Critical Elements in the Magnet Cove Carbonatite

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Geol 393

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Introduction

As defined by the National Research Council, a critical element is a "nonfuel [element] that is essential for use and faces considerable supply chain vulnerabilities" (Rowan, 2022). Critical elements are needed for growing technological demand. Carbonatites are rare igneous rocks that are more than 50% carbonates. Due to the extreme differentiation that forms them, they often have highly elevated concentrations of rare earth elements (REEs). There are ~550 locations worldwide where they occur; most of which have small, exposed surface area (a few square kilometers). The Magnet Cove Complex (MCC) is a series of small igneous intrusions located in the Ouachita Mountains in central Arkansas (Figure 1) composed of 5 distinct zones, with a carbonatite core (Figure 2).

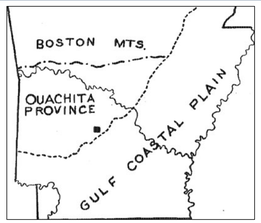
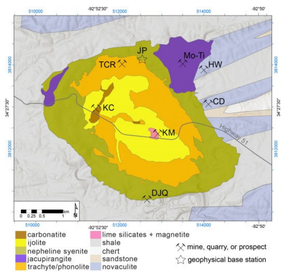


Figure 1: General map of Arkansas (above), with location of Magnet Cove marked (Landes, 1931)

Figure 2: Geologic Map of Magnet Cove (below) from Amaral et al., 2024.



Hypotheses

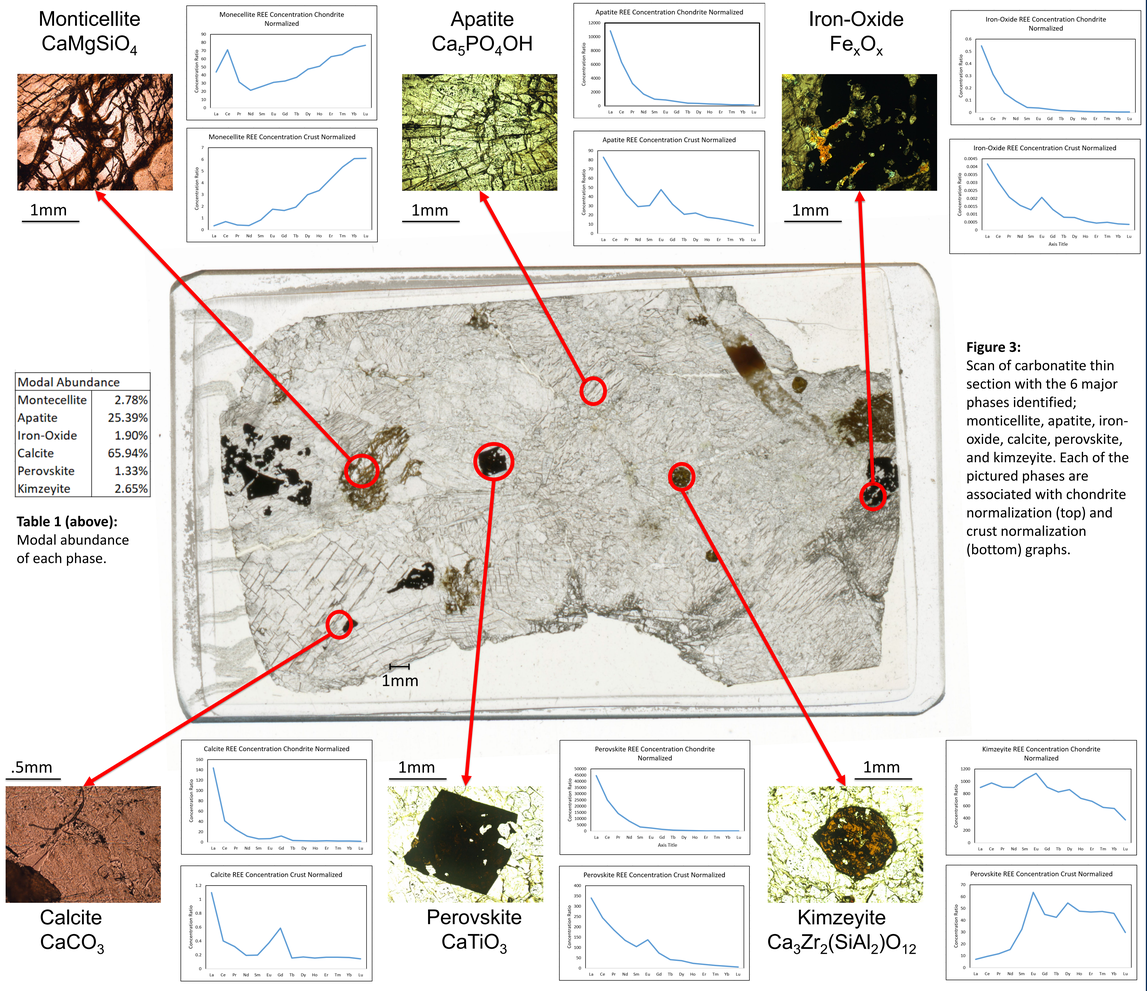
Null: Apatite, as the primary accessory phase in many carbonatites, is the major host of REE and other critical elements in the Magnet Cove carbonatite.

