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Using clinopyroxene mineral chemistry to decipher magma composition changes over 13 million years in the Izu-Bonin volcanic arc

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

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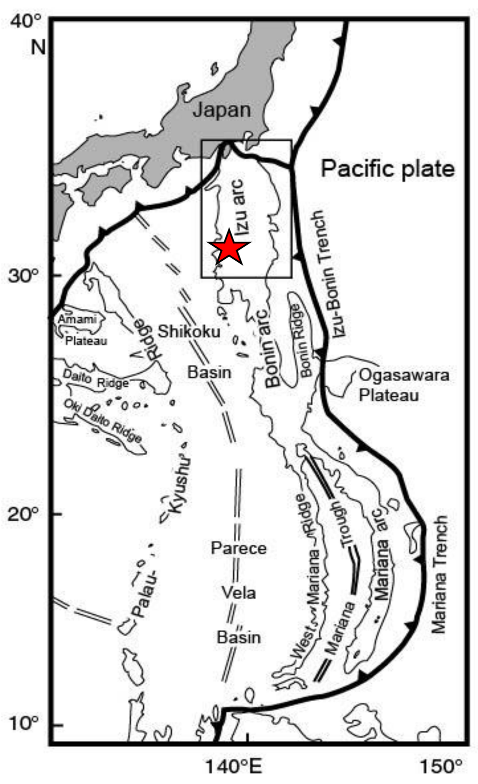
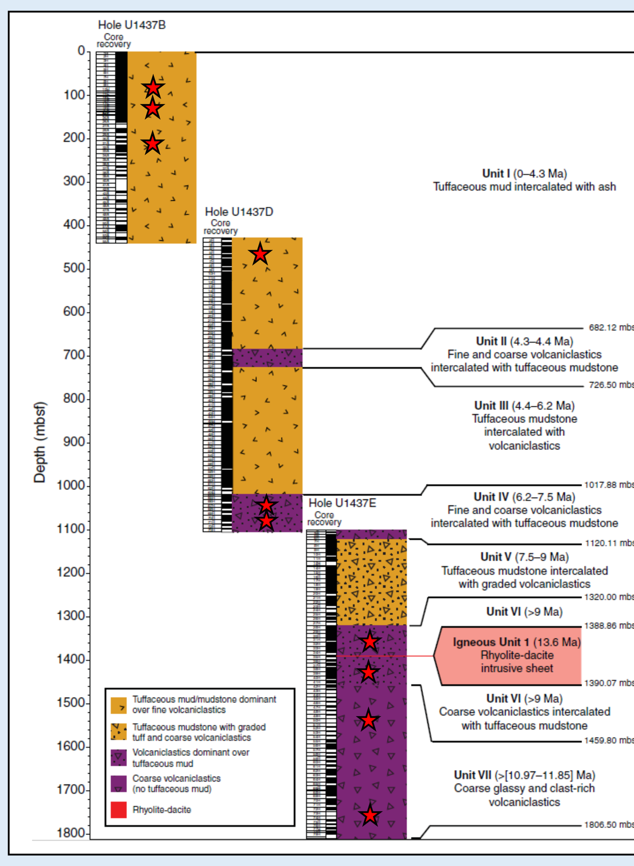
Introduction

