Oxides and silicates in gabbros tell two tales of the mid-Cayman Rise magma chamber

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The Mid-Cayman Rise (MCR) is a 110-km long spreading center in the Cayman Trough in the Caribbean. MCR glasses define major and trace element trends consistent with fractional crystallization of an olivine-plagioclase-clinopyroxene assemblage. They have low $^{87}Sr/^{86}Sr$ (0.70248–0.7260) and high $^{143}Nd/^{144}Nd$ (0.51311–0.51314). Major-element compositions of silicate minerals in MCR gabbros are compatible with their separation from mafic liquids to produce the glass trends (Elthon *et al.*, 1995). More detailed study of minerals in the gabbros has revealed that they did not form as series of primocrysts from a liquid evolving in a closed system. We present the results of chemical study of spinel grains from several gabbros and show that these grains record a different evolution than that suggested by the silicate phases.

Silicate geochemistry

The MCR gabbroic rocks contain olivine, clinopyroxene, and plagioclase. As a suite, olivine ranges from Fo_{87} to Fo_{73} and plagioclase from An_{77} to An_{50} and major-element compositions of silicate minerals show correlations consistent with evolution of the crystallizing liquid by fractional crystallization of those minerals (Elthon, 1987).

Minerals in an individual gabbro are unzoned in major elements at the precision of the electron microprobe. Although subsolidus diffusion can remove variations in major-element chemistry of olivine and pyroxene, Ca-Na variations in plagioclase are resistant to homogenization. The range of An content in many points in plagioclase grains in any given gabbro is #0.2%. Such small variations suggest that each gabbro formed from a reservoir of sufficient size that crystallization of gabbroic minerals did not cause measurable variations in the composition or temperature of the liquid.

REE patterns of clinopyroxene grains determined by both INAA and SIMS show increases in ΣREE as Mg# decreases and the small change in patterns expected from crystallization of a gabbroic assemblage. SIMS denotes no intra grain variation outside analytical error. Again, *REE* patterns of pyroxene grains and those of the glasses track as expected for a fractional crystallization origin. Finally, pyroxenes and glasses have Sr-Nd-Pb isotopic compositions that fall in the same (narrow) field.

Spinel geochemistry

Those gabbroic rocks containing olivine of Fo>83 contain Cr-Al-spinel. Spinel grains are generally small (10–50 μm) and widely distributed, occurring as inclusions in all three silicate minerals and on grain boundaries. Each spinel grain (or cluster of grains) has limited compositional range. Grains in a single gabbro have a much wider range of composition than expected based on the homogeneity of host silicate grains. Figure 1 shows compositions of spinel grains in five gabbros on a conventional Mg#-Cr# diagram. The most magnesian spinel in each rock has a composition that would be in equilibrium with coexisting olivine at ~ >1100°C. Mg# of spinel is readily reset by exchange with an olivine host. Mg# of many spinel grains in plagioclase are lowered from plausible magmatic values, suggesting extensive subsolidus communication, perhaps through a fluid phase. No obvious medium for Cr-Al exchange exists, however, and Cr# of spinel grains presumably reflect those of the crystallized grains. The higher Cr# of many spinel grains reflects their crystallization from a lower-temperature, more-evolved liquid than do the less chromian spinel grains.

Few spinel grains that compositions more primitive (more magnesian, less chromian) than those plausibly in equilibrium with coexisting olivine. The array of spinel compositions extends to some formed at lower temperatures and presumably from liquids with lower Mg# and higher Cr#. Variation in spinel compositions does not, therefore, reflect retention in the liquid of spinel grains formed at higher temperatures. The range defined by the spinel grains in a single gabbro are more consistent with

