How does the style of plate spreading govern the architecture of oceanic crust

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Oceanic plate at the mid-ocean ridges consists of the oceanic crust that grows to form brittle lithosphere within <200 Kyr from the ridge axis. Consequently, spreading of plate at the ridge axis is accomplished by the formation and deformation of the oceanic crust. Fast and intermediate spreading ridges differ in style of crustal extension that leads to the distinct density structures of the upper crust (Morishita et al., 2019). The density structure of the upper crust determines the preferential levels of magma emplacement (Umino et al., 2008) and the fraction of magma consumed to relax the crustal strain due to plate spreading, M (Buck et al., 2005).

Fast-spread oceanic crust comprises dense sheet flow-dominant extrusive rocks underlain by thin sheeted dikes (Fig. 2A). This density structure enhances more magma to extrude, allowing the crust to extend solely by magmatic accretion (M=1). In contrast, the intermediate-spread crust consists of less dense, pillow-dominant extrusive rocks, yielding an apparent level of neutral buoyancy that traps magma to develop the sheeted dikes below (Fig. 2B). The crust consequently extends by dike intrusions in the lower levels and by faults in the shallow levels that results in the formation of axial troughs (M<1). This density-controlled magmatic accretion results in the contrasting crustal architecture with thicker upper crust and higher ratios of extrusive to intrusive rocks for fast-spread crust.

The crustal architecture and the style of crustal extension are more directly linked to the rate of magma supply rather than the spreading rate. The well-known inverse correlation of the depth to the axial magma chamber (AMC) and the spreading rate for >4 cm/a is caused by higher supply rates of magma for faster-spreading ridges, indicating that the AMC depth is a proxy of magma supply rate (Fig. 3). At a given spreading rate, AMCs are shallower in the magmatically robust segment center than in the ends. As the axial magma chamber (AMC) deepens, the supply rate becomes lower and the total extrusive rocks become thinner.

A ridge segment along the Galapagos spreading Center (GSC) spread at intermediate rates (4.9-5.5 cm/a) shows thinning of the extrusive rocks emplaced on axis toward the segment ends with increasing AMC depth, namely, with decreasing magma supply rate and M (Fig. 4). This means that axial troughs develop with the decrease in M (<0) and more flows are trapped on the axis. In contrast, the thickness of axial extrusive rocks on the fast-spreading (10-14 cm/a) East Pacific Rise (EPR) (M=1) does not change with the AMC depth, resulted from the absence of axial troughs that holds thick flows on the axis. Toward the segment ends with decreasing supply rate of magma or M, the extrusive rocks become thinner while the sheeted dikes become thicker on both GSC and EPR. This tendency is consistent with the crustal architecture observed at Hole 504B and 1256D, Hess Deep, and with the observations of the Troodos and Oman ophiolites.

The style of crustal extension from magmatic accretion to stretching changes in a spreading rate interval of 7–10 cm/a. To understand the relationship between the plate spreading mode and the resulting crustal architecture, we propose to drill a complete upper crustal section and into the uppermost gabbros in the 80-Ma crust spread at 8 cm/a on the North Arch off-Hawaii.

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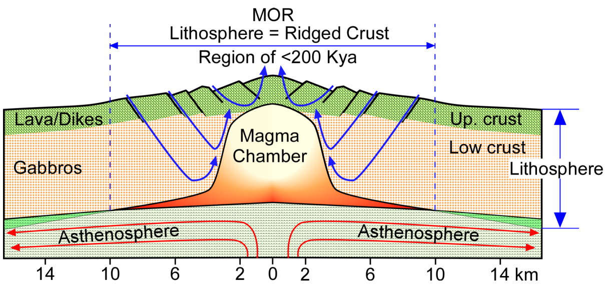

Fig. 1. Oceanic plate at the mid-ocean ridges consists solely of the oceanic crust that grows to form brittle lithosphere in <200 Kyr from the ridge axis.

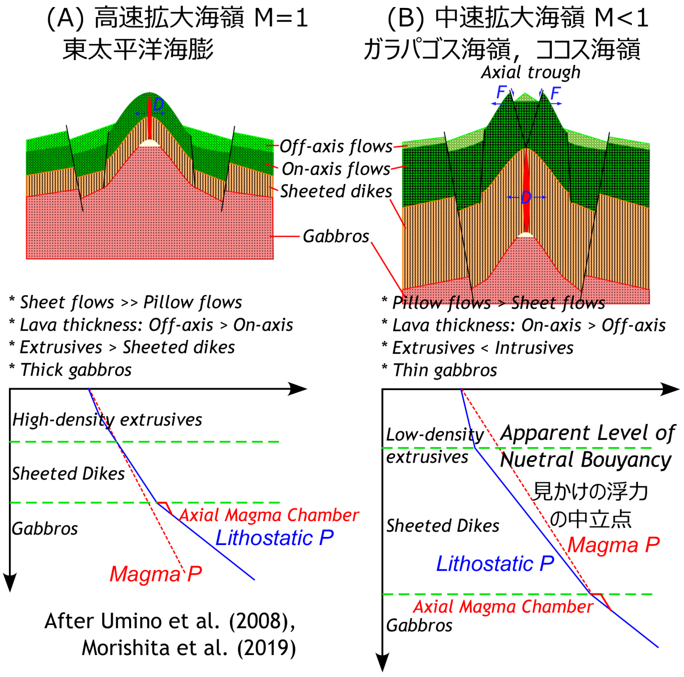

Fig. 2. Crustal architecture and the mode of crustal extension in the ridges spreading at fast (left) and intermediate (right) rates. Contrasting density structures are shown below.

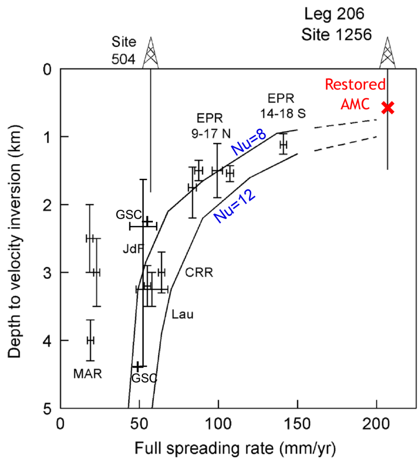

Fig. 3. Depth to the axial magma chamber vs. spreading rate. Sources: Blacic et al. (2004), Carbotte et al. (1997), Purdy et al. (1992). Depth vs. spreading rate predictions from two models of Phipps Morgan and Chen (1993). Data added after Teagle et al. (2006).

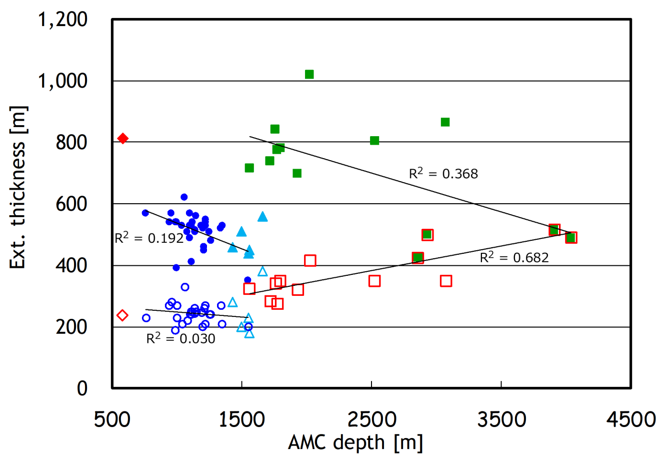

Fig. 4. Extrusive thickness plotted against the AMC depth for the present GSC and EPR segments and the 15-Ma 1256D crust. Solid and open symbols are data based on total and on-axis extrusive thicknesses.

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