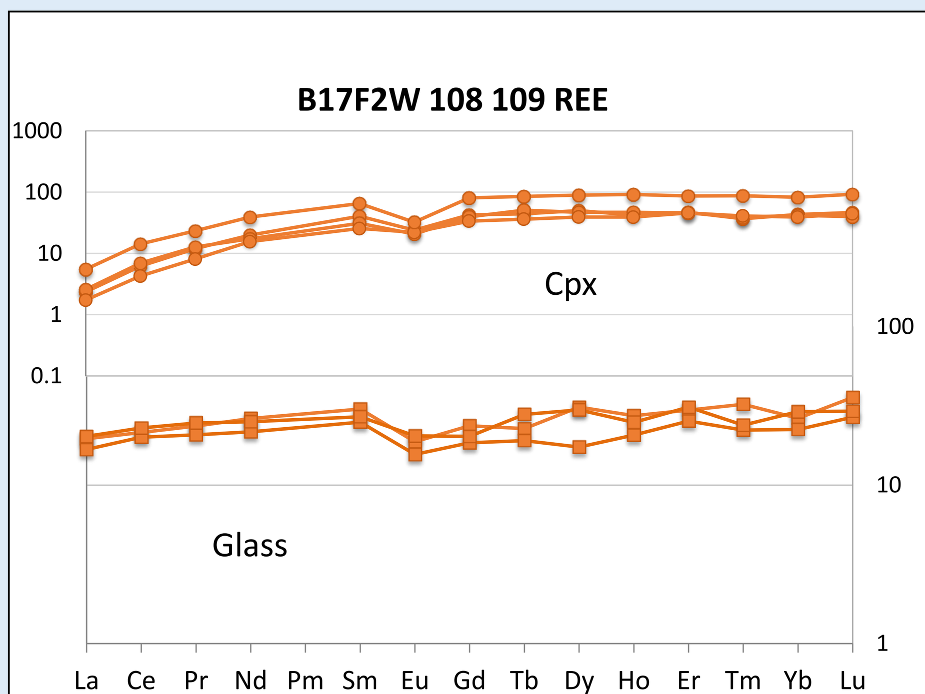
International Ocean Drilling Program (IODP) Expedition 350 drilled into the relatively unexplored rear arc of the Izu-Bonin-Mariana system (see map). It recovered 2000 meters of volcanic rock core in the spring of 2014. The core has been divided into seven lithostratigraphic units, from age 0 at the top to at least 13 million years at the bottom. I 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).



