SLATT UNDERGRADUATE RESEARCH FELLOWSHIP
FINAL REPORT

SCHOLAR NAME:	Bennett Schmitt
FACULTY ADVISOR:	Dr. Antonio Simonetti
PROJECT PERIOD:	January 16th, 2024 – May 1st, 2024
PROJECT TITLE:	Investigating Rare Earth Element Mineralization Within Fenite Alteration Zones Using Isotopic Analysis
CONNECTION TO ONE OR MORE ENERGY-RELATED RESEARCH AREAS (CHECK ALL THAT APPLY):	**( ) Energy Conversion and Efficiency** **(x) Smart Storage and Distribution** **( ) Sustainable Bio/Fossil Fuels** **( ) Sustainable and Secure Nuclear** **( ) Transformation Solar** **( ) Transformative Wind**

MAJOR GOALS AND ACCOMPLISHMENTS

Summarize your research goals and provide a brief statement of your accomplishments (no more than 1-2 sentences). Indicate whether you were able to accomplish your goals by estimating the percentage completed for each one. Use the next page for your written report.

RESEARCH GOALS	ACTUAL PERFORMANCE AND ACCOMPLISHMENTS	% OF GOAL COMPLETED
Obtain bulk rock δ^{11}B (‰) isotope compositions	We obtained δ^{11}B (‰) isotope compositions of our samples to distinguish between varying types of open system behavior indicated by the variable in-situ Pb isotope compositions. Several methods of sample digestion—flux, hot, cold—were utilized to analyze the different types of samples (namely, silicates and carbonates) being investigated.	100
Synthesize isotope ratios, petrological data, and elemental abundances (B, Sr, Pb, REEs) to understand petrogenesis	We continue to synthesize all data obtained from a wide range of analyses (isotopic, mineralogical, concentration, etc.) and compare them to those obtained from previous studies. This will undoubtedly heighten understanding of the petrogenetic history of the deposits investigated.	50

RESEARCH OUTPUT

Please provide any output that may have resulted from your research project. You may leave any and all categories blank or check with your faculty advisor if you are unsure how to respond.

CATEGORY	INFORMATION
EXTERNAL PROPOSALS SUBMITTED	(Sponsor, Project Title, PIs, Submission Date, Proposal Amount)
EXTERNAL AWARDS RECEIVED	(Sponsor, Project Title, PIs, Award Date, Award Amount)
JOURNAL ARTICLES IN PROCESS OR PUBLISHED	(Journal Name, Title, Authors, Submission Date, Publication Date, Volume #, Page #s)
BOOKS AND CHAPTERS RELATED TO YOUR RESEARCH	(Book Title, Chapter Title, Authors, Submission Date, Publication Date, Volume #, Page #s)
PUBLIC PRESENTATIONS YOU MADE ABOUT YOUR RESEARCH	(Event, Presentation Title, Presentation Date, Location) Goldschmidt Conference; *Investigating REE Mineralization Within Fenites and Mineralized Carbonatites Using Geochemical Data and B, Sr, Nd, and Pb Isotope Signatures;* Aug. 18th-23rd, 2024; Chicago, IL
AWARDS OR RECOGNITIONS YOU RECEIVED FOR YOUR RESEARCH PROJECT	(Purpose, Title, Date Received)
INTERNAL COLLABORATIONS FOSTERED	(Name, Organization, Purpose of Affiliation, and Frequency of Interactions)
EXTERNAL COLLABORATIONS FOSTERED	(Name, Organization, Purpose of Affiliation, and Frequency of Interactions) Dr. Wei Chen, China University of Geosciences (Wuhan), Dr. Chen provided the fenite and carbonatite samples investigated in this work.
WEBSITE(S) FEATURING RESEARCH PROJECT	(URL)

OTHER PRODUCTS AND SERVICES (e.g., media reports, databases, software, models, curricula, instruments, education programs, outreach for ND Energy and other groups)	(Please describe each item in detail)

RESEARCH EXPERIENCE
Please let us know what you thought of your research experience: Did this experience meet your expectations? Were lab personnel helpful and responsive to your needs? What else could have been done to improve your experience or achieve additional results?
I thoroughly enjoyed this semester research experience. The opportunity to continue working on my project which I began during Summer 2023 helped foster immense development as both a researcher and student. My advisor, Dr. Antonio Simonetti, offered excellent mentorship and helped me to learn an incredible amount about isotopic geochemistry, data analysis, and more.

FINAL WRITTEN REPORT

(Please use the space below to describe your research project and objectives, any findings and results you can share, and graphs, charts, and other visuals to help us understand what you achieved as a result of this research experience.)

Rare Earth Elements (REEs) have garnered global attention in recent decades for their wide range of applications in high-technology devices and, more recently, for their integral role in the expansion of clean energy technology and next-generation energy storage capabilities. This work investigates carbonatites—a carbonate-rich subset of igneous rocks known to harbor the largest proportion of economically viable REE deposits worldwide—and associated rocks, known as fenites, that have been metasomatically altered by the intruding carbonatitic magma. Using fenite and mineralized carbonatite samples from three of the world's largest REE deposits—Maonuiping-Dagudao, Bayan Obo, and Miaoya—we compare their respective chemical (major and trace element) characteristics and Sr, Nd, Pb, and B isotope signatures with those of their corresponding magmatic rocks to explore the petrogenesis of these complexes and investigate the similarities and differences in REE budgets. To our knowledge, this work is the first to report B concentrations and their corresponding isotope ratios for fenites.

Bulk rock analysis of fenites from the Maonuiping-Dagudao and Bayan Obo complexes reveals extreme REE enrichment, whereas mineralized carbonatites from Miaoya contain lower REE contents relative to their corresponding magmatic rocks. Boron abundances for the fenites and mineralized carbonatites range between 2 and 7 ppm, well exceeding standard abundances for mantle-derived rocks (<1 ppm). Across all three complexes, B abundances for the fenites and mineralized carbonatites do not correlate with their total REE contents, while $\delta^{11}B$ values—ranging between roughly -5 and +16 ‰— correlate positively with LREE abundances for fenites from the three complexes (Figure 1).

Bulk rock Sr, Nd, and Pb isotopic ratios obtained for the fenites and published data from their associated carbonatite/alkaline rock samples exhibit large ranges and overlapping ratios, thus indicating both open-system behavior and a petrogenetic link between these two rock regimes in their formation. Highly variable Pb isotope ratios define linear arrays in Pb-Pb isotope plots, likely reflecting interaction between magmatic fluid and surrounding rock (Figure 2). The combined chemical and isotