Understanding of the mode of seafloor spreading and the architecture of upper oceanic crust by oceanfloor drilling at off-Hawaii MoHole candidate site

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Understanding how seafloor spreading and mantle melting are linked to ocean crust architecture is Challenge 9 of the IODP Science Plan for 2013-2023 and is one of the major goals of the mantle drilling project MoHole to Mantle (M2M). Deep basement drilling is skewed to young and slow-spread crust, with a wide gap of crust age between 20 and 110 Ma, including the world average of 62.5 Ma and spreading rate of 7.6 cm/a. Among the three candidate sites of M2M, only off-Hawaii site can provide the information of oceanic crust of the missing age and spreading rate. We propose a deep drilling off-Hawaii to penetrate through the upper crust and into the gabbros to understand the architecture and governing processes of the upper oceanic crust.

ODP Holes 504B and 1256D have brought invaluable information and fruitful insight into the architecture and formation processes of the upper oceanic crust.

Hole 504B is the deepest drill hole that penetrated 1815 m into 6.9-Ma basement formed at an intermediate rate of 6.6 cm/a at the Costa Rica Rift (Dick et al., 1992). The 504B upper crust, consisting of less dense extrusive rocks underlain by denser sheeted dikes than their source magmas, yields an apparent level of neutral buoyancy that traps accreted magma as dike intrusions. Thus, the 504B crust relaxes stress induced by plate movement and extends by both fault displacement and dike intrusions, which leads to development of rugged summit and axial troughs.

On the contrary, the 15-Ma 1256D crust, formed at the East Pacific Rise, has a distinctly high extrusive to intrusive ratio (814 m / 343 m) compared to that of the 504B crust (780 m / >1056 m). As is expected for the ultrafast spreading rate of 22 cm/a, the extrusive rocks are dominantly of massive and lobate sheet flows, which are as dense as the extruding magma (Umino et al., 2008). This results crust without an apparent level of neutral buoyancy and the persistently over pressurized axial magma chamber (AMC). Only a small increase in magmatic pressure or reduction in horizontal stress leads to dike intrusions followed by eruptions. Conversely, extension of the 1256D upper crust was primarily accomplished by dike intrusions without large faults.

These examples articulate how the density structures of upper crust partition magma into extrusive and intrusive rocks and form characteristic architectures.

Density structures are intimately correlated with magma budget, the amount of magma supplied and consumed to keep the same cross-sectional area of the ridge for a time scale of 100 ky.