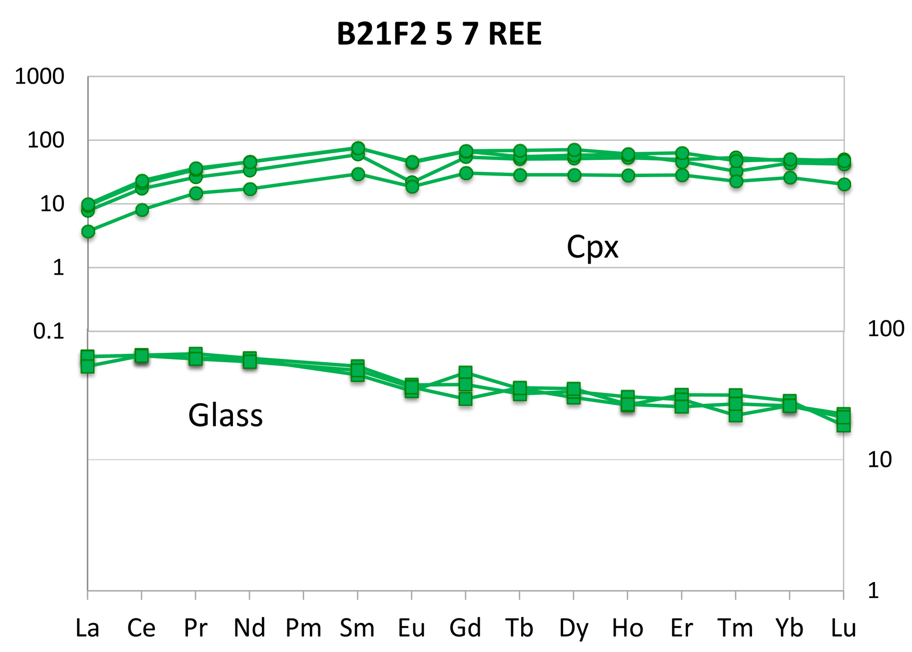
Methods



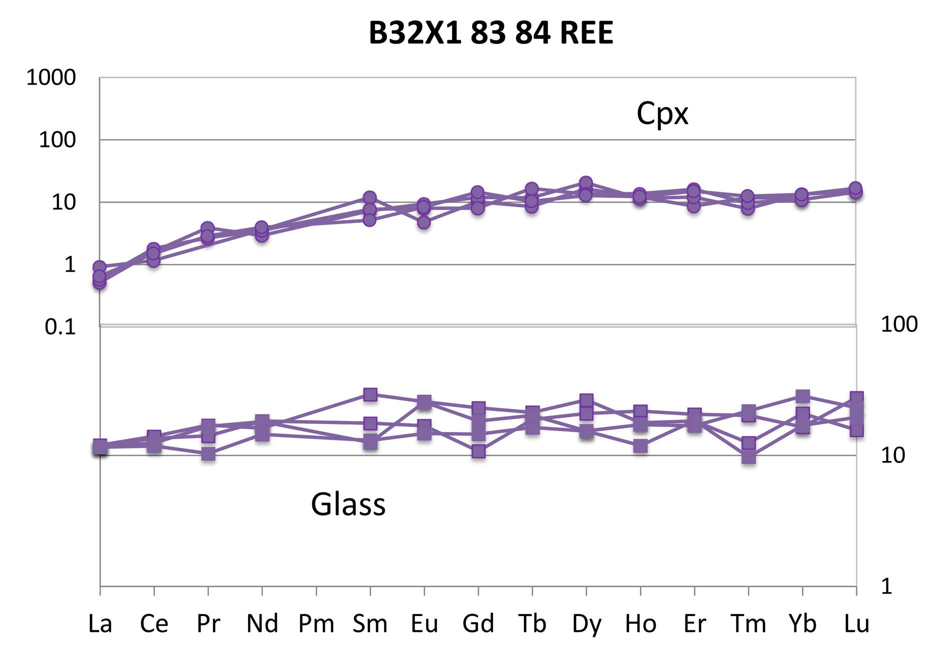
Minerals were analyzed for major elements (by electron microprobe at the University of Washington and Washington State University) and trace elements (by Laser Ablation Inductively Coupled Plasma Mass Spectrometer, LA-ICP-MS at WWU). Four samples from Unit I and two samples each from Units IV, VI, and 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.



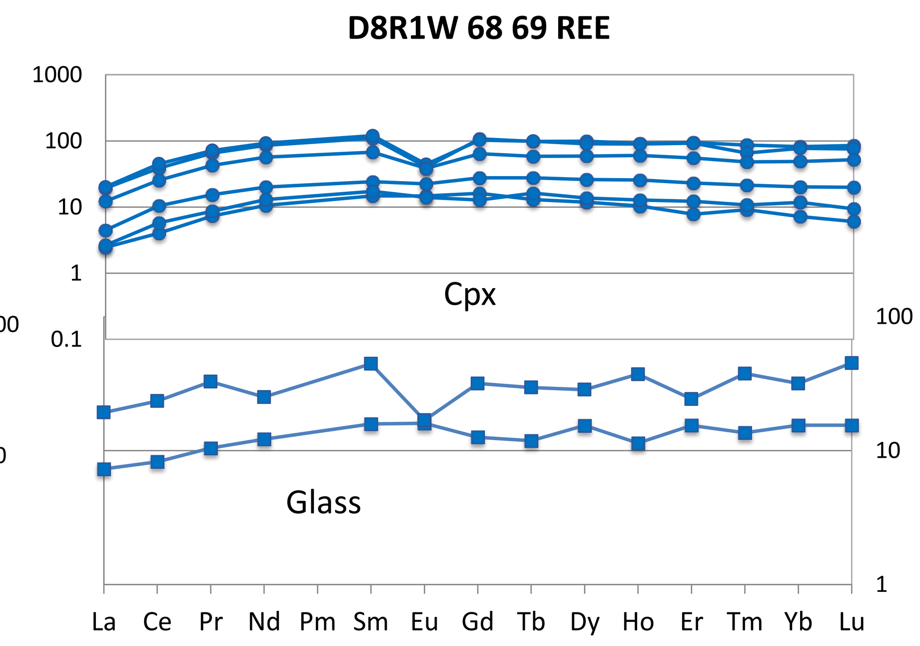
Interval B17F2W 108/109 is a Low-K interval. Coexisting cpx has $(Sm/La)_N > 5$. Partition coefficients (see below) were calculated for this interval but were excluded in later analyses because the cpx was more Mg-poor than the cpx from the deeper units. Glass from this interval is also much more felsic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



Interval B21F2 5/7 is a Medium-K interval. Coexisting cpx has $(Sm/La)_N < 5$.



