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Geochemical Characterization of Intermediate to Silicic Rocks in the Global Ophiolite Record

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1 Abstract

Ophiolites consist predominantly of mafic-ultramafic rocks but also contain in subordinate amounts intermediate to silicic intrusive – extrusive rocks in them. These rocks, although not in large volumes in comparison to mafic-ultramafic units, reveal significant clues about melt evolution, magmatic accretion processes, and partial melting of pre-existing oceanic crust during ophiolite evolution. They also yield ample accessory minerals, such as zircon and monazite, which are widely used to date the timing of oceanic crust generation. We present a global synthesis of the occurrence of such leucocratic, intrusive and volcanic rocks from 150 Phanerozoic to Archean ophiolites, and evaluate models for their genesis during the development of oceanic crust in different tectonic environments.

In the ophiolite complexes we have investigated, intrusive and extrusive rocks show a wide range in composition. Intermediate rocks (with SiO₂ between 52 and 63 wt.%) include andesite and diorite, whereas the silicic rocks (with SiO₂ more than 63 wt.%) include dacite, trondjemite, tonalite and granite. For subduction-related and subduction-unrelated MORB-type ophiolites in the Phanerozoic orogenic belts, the most commonly reported intermediate to silicic intrusive rocks, independent of their original tectonic setting, are trondjemite, plagiogranite and tonalite, and less commonly quartz-diorite and diorite. These rock types have been documented from 80 percent of the 104 ophiolites included in this study. Intermediate to silicic lavas and/or pyroclastic rocks (basaltic andesite, andesite, dacite and rhyolite) are less abundant, and have been reported from only 35 percent of the 104 ophiolites. Trachyte occurs in some of the Rift/Continental Margin

type, subduction-unrelated ophiolites

Evolved rocks in subduction-unrelated, Rift/Continental Margin ophiolites are predominantly basaltic andesite and andesite, whereas MOR type (mid-ocean ridge) ophiolites exhibit nearly equal proportions of basaltic andesite/andesite and rhyodacite and Plume/MOR type ophiolites are characterized by rhyolites. Intermediate to silicic volcanic units in the Backarc sub-group of subduction-related ophiolites are characterized by similar amounts of basaltic andesite/andesite and rhyodacite, whereas in the Backarc to Forearc, Forearc, and Volcanic Arc sub-groups they are mainly basaltic andesite/andesite. Intermediate to silicic rocks in Rift/Continental Margin and Plume/MOR type ophiolites are generally LREE-enriched, whereas those in the MOR type vary from LREE-depleted to LREE-enriched. The Backarc and Backarc to Forearc types are similar to the MOR type; silicic rocks of the Forearc and Volcanic Arc types are generally LREE-enriched. The main process in the formation of the majority of the intermediate to silicic rocks in both subduction-unrelated and subduction-related ophiolites is partial melting of basaltic and/or gabbroic rocks beneath the spreading centers, whereas a minor volume in subduction-related ophiolites are adakites that were produced from partial melting of a subducting slab. Silicic to intermediate rocks in Plume/MOR type ophiolites are generated by fractional crystallization of basaltic melt. The incompatible, non-conservative elements, such as Ba and Th, are weakly to strongly enriched in subduction-related ophiolites as a result of shallow to deep enrichment associated with subduction zone processes. The field occurrence and the geochemical character of leucocratic rocks in ophiolites show considerable variations, providing additional constraints on the petrogenesis of ophiolites in different tectonic settings.

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Fractional crystallization appears to have been an important process in the formation of the intermediate to silicic rocks in Rift/CM and P/MOR ophiolites in the subduction-unrelated class, as well as VA ophiolites in the subduction-related class. In these types of ophiolites magma chambers might have operated as closed-systems for a sufficient amount of time for fractionation and compositional zoning of the magma to take place (Fig. 1C1).

Fractional crystallization was of subordinate importance during the igneous construction of the MOR, BA, FA, and BA-FA ophiolites. Instead, partial melting of hydrothermally altered crust was the most common process resulting in the majority of the intermediate to felsic rocks of the Rift/CM (estimated to 60%), MOR (estimated to 95%), and the BA, FA and BA-FA

(estimated to 75%) ophiolites, as well as a high proportion of the VA ophiolites (~40%) (Fig. 1C2).

Slab-generated melts that result in the production of intermediate to silicic rocks of adakitic character represent a relatively small fraction (~15% in Phanerozoic ophiolites) of subduction-related ophiolites (Fig. 1C3). Some adakites are very low in incompatible elements (e.g., La), suggesting that these melts were generated from highly depleted MORB. Precambrian ophiolites contain a higher percentage of adakites (ca. 35%), indicating that physical conditions were more favorable for slab melting during the Precambrian than in the Phanerozoic. This phenomenon may have resulted from higher geothermal gradient along relatively shallow-dipping subduction zones during the Precambrian.

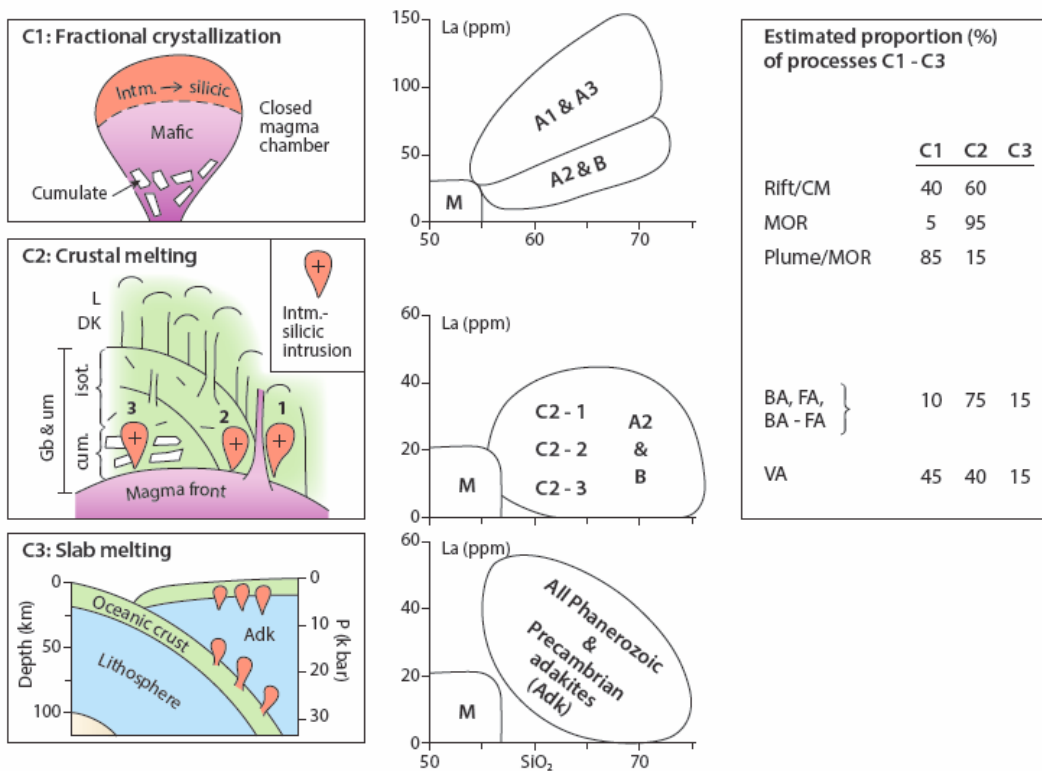


Fig. 1. Intermediate to Silicic Magma Generation Models in Ophiolites (after Furnes & Dilek 2017).