Ferrodiorites from the Mid-Cayman Rise

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Introduction

The Cayman Trough in the Caribbean is a very small ocean basin (1000 km x 110 km) that is surrounded by older terranes, some of which are continental (Case et al., 1990). The spreading rate at the Mid-Cayman Rise is extremely slow (possibly 1.2 cm a⁻¹ for the last 5.5 Ma — Rosencrantz et al., 1988). Magmas contributing to the basalts that form the Cayman Trough potentially formed from several sources, including non-asthenospheric ones. This region, therefore, provides an ideal area to investigate the processes that occur in magma chambers beneath ocean ridges as the magmas here potentially have the greatest ranges in isotopic ratios and trace-element patterns.

Basaltic Glasses and Gabbros

Glasses dredged from near the Mid-Cayman Rise (MCR) in the Cayman Trough formed from some of the most Na-rich MORB liquids. The more magnesian glasses are also relatively enriched in LREE—CeN/LaN≈1.3 although La is depleted (see figure). Major-element evolution of the glasses is well-modelled by separation of olivine, plagioclase, and augitic clinopyroxene from the parental liquid. Incompatible trace elements show enrichments in derived liquids consistent with ~50% fractional crystallization from the parental liquid—a value totally consistent with major-element modelling. The least magnesian glasses have CeN/LaN≈1.6. The glasses have a very limited range in Sr-Nd-Pb isotopic compositions. Twelve samples have ⁸⁷Sr/⁸⁶Sr=0.70248–0.70260 and ¹⁴³Nd/¹⁴⁴Nd = 0.51311–0.51314 (εNd = 9.3–9.8). They lie along the Northern Hemisphere Reference Line (NHRL) on a ²⁰⁸Pb/²⁰⁴Pb diagram and near (but at a high angle to) the NHRL on a ²⁰⁷Pb/²⁰⁴Pb diagram.

Coarse-grained gabbroic to dioritic rocks are exposed in the axial valley of the MCR. Olivine, plagioclase, and augitic clinopyroxene have major-element compositions that are consistent with their having crystallized from liquids similar to the MCR glasses (Elthon, 1987). REE patterns and contents of acid-leached clinopyroxene separates are also similar to those expected if this mineral formed from liquids compositionally-identical to the glasses. Nd and Pb isotopic compositions of acid-cleaned clinopyroxenes are also identical to those of the glasses, suggesting consanguinity. Displacement of ⁸⁷Sr/⁸⁶Sr of some clinopyroxenes to higher values than in the glasses plausibly results from interaction with seawater-derived hydrothermal fluids.

Detailed studies of the gabbroic rocks reveal the presence of another component in these rocks. Pb and Nd isotopic compositions of ten of twelve acid-leached plagioclase separates differ from those of the clinopyroxenes (and glasses). Values of εNd in plagioclase are as low as +4.0. Coexisting clinopyroxene and plagioclase have ¹⁴³Nd/¹⁴⁴Nd that differ by as much as 0.00012 (2.3 εNd units). Ten plagioclase separates also define distinct trends on Pb isotopic ratios. They have higher ²⁰⁶Pb/²⁰⁴Pb than the glasses but also have higher ²⁰⁷Pb/²⁰⁴Pb at a given ²⁰⁶Pb/²⁰⁴Pb than the Northern Hemisphere Reference Line (NHRL). Values of Delta-7/4 are 5-16. ²⁰⁶Pb/²⁰⁴Pb, ²⁰⁸Pb/²⁰⁴Pb data scatter about the NHRL, however. The contaminant was derived from a source with a Th/U near that of the mantle but had had an elevated U/Pb earlier in its history. Acid leachates from minerals have Pb isotopic compositions that lie along the trends defined by the plagioclase separates. They also have very low εNd - in some cases < 0.

Some gabbroic rocks also have trace-element contents inconsistent with their petrographic interpretation as adcumulates. Many samples have trace-element contents that suggest 10-40% liquid is trapped in these rocks (if the trapped liquid were similar to the MCR glasses). There is little evidence in these cumulates for the presence of that much liquid insofar as the cumulate minerals are unzoned in major elements and there is little or no intercumulate material. One sample has very high contents of Zr (470 ppm) and Hf (16 ppm), and modal zircon, although it is one of the most primitive cumulates (An71, Foss). These Hf and Zr contents exceed those in the glasses and the cumulate has REE contents similar to those in the glasses, suggesting that the liquid trapped in the cumulate was much more enriched in these elements than are the glasses.
Ferrodiorites

The liquid that apparently affected the gabbroic cumulates may also have been involved in the formation of the small number of ferrodiorites collected from this ridge. These rocks contain little or no olivine and are dominated by plagioclase and clinopyroxene. They also contain orthopyroxene, iron-titanium oxide, and apatite. Plagioclase contains 30–40% An and 0.1–0.2% K_2O, and clinopyroxenes have Mg# of 60–70 (Elthon, 1987).

We have begun a detailed study of the minerals that comprise these ferrodiorites. Apparently, the minerals crystallized from a LREE-enriched liquid. A hypersthene separate from one sample has LaN≈0.9, SmN≈2, LuN≈7. This suggests that the crystallizing liquid had ≈130 × chondrite La; ≈35–40 × HREE (see figure). The pattern is almost straight from Sm to Lu with a slightly flatter LREE pattern. There is apparently a significant negative Eu-anomaly.

The location of enriched material in the minerals is of critical importance to this study. If the mineral is uniformly enriched in LREE, the ferrodiorite plausibly crystallized totally from an enriched liquid. Alternatively, the minerals may have cores with relatively low contents of incompatible elements and rims enriched in such elements. This would result if the ferrodiorites formed from two liquids - the first a derivative of the MCR glasses; the second an enriched late-stage liquid.

Major- and trace-element contents in the hypersthene are homogeneous. Seven point analyses of one 500 μm by 200 μm hypersthene grain show that it has Mg# of 71.7±0.5 (1σ). The range in the content of V across that grain is 440±17 ppm, of Sc 48±5 ppm, of TiO_2 0.28±0.04%, etc.

Hypersthene and augite in the ferrodiorite are only slightly more magnesian than those that would have crystallized from the more evolved MCR glasses shown in the figure. The liquid that formed them was, however, enriched in LREE by a factor of ≈4 over the most evolved of those liquids. The presence of zircon and apatite in the ferrodiorites also attest to the enriched nature of the liquid that formed these rocks. The orthopyroxene could not have crystallized from liquids derived from ones like the MCR glasses. The liquid that formed these two-pyroxene diorites was not alkalic but was highly enriched in incompatible trace-elements.

References

