

Petrological and geochemical variations within an off-axial submarine large lava flow from the Oman Ophiolite

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Large submarine lava with thicknesses >100 m and volumes exceeding a few cubic kilometers are not uncommon volcanic constructs of mid-ocean ridges and around Hawaii Islands, yet details of the physical processes of eruption of these large lava flows are poorly understood. The V3 flow of the Oman ophiolite extruded at 90 Ma far off the paleospreading axis as thick lava flows with a minimum areal extent of >11 km by 1.5 km and the maximum thickness >270 m, yielding a minimum estimated volume >1.2 cubic kilometers. The V3 flow was fed by a thick feeder dike in the SW of the flow field and buried off-axial fault-bounded basins with a thick sedimentary cover in ~40 days. The upper V3 flow field consists of compound lobes that merge upstream into larger and thicker sheet-like lava, which grew endogenously as a vast sheet lobe.

Low-T hydrothermal alteration and weathering slightly modified the bulk compositions as indicated by moderate albitization of plagioclase and partial replacement of titanomagnetite and clinopyroxene by titanite and chlorite, respectively. However, strong positive correlations among incompatible HFSEs and REEs and relatively good correlations with major elements besides LILEs and Pb show that these elements were less mobile and preserve primary characteristics. FeO and TiO₂ show moderate increases with a decrease in MgO from 8 to 5 wt%, and then decreases with the decrease in MgO down to 4 wt%. 20-50 times enrichment in Th and depleted HREEs compared to primitive mantle of the V3 flow is similar to differentiated EMORBs.

Whole-rock major and trace element variations through a vertical transect at 8.7 km (T-21) from the feeder dike show fractional crystallization of clinopyroxene and plagioclase, the major phases in the groundmass of the lava, at a pressure of the paleowater depth. The stratigraphic variations show a notable enrichment in MgO and depletion in incompatible elements in the lowermost core, consistent with accumulation of olivine phenocrysts. Enrichment in incompatible elements in the uppermost core of the flow is in accordance with the model that the last solidified, residual melt resided in this horizon.

By contrast, samples collected from the basal crust every 0.5-1 km from the feeder dike, and vertical transects at 6.7 km (T-14) from the dike have whole-rock compositions spread over compositional spaces that could be explained by internal mixing of variably differentiated magmas. Interestingly, incompatible elements like Yb and Ti of the basal crust show increases downflow to ~5 km from the feeder dike and decreases further downflow. Because the basal crust is the quenched lava that came to rest first at that place, samples farther away from the feeder were extruded and emplaced later in the eruptive event. The downflow variations show extrusion of differentiated lava in the middle stage of the eruption and less differentiated lava in early and late stages. Meanwhile, the transect at T-14 is differentiated in the upper and lower crust and less differentiated in the core.

These intraflow variations in the bulk geochemistry indicate supply of less differentiated magma in an early stage of the eruption, which was progressively replaced by mixed magmas of variably differentiated and less differentiated ones toward the end of the eruption. The eruptive sequence of less differentiated to differentiated magmas with increasing FeO suggests extrusion from a density stratified magma chamber with less dense and Mg-rich magma underlain by more dense Fe-rich magma. The internal mixing among variably differentiated magmas with the progress of the eruption and the extrusion of less differentiated magma toward the end of the eruption suggest a renewal of magma toward the end of the eruption caused mixing of newly supplied less differentiated magma with the differentiated magma within the conduit and the lava tubes.

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