphere, whereas the magma injection rate below the brittle–ductile boundary has no influence except on gabbros exhumation. The domed and corrugated megamullions formed by a large offset low angle detachment faults and defined as oceanic core complex, expose a variety of rocks. The widely distributed serpentinized peridotites with less gabbros may represent a reduced or varying rate of magmatic injection into the brittle lithosphere (Olive et al., 2010). Geodynamic modelling and detailed quantitative investigations of the detachment faulting and the magmatic distribution patterns at mid-ocean ridges lead to the key findings; the rate of magma injection into the brittle-ductile lithosphere strongly controls the development of detachment faulting and the distribution of magmatic lithologies at mid-ocean ridges.

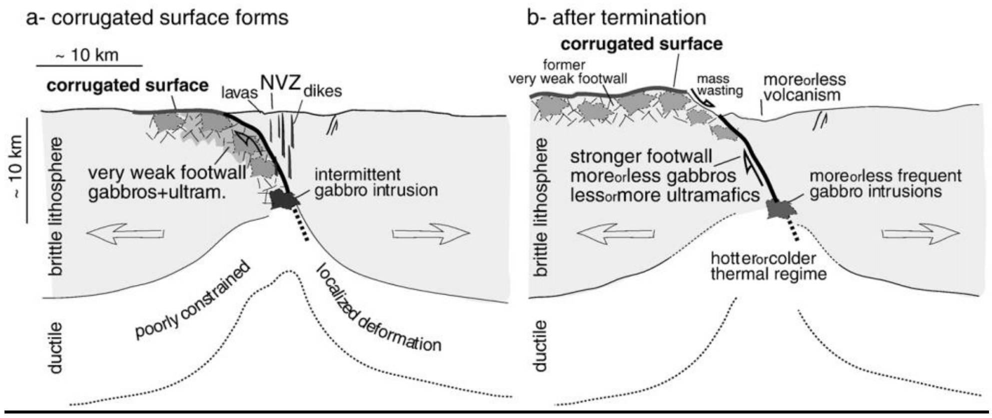

Figure 3: A contrasting model representing the initiation and termination of oceanic core complex and the magma injection control on the development of detachment faults: (a) development of a weak detachment fault with small uplift and large roll-over. (b) More magma supply in the upper part of the footwall, less roll-over but large uplift (Cannat et al., 2009).

A tectono-magmatic model (Cannat et al., 2009) proposed two contrasting processes for the development of detachment faults (fig. 3). The observations revealed that the initiation of the core complex formation is related to the development of a weak detachment fault in intermittent magmatic emplacement condition. Yet, paradoxically, the detachment is terminated when more magma is intruded into the fault.

The in situ lithologies of the smooth domes are dominated by serpentinised peridotite, with a partial basaltic scree cover. Additionally, some hydrothermal massive sulfide deposits with minor associations of dolerite dykes are sampled near the toe of oceanic core complex. On a contrary, the corrugated segment of the oceanic core complex is characterized by a dominant basaltic lithology with associated greenschist dolerite and minor amounts of gabbro. Serpentized preditotes are appeared to be absent in this segment (MacLeod et al., 2009).

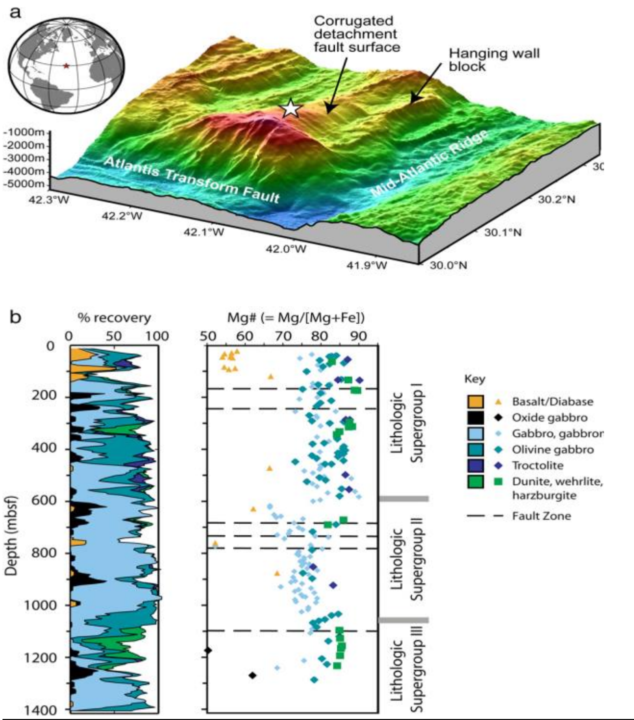

Figure 4: (a) Topographic map of the Mid-Atlantic Ridge 30° N and Atlantis fracture zone region based on multi-beam bathymetry data from Blackman et al. (1998). Lithology profiles recovered from IODP Hole U1309D (white star) located on the central dome of the Atlantis Massif. (b) Vertical distribution of different rocks recovered in Hole U1309D divided into lithologic supergroups with the reference of fault zones (Morris et al., 2009).

A core of 1415.5 m below seafloor (mbsf) recovered from IODP Hole U1309D located 14 km west of the Atlantis Massif (Blackman et al., 2006), provides a complete in situ lithology observation of the lower oceanic crust (Fig. 4b). The core is dominantly (80%) comprised of gabbro, gabbronorite and olivine gabbro. Some other rock types include Fe-Ti oxide gabbro with a 7 % of the total core composition, about 3 % diabase, more or less than 5 % ultramafics and some felsic dykes contribute less than 1% of the total core composition (Morris et al., 2009). Based on the vertical chemical composition and variation patterns with relation to the depth of the core, the core is divided into three lithological subgroups. A high precision zircon U-Pb dating of gabbros from the Vema Fracture Zone on the Mid-Atlantic Ridge reveals that the crust is formed in a shallow melt regime (Lissenberg et al., 2009).

4. Conclusions

The oceanic core complexes are the corrugated massifs, exposing the lower crustal and upper mantle rocks on the seafloor. Oceanic core complexes are important components of seafloor spreading, providing the in situ observations of lower crustal and upper mantle lithologies.

The core complex formation is strongly controlled by low angle large offset detachment faults. The development of these detachment faults follow a schematic set of evolution processes leading from the initiation to the termination of oceanic core complex formation.

Magma plays a significant role in the core complex formation as the rate of magma injection controls the patterns of detachment faulting. Although, the evidences show that a magmatic intrusion into the fault leads to its termination, the emplacement of magma may also trigger the formation of several new localized faults.

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