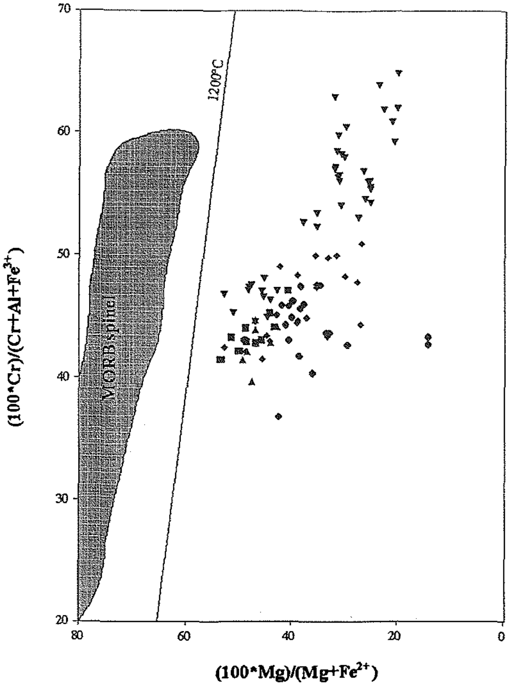

FIG. 1. Variation of Cr# (ordinate) and Mg# (abscissa) of spinel grains from five MCR gabbros. 739-2-2 (squares) contains $Fo_{87.3}$; 739-4-4 (triangles point up) has $Fo_{87.2}$; 623-3-2 (diamonds) has $Fo_{86.6}$; 622-1-1 (triangles point down) $Fo_{86.1}$; 623-1-1 (circles) $Fo_{85.5}$.

crystallization of those spinel grains from liquids that vary to lower temperatures. The simplest interpretation of this compositional range is that spinel grains crystallized from a magma chamber with a thermal gradient. Small dense spinel grains formed from a magma column of greater vertical extent than that which speeded the silicate minerals. Chemical variations in spinel grains within a single gabbro may, therefore, yield information about the chemistry of magmas that simultaneously crystallized over a temperature range.

Most MCR spinel analyses show measurable TiO_2 despite their dominant contents of $(Mg,Fe)(Al,Cr)_2O_4$. Ti is highly incompatible at this level of evolution of the mafic liquid and shows a progressive increase in content in spinel as Cr# increases. Ti content of spinel is not likely to be changed by subsolidus processes so we use Ti contents as a measure of the evolutionary stage of the crystallizing liquid.

Figure 2 shows Ti, Fe^{3+} and Cr+Al contents of spinel in five MCR gabbros. Ti contents in spinel grains from one gabbro typically have a range of

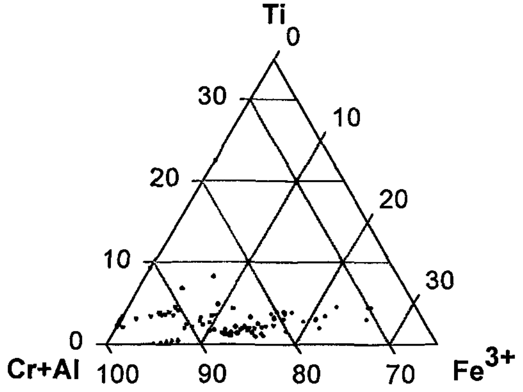

FIG. 2. Compositions of same spinel grains as shown in Fig. 1 expressed in terms of site occupancy. This is the very (Cr+Al)-rich corner of the ternary diagram. All grains have ⩾70% (Cr+Al) occupancy.

<~50%, suggesting a variable degree of evolution of the crystallizing liquids. The crystallization intervals inferred are greater than suggested by the chemistry of the host silicate minerals but compatible with variations in Cr#.

The ferric iron contents of some spinel grains are much greater than explicable solely by crystallization-enrichment of the incompatible Fe^{3+} in the liquid. The ferric iron content is not measured directly. Attention must be paid to the errors endemic in determining Fe^{3+} contents based on an assumption of a charge-balanced molecule of M_3O_4-stoichiometry but the variation in Fe^{3+} is too great to be an artifact of calculation (Fig. 2).

A spinel with high (Cr+Al) tends to have low Fe^{3+}/Ti but this value increases as (Cr+Al) falls. Spinel grains with high Fe^{3+} show few signs of oxidation in reflected light. On the other hand, 622-1-1 contains spinel grains with very low Fe^{3+} contents and very high Cr#. These spinel grains are associated with secondary iron sulphide and do appear to have been altered in the subsolidus. The Fe^{3+} in these grains appears to have been reduced by sulphur-bearing fluids.

The variation in ferric iron contents in spinel grains might represent subsolidus oxidation of the grains or a marked change in the partition coefficient of Fe3+ between liquid and spinel as crystallization continued. Alternatively, it may reflect a true change in the oxidation state of Fe in the liquid, presumably reflecting incorporation of oxidized material (e.g. altered oceanic crust). This possibility is being investigated by analysis of spinel grains for trace amounts of transition metals.