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

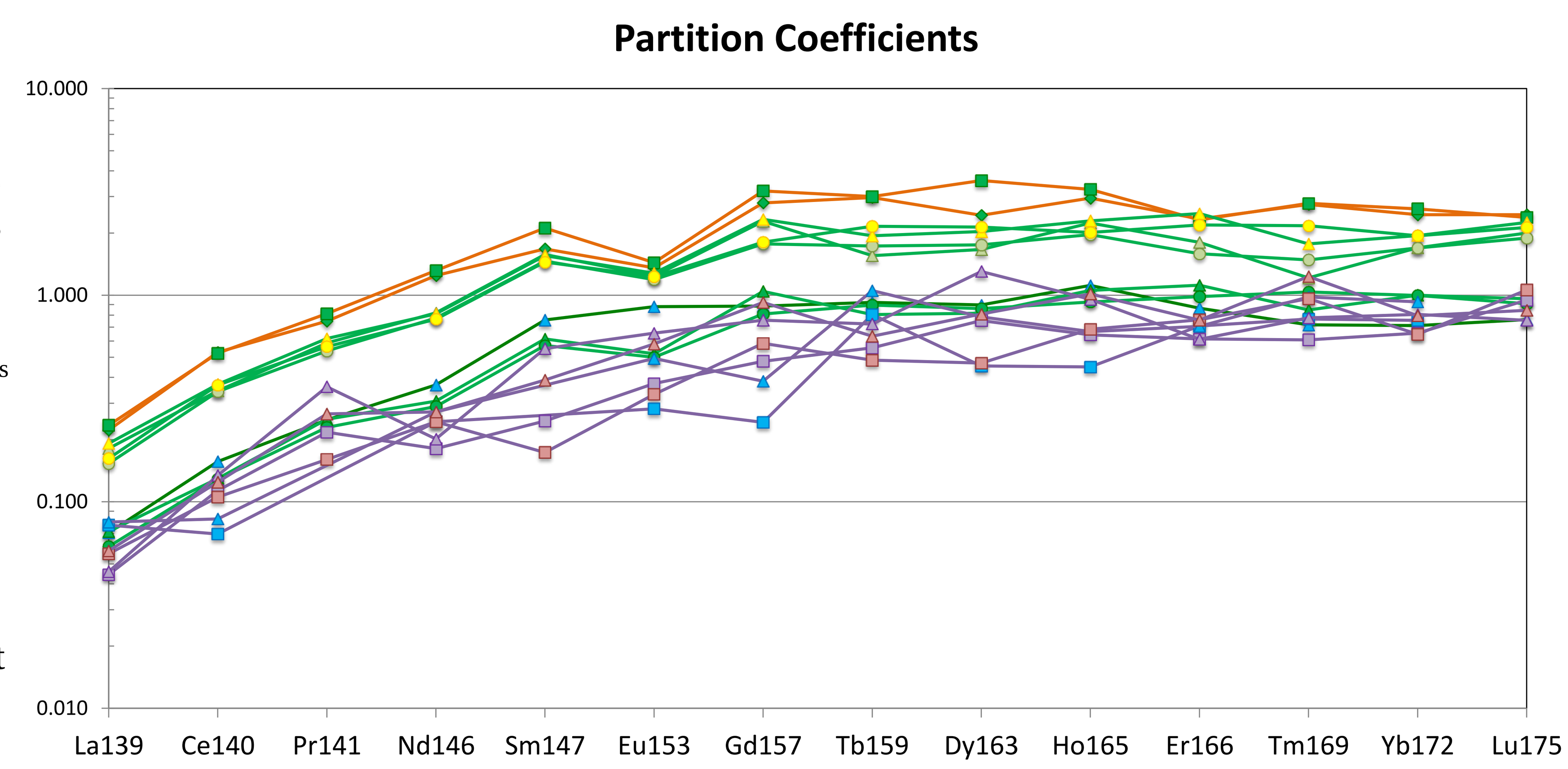


Interval D8R1W 68/69 is a mixed interval. All analyzed cpx has $(Sm/La)_N < 5$ (Medium K). Some analyzed glass was Low-K and some was Medium-K. Unfortunately only the Low-K glass was able to be analyzed via LA-ICP-MS.

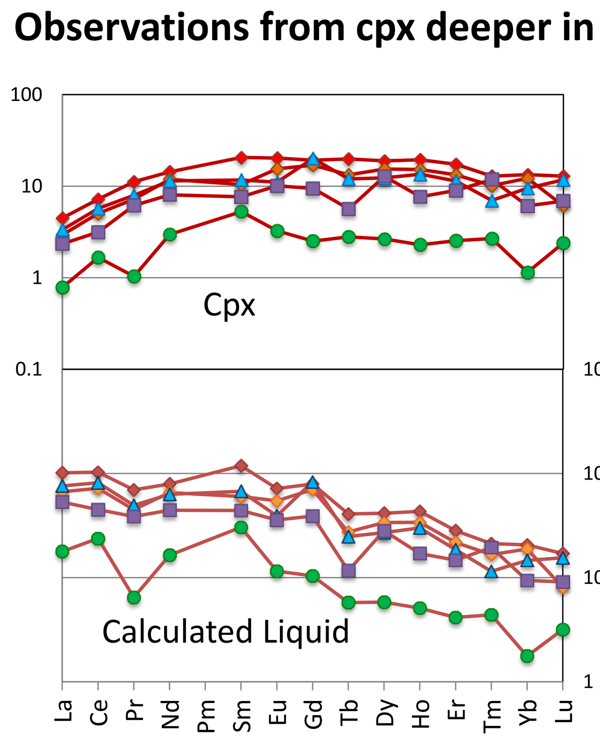
Calculating K_d and Liquid Composition

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_d). Glass cools 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, $K_d = i_{cpx}/i_{glass}$ 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_2O and MgO weight percent.

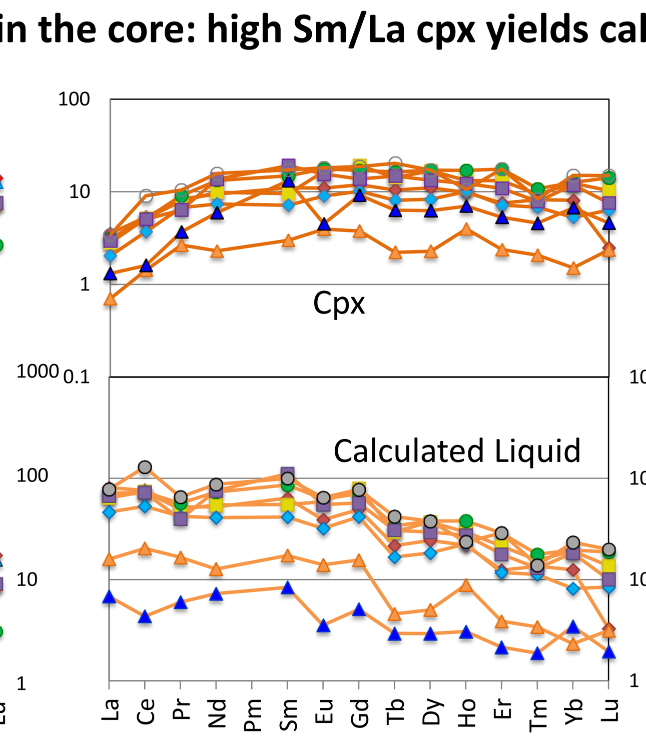
For the deeper units where glass was altered, the range of K_ds was used to calculate a range of possible magma compositions based on the concentrations of trace elements in the unaltered clinopyroxene. The result is a split in liquid compositions. The graphs below show the liquid composition calculated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



