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Transition between intermediate- and fast-spreading oceanic crustal structures in response to varying rate of magma supply

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The upper crustal structure formed at an intermediate-fast spreading rate is determined by balance between magmatic supply rate at the ridge axis and strain rate due to plate spreading. This leads to higher ratios of the thickness of the extrusive to intrusive rocks (Re/i) for faster-spreading ridges with shallower Axial Magma Chamber (AMC). This paper discusses the factors causing the different upper crustal structures on the basis of ODP drill Holes 1256D and 504B.

More than half of the extrusive layers deposit off axis at a fast-superfast spreading system [Hooft et al., 1997; Tominaga et al., 2008]. This means that the upper crust at the ridge axis consists of the dense sheeted dike complex, resulting in the absence of Level of Neutral Buoyancy (LNB) [Umino et al., 2008]. High absolute pressure of magma in the AMC leads to an eruption once dike intrusion begins. Because the ridge crest is so flat and lacks any axial troughs, extruded lava will flow downslope and form a thick off-axial lava pile.

In contrast, an intermediate spreading ridge is underlain by thick less dense extrusive layers dominated by pillow lava resting on the sheeted dikes. This density structure results in the formation of LNB in the upper crust, which traps intruding magma as a dike before reaching the surface. An eruption occurs only sufficient amount of magma is available. Because the dike head is deep in the upper crust, strain in the shallow crust is released by faulting, which results in the development of a wide and deep axial trough. Lava extruded at the ridge axis remains in the axial trough and seldom overflows onto the ridge flank. The axial topography is rugged due to intense faulting and extruding lava will take the form of less dense pillows.

Such a crustal structure will develop a self-regulating system that controls intrusion and extrusion of magma by negative feedback. High magmatic supply rate will lead to an eruption. A prolonged period of high magmatic supply forms thick pillow piles within the axial trough, accompanied by an expansion of the AMC that erodes the base of the sheeted dike complex. This reduces density of the upper crust and enlarges the LNB which traps more magma as a dike without an eruption.

To the contrary, a prolonged period of low magmatic supply will form dike intrusions without eruptions, which extends the upper crust by faulting. Thinned extrusive layers are replaced by dense sheeted dikes, resulting in the formation of dense upper crust and diminishing the LNB. This switches the mode of magma emplacement from intrusions to extrusions.

In spite of the presence of such a self-regulating system, an extremely high magmatic supply will turn on the positive feedback for the crustal structure to change from the intermediate- to fast-spreading ridges. Copious outpouring of lava buries the axial trough and flatten the ridge crest, which favors the formation of dense sheet flows instead of pillows. This leads to the dense upper crust without LNBs, that enhances more magma to erupt, resulting in high Re/i.

Conversely, magma-deficient conditions turns on the positive feedback from the fast- to intermediate-spreading crustal structures and reverse the above process. The upper crust extends by dike intrusions and fault movements, developing a deep axial trough with rugged topography. Thinned extrusive layers result in the dense crust, which enforces more magma to extrude within the rugged axial trough as pillow lava. This changes the upper crustal structure with a LNB, which develops into the intermediate ridge crust with a low Re/i.