Alternative: Apatite is not the primary host of REE and critical elements in the Magnet Cove carbonatite.

Methods

- Petrography: Identify major phases through habit, birefringence, and opacity.
- EPMA: Obtain major element concentrations for internal standards of LA-ICP-MS data and confirm identified phases in petrographic analysis.
- LA-ICP-MS: Obtain trace element concentration of select, potentially significant elements.
- Normalization: Trace element concentrations normalized to chondrites (McDonough & Sun, 1995) and crust (Rudnick & Gao, 2003). Chondrite normalization allows for better comparison to literature. Crustal normalization for easier analysis and understanding the significance of the concentrations of each phase.

Results



Modal Abundance	
Montecellite	2.78%
Apatite	25.39%
Iron-Oxide	1.90%
Calcite	65.94%
Perovskite	1.33%
Kimzeyite	2.65%

Table 1 (above): Modal abundance of each phase.

Figure 3: Scan of carbonatite thin section with the 6 major phases identified; monticellite, apatite, iron-oxide, calcite, perovskite, and kimzeyite. Each of the pictured phases are associated with chondrite normalization (top) and crust normalization (bottom) graphs.

Phase Contribution to the Rock	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
Apatite [3 analyses]	2758.1	1608.9	822.3	436.3	245.7	215.4	161.8	102.8	89.8	68.7	59.1	43.0	35.3	27.3
Perovskite [3 analyses]	592.5	333.4	189.6	106.0	44.0	32.4	19.7	10.7	7.6	4.7	3.4	2.0	1.4	0.8
Kimzeyite [4 analyses]	23.8	25.8	24.0	23.8	27.3	29.9	24.0	21.9	23.0	19.2	17.9	15.3	14.8	9.9
Iron-Oxide [5 analyses]	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Montecellite [2 analyses]	1.2	2.0	0.9	0.6	0.7	0.9	0.9	1.0	1.3	1.4	1.7	1.8	2.1	2.1
Calcite [5 analyses]	94.8	27.1	16.1	7.5	4.1	4.4	7.8	2.0	1.8	1.5	1.6	1.3	1.3	1.2
REE Budget														
Apatite	79.5%	80.6%	78.1%	76.0%	76.3%	76.1%	75.5%	74.3%	72.7%	71.9%	70.6%	67.8%	64.3%	66.0%
Perovskite	17.1%	16.7%	18.0%	18.5%	13.7%	11.4%	9.2%	7.7%	6.2%	4.9%	4.0%	3.2%	2.6%	1.9%
Kimzeyite	0.7%	1.3%	2.3%	4.2%	8.5%	10.6%	11.2%	15.8%	18.6%	20.1%	21.4%	24.1%	26.9%	24.0%
Iron-Oxide	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Montecellite	0.0%	0.1%	0.1%	0.1%	0.2%	0.3%	0.4%	0.8%	1.1%	1.5%	2.1%	2.9%	3.7%	5.2%
Calcite	2.7%	1.4%	1.5%	1.3%	1.3%	1.6%	3.6%	1.4%	1.4%	1.6%	1.9%	2.1%	2.4%	2.9%

Table 2: The phase contribution to the rock (top) is the average concentration of the associated element in each phase times the modal abundance. REE budget (bottom) is the percent is the percent of the REE that is in that phase of this sample.

Future Work

This is data from one sample with a max of 5 data points for any one phase. This is not yet a statistically significant amount of data. To increase the amount of data the main source of samples will be the Smithsonian who have agreed to lend us rocks from different locations such as Bayan Obo, China, Mountain Pass, CA (the most productive REE mines in the world) and Magnet Cove. There is also more rock that this sample was made from, that more thin sections will be made, to do similar analysis to ensure consistency in data. With these samples there can be a comprehensive analysis of the Magnet Cove carbonatite, to determine where it falls in the larger scheme of potential sources of REE and other critical elements.

Discussion/Summary

- Apatite makes up the majority of the REE budget in the Magnet Cove carbonatite; the proportion decreases from 80% to 60% from the LREEs to HREEs.
- Kimzeyite and monticellite are enriched in HREEs compared to the other phases in the rock, accounting for ~25% and ~5%, respectively.
- Perovskite has low modal abundance (~2%) but contains a significant proportion of the LREE (up to ~18%).
- Both calcite and iron-oxide have extremely low concentrations of REE and take up a small percentage of the budget despite, in the case of calcite, having a high modal abundance of ~65%.

References

[1] Amaral, C., Lamb, A., Dumond G., 2024, Geophysical characterization of an alkaline-carbonatite complex using gravity and magnetic methods at Magnet Cove, Arkansas, USA, Tectonophysics, v. 893, 230545, ISSN 0040-1951. [2] Landes, Kenneth, 1931, A Paragenetic Classification of the Magnet Cove Minerals, American Mineralogist, v. 16, p.313-326. [3] McDonough, W., Sun, S., 1995, Chemical Geology, The composition of the Earth, v.120, p.223-253. [3] Rowan, L., 2024, Critical Mineral Resources: National Policy and Critical Minerals List, Congressional Research Service, Report R47982. [4] Rudnick, R., Gao, S., 2003, Composition of the Continental Crust, Treatise in Geochemistry, v. 3, p. 1-64.

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