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Using clinopyroxene mineral chemistry to decipher magma composition changes in the Izu-Bonin volcanic arc

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Introduction

International Ocean Drilling Program (IODP) Expedition 350 drilled into the relatively unexplored rear arc of the Izu-Bonin-Mariana system (see map). It recovered 2000 meters of volcanic rock core in the spring of 2014. The core has been divided into seven lithostatigraphic units, from age 0 at the top to at least 13 million years at the bottom. 1 analyzed the major and trace element geochemistry of representative clinopyroxene and glass (in Unit I) and just clinopyroxene (in all other units) in volcaniclastic rocks throughout the core from top to bottom and used them as a proxy for interpreting magma compositional changes through time, which is connected to the development of medium-K2O, light-REE-enriched continental crust (as compared to low-K2O, light-REE-depleted oceanic crust).

Methods

Minerals were analyzed for major elements (by electron microprobe at the University of Washington and Washington State University) and trace elements (by Laser Ablation Inductively Coupled Plasma Mass Spectrometer, LA-ICP-MS at WU). Four samples from Unit I and two samples each from Units IV, VI, and VII were analyzed (see image of core to the left). In Unit I, unaltered glass and clinopyroxene were found together. The glass and associated clinopyroxene were used to develop partition coefficients. In deeper units, the glass has been altered, rendering the original composition of the magma unidentifiable. By applying the partition coefficients I developed, a range of possible magma compositions were identified and grouped into low or medium-K. All REE diagrams are chondrite-normalized diagrams.

Calculating $K_a$ and Liquid Composition

As a magma chamber develops, minerals begin to form. Trace element concentrations are not high enough to form their own minerals, but they are incorporated into the structure of minerals such as clinopyroxene (cpx), replacing in small quantities some major elements. Because trace elements behave according to Henry’s Law, the ratio between the amount of a trace element in a clinopyroxene grain compared to the amount remaining in the liquid is called a partition coefficient ($K_a$). Glass cores so rapidly that crystals have no time to form, so glass is a snapshot of the magma chamber. Therefore, where $i$ is the concentration of the element, $K_{a(i)}$ is the partition coefficient between the liquid (magma) and the solid (clinopyroxene) for a particular element. The graph to the right displays the partition coefficients for the Rare Earth Elements, calculated using the Unit I samples above. Individual glass shards and cpx crystals were paired using K$_2$O and MgO weight percent.

For the deeper units where glass was altered, the range of $K_a$ was used to calculate a range of possible magma compositions based on the concentrations of trace elements in the unaltered clinopyroxene. The result is a split in liquid compositions. The graphs below show the liquid composition calculated using $K_a$ appropriate for that clinopyroxene. I applied the $K_a$ from the high-Sm/La cpx from Unit I to the high-Sm/La cpx in deeper units, and I applied the $K_a$ from the low-Sm/La cpx from Unit I to the low-Sm/La cpx in deeper units.

Conclusions

• Clinopyroxene in Unit I that belongs to low-K (oceanic) glasses with flat liquid REE patterns have high cpx Sm/La ratios, whereas clinopyroxene in Unit I that belongs to medium-K (continental) glasses with steep liquid REE patterns have low cpx Sm/La ratios. Thus, Sm/La ratios in clinopyroxene deeper in the core can be used as a proxy for the K-content of their parental magmas.

• potassium (K) concentration is a key indicator of continental crust. The deepest sections of the core (Units VI and VII) tend to have clinopyroxene that indicate low-K (oceanic) parental magmas, whereas higher sections of the core (above Unit VI) have clinopyroxene that indicate dominantly Medium-K (continental) parental magmas (see exception below).

• A consistent negative Eu anomaly appears in clinopyroxene from the low-K units in Units VI and VII. Plagioclase must have crystallized before clinopyroxene in these samples, because Eu$^6^{2+}$ is unstable in plagioclase. This crystallization order is typical of low-H$_2$O magmas. In contrast, medium-K magmas typically have higher H$_2$O contents, and plagioclase crystallization is suppressed. This is supported by the lack of Eu anomaly in the cpx in the medium-K intervals in Units IV.

• Unit VII Interval E72RS 694 is an exception to these conclusions: it has a low Sm/La ratio like a medium-K unit, but also has a (minor) Eu anomaly. We hypothesize this may be a transitional interval, but further investigation is required.

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Citations


Observations from cpx deeper in the core: high Sm/La yields calculated liquids with flat light-REE patterns (low-K), whereas low Sm/La cpx yields calculated liquids with steep REE patterns (medium-K)

Interval B17F2W 108/109 is a Low-K interval. Coexisting cpx has (Sm/La)$_{Cpx}$ > 5. Partition coefficients (see below) were calculated for this interval but were excluded in later analyses because the cpx was more Mg-poor than the cpx from the deeper units. Glass from this interval is also much more felsic than from other intervals.

Interval B21F2 5/7 is a Medium-K interval. Coexisting cpx has (Sm/La)$_{Cpx}$ > 5.

Interval B32X1 83/84 is a Low-K interval. Coexisting cpx has (Sm/La)$_{Cpx}$ > 5.

Interval D8HRW 68/69 is a mixed interval. All analyzed cpx has (Sm/La)$_{Cpx}$ < 5 (Medium K). Some analyzed glass was Low-K and some was Medium-K. Unfortunately only the Low-K glass was able to be analyzed via LA-ICP-MS.