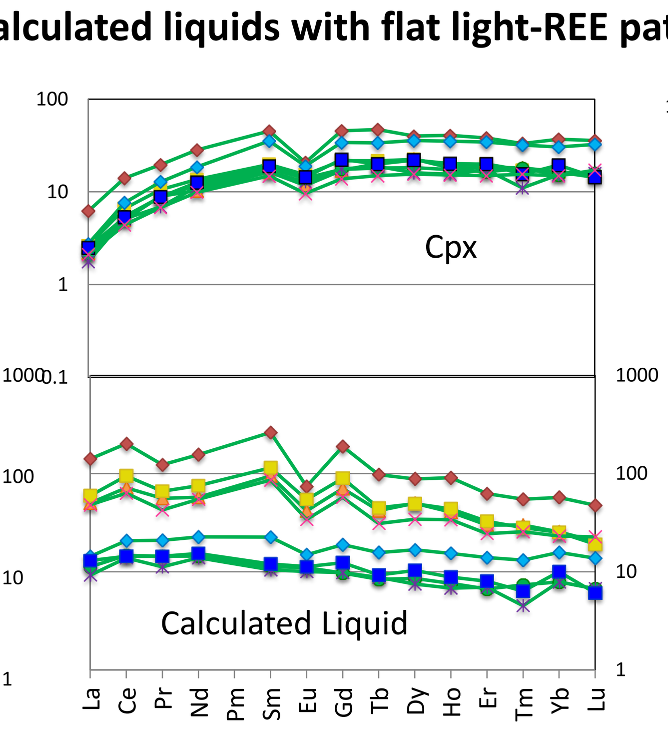
Observations from cpx deeper in the core: high Sm/La cpx yields calculated liquids with flat light-REE patterns (low-K), whereas low Sm/La cpx yields calculated liquids with steep REE patterns (medium-K)



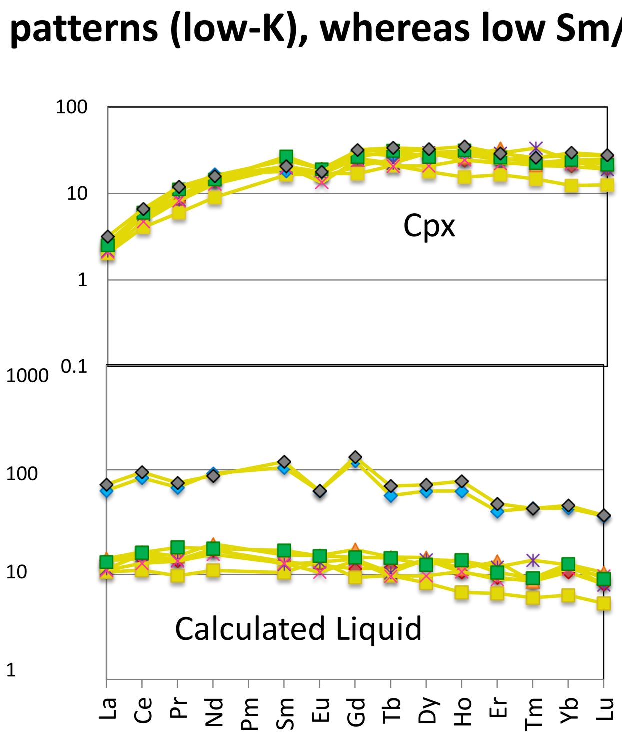
D70R5 50/53: Low Sm/La cpx (2.7 average); steep liquid REE pattern; Med-K



