

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 × 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*— $Ce_N/La_N \approx 1.3$ 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 $\approx 50\%$ fractional crystallization from the parental liquid — a value totally consistent with major-element modelling. The least magnesian glasses have $Ce_N/La_N \approx 1.6$. The glasses have a very limited range in Sr-Nd-Pb isotopic compositions. Twelve samples have $^{87}Sr/^{86}Sr = 0.70248-0.70260$ and $^{143}Nd/^{144}Nd = 0.51311-0.51314$ ($\epsilon_{Nd} = 9.3-9.8$). They lie along the Northern Hemisphere Reference Line (NHRL) on a $^{208}Pb/^{204}Pb$ - $^{206}Pb/^{204}Pb$ diagram and near (but at a high angle to) the NHRL on a $^{207}Pb/^{204}Pb$ - $^{206}Pb/^{204}Pb$ 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 $^{87}Sr/^{86}Sr$ 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 ϵ_{Nd} in plagioclase are as low as +4.0. Coexisting clinopyroxene and plagioclase have $^{143}Nd/^{144}Nd$ that differ by as much as 0.00012 (2.3 ϵ_{Nd} units). Ten plagioclase separates also define distinct trends on Pb isotopic ratios. They have higher $^{206}Pb/^{204}Pb$ than the glasses but also have higher $^{207}Pb/^{204}Pb$ at a given $^{206}Pb/^{204}Pb$ than the Northern Hemisphere Reference Line (NHRL). Values of Delta-7/4 are 5–16. $^{206}Pb/^{204}Pb$ - $^{208}Pb/^{204}Pb$ 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 ϵ_{Nd} — 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, Fo₈₅). 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.

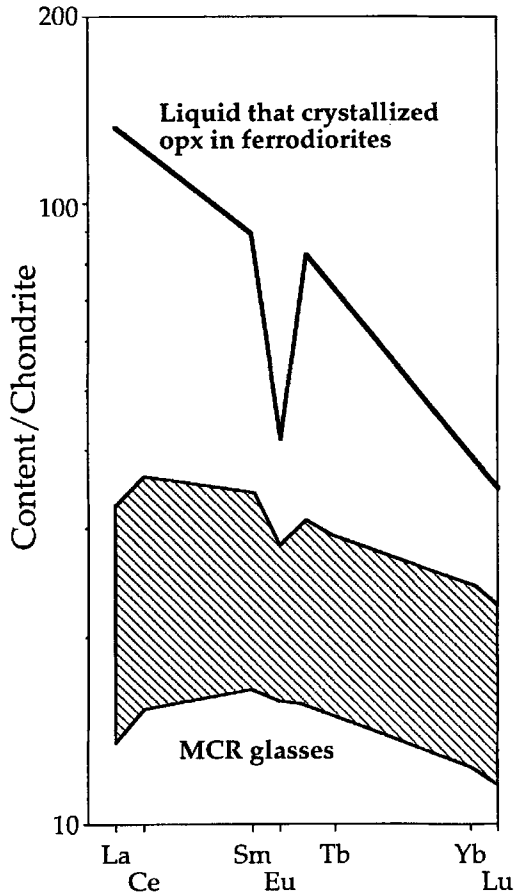


FIG. 1. Chondrite-normalized REE patterns for MCR glasses that have MgO = 7.7 to 5.3%. REE abundances and LREE:HREE increase as MgO falls. The broad line shows the REE pattern calculated to have crystallized hypersthene in a ferrodiorite from the MCR. It has $\sim 4 \times$ the LREE of even the most evolved glasses, but crystallized from a liquid with only slightly lower Mg# than those 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% K₂O, 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 $La_N \approx 0.9$, $Sm_N \approx 2$, $Lu_N \approx 7$. This suggests that the crystallizing liquid had $\approx 130 \times$ chondrite La; $\approx 35\text{--}40 \times$ 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 μ m by 200 μ m 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 TiO₂ $0.28 \pm 0.04\%$, 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

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