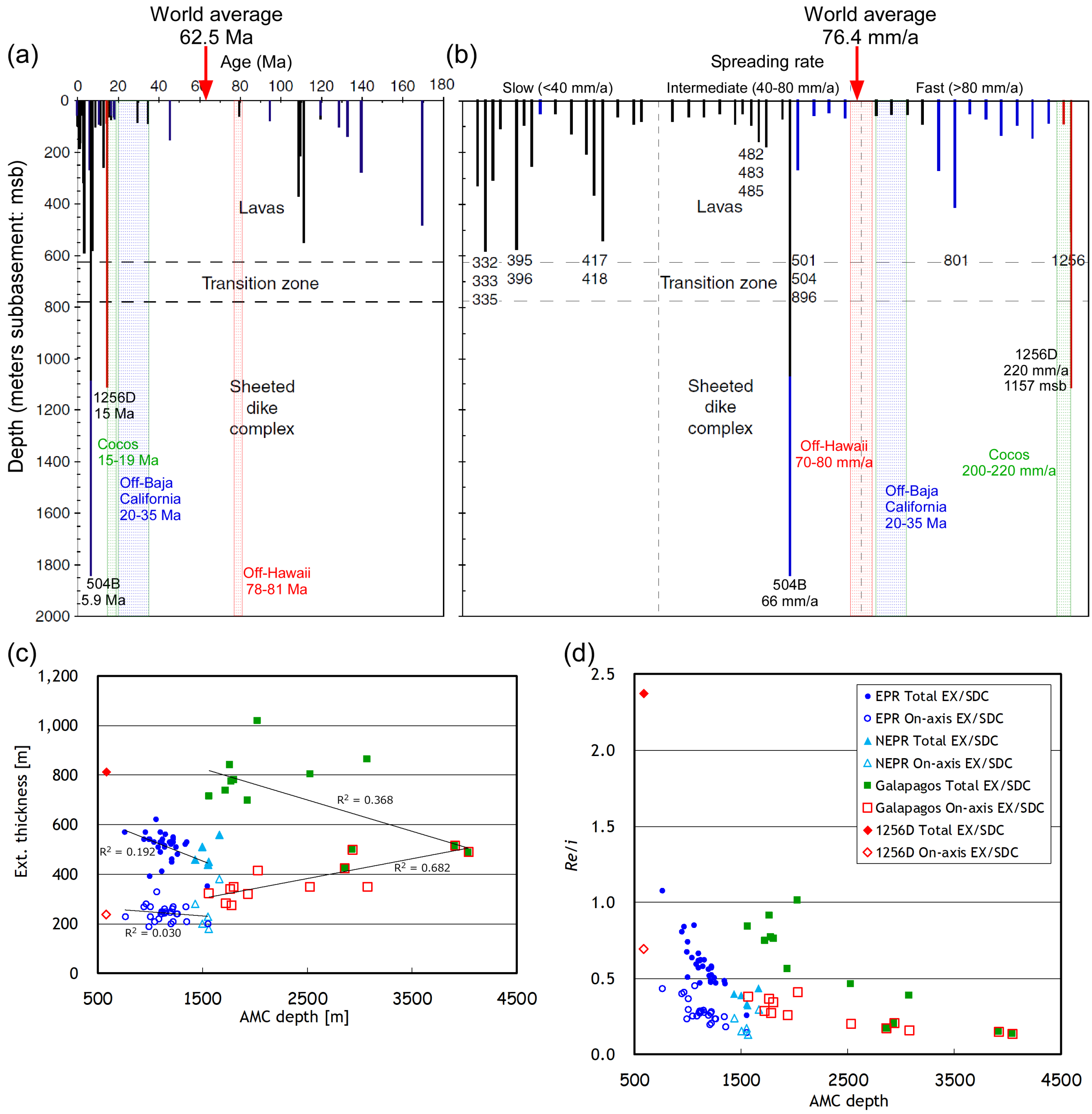
The Galapagos Spreading Center (GSC) shows thickening on-axis and thinning total extrusive rocks with AMC depth, indicating axial valleys develop to trap thick on-axis flows with deepening AMC and decreasing magma budget (Blacic et al., 2004). For the GSC spreading rate of 4.5–5.5 cm/a, more than

50 % of flows in the axial valleys are pillows. Consequently, the GSC is underlain by less dense pillows interbedded with fault breccias. The density structure of this crust is essentially the same as the 504B crust.

Likewise, the magmatically robust East Pacific Rise (EPR) shows a negative correlation of total extrusive thickness and AMC depth, while on-axis flow thickness remains constant (Hooft et al., 1996, 1997). Accordingly, the axial troughs do not develop, and the upper crust extends mainly by dikes intrusions. This is facilitated by the presence of dense extrusive rocks comprising more than 80 % sheet flows, considering the spreading rates of 11–14 cm/a, primarily the same as the 1256D crust.

How two types of upper crust architecture change from one type to the other is yet to be understood. If any critical threshold that distinguishes two crust types exists, it would reside in the crust with a spread rate between 7 cm/a and 10 cm/a. The off-Hawaii crust spread at 7–8 cm/a will provide a missing link that connects the two crust architectures and brings us thorough understanding of the seafloor spreading.

Keywords: Oceanfloor Drilling, MoHole, Off-Hawaii site, Upper crust architecture, Density structure, Plate spreading



Above: Ocean drill holes deeper than 50 m into the oceanic basement plotted against the basement age (a) and categorized on the basis of spreading rate that formed the basement crust (b). World average age and spreading rate are based on the 3.6 min grid data from EarthByte agegrid 2008 (Muller et al., 2008).
Below: Extrusive thickness (c) and Re/i (ratio of extrusive to intrusive thickness) (d) plotted against the AMC depth for the present GSC and EPR segments and the 15-Ma 1256D crust. Solid and open symbols are data based on total and on-axis extrusive thicknesses.