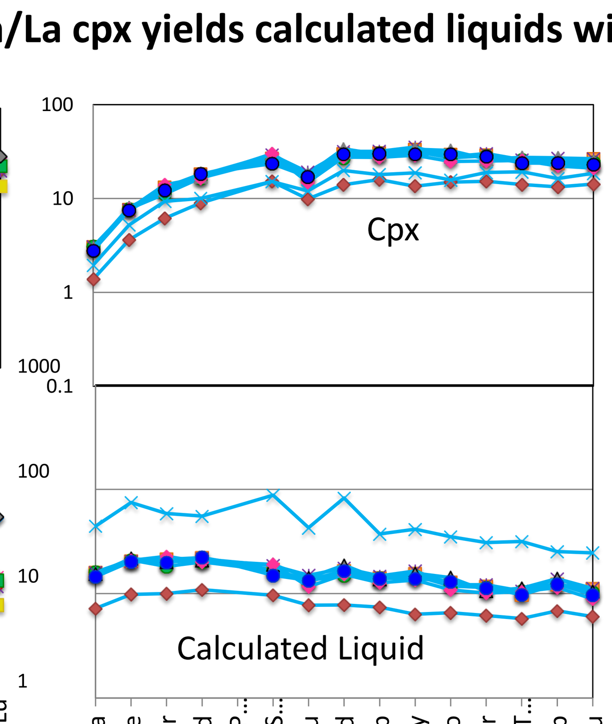
D71R1 7/9: Low Sm/La cpx (2.72 average); steep liquid REE pattern (except for one cpx); Med-K



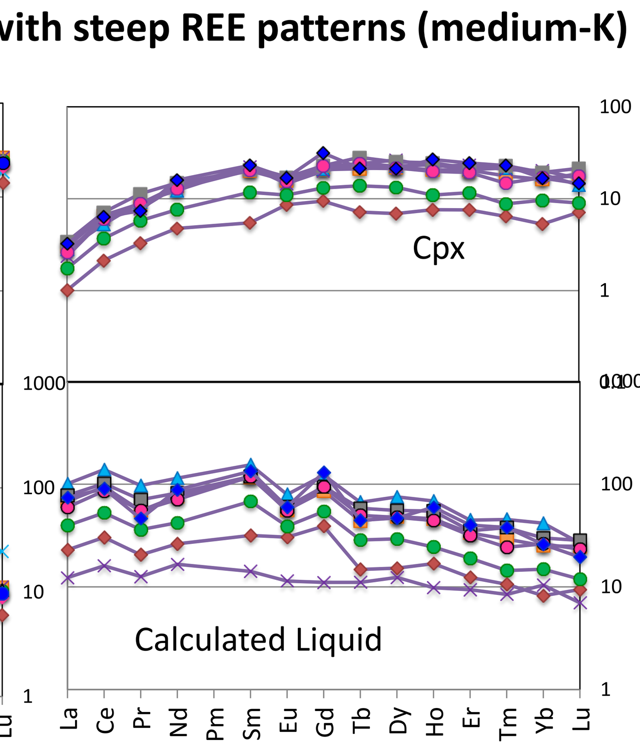
E41R2 6/8: both low and high Sm/La cpx (average 4.5 and 6.3) and both steep and flat liquid REE patterns; mixed K



E41R2 21/24: High Sm/La cpx (5.64 average); flat liquid REE pattern; Low-K



E59R1 62/64: High Sm/La cpx (5.97 average); flat liquid REE pattern (except one cpx); Low-K



E72R5 0/4: Average Sm/La ratio of 4.25. This sample may be transitional between Low and Med-K

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^{2+} is compatible in plagioclase. This crystallization order is typical of low-H_2O magmas. In contrast, medium-K magmas typically have higher H_2O contents, and plagioclase crystallization is suppressed. This is supported by the lack of Eu anomaly in the cpx in the medium-K intervals in Unit IV.
- Unit VII Interval E72R5 0/4 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.

Acknowledgements

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Citations

Tamura, Y., Busby, C.J., Blum, P., and the Expedition 350 Scientists, 2015. *Proceedings of the International Ocean Discovery Program, Expedition 350: Izu-Bonin-Mariana Rear Arc:* College Station, TX (International Ocean Discovery Program)