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Sulfide differentiation at the lower oceanic crust with high magma supply: fractional crystallization and melt-rock reaction (IODP Hole U1473A, Atlantis Bank)

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Magma evolution in the lower oceanic crust affects the metal contents in the derivative magmas and the formation of seafloor massive sulfides. At spreading segments with low magma supply, sulfide differentiate primarily by melt-mantle reaction, with subordinate role of fractional crystallization[1,2]. At spreading segments with high magma supply, differentiation mechanisms of sulfides are yet not well constrained.

The International Ocean Discovery Program Expedition 360 cored 810-m-long section of fully developed lower crust from Hole U1473A at the Atlantis Bank ocean core complex along the Southwest Indian Ridge (32˚42'S, 57˚17'E). We studied 101 samples spread throughout the hole to understand major mechanisms of sulfide differentiation at the lower crust accreted during high magma supply. Importantly, magmatic sulfides (pyrrhotite-chalcopyrite-pentlandite grains) occur in all the samples with hydrothermal pyrite in only two samples. Consequently, the mantle-derived isotopic signatures of δ^{34}S (-0.1 to +0.6‰ except for 1.5-4.8‰ in three samples and biogenic -24.9‰ in one sample), ^{87}Sr/^{86}Sr (0.70275-0.702796), and δ^{18}O (4.2-5.8‰) indicate scarce hydrothermal alteration.

The sulfides co-exist with oxides and apatites, and we observe correlations between the bulk-rock S, MnO, TiO_2, Fe_2O_3 and P_2O_5 contents. All of them and Mg-numbers show upward-decreasing trends within two large-scale gabbroic bodies at 60-300 and 300-750 mbsf. This indicates predominant role of fractional crystallization in sulfide differentiation. As sulfides and oxides fractionate early, they tend to accumulate at the lower portions of the gabbroic bodies enriched in Cu by ∼50% and in S by ∼100% with respect to the upper portions.

These large-scale trends related to fractional crystallization are locally disrupted by narrow zones enriched in Cu by 200-450%, where sulfide differentiation was driven by melt-rock reaction. There, sulfides were attracted by boundaries between chemically contrasting units of early-stage coarse-grained gabbro and late-stage fine-grained gabbro. Based on the Platinum Group Element analysis of inherent sulfides, the populations of sulfides in late fine-grained gabbro and the contact zone are similar to each other and differ from the coarse-grained gabbro. We conclude that sulfides of the contact zone are crystallized from the focused late-stage magma (represented by the fine-grained gabbro) flowing through crystal mush (represented by the coarse-grained gabbro) due to local chemical disequilibrium at their interface. The chemical disequilibrium might be driven by FeO loss followed by a decrease in sulfur concentration at sulfide saturation level of the late-stage melt in contact with the crystal mush. The enhanced precipitation of sulfide grains at layer boundaries affects metal budget of the lower oceanic crust, which is thus not fully controlled by fractional crystallization. We estimate that ∼11% of the Cu budget in the lower oceanic crust could accumulate at layer boundaries and be missed in global mass balances as those are rarely sampled.

1. Ciazela, J. *et al.* Thin crust and exposed mantle control sulfide differentiation in slow-spreading ridge magmas. *Geology* **45,** 935–938 (2017).

2. Ciazela, J. *et al.* Sulfide enrichment at an oceanic crust-mantle transition zone: Kane Megamullion (23˚N, MAR). *Geochim. Cosmochim. Acta* **230,** 155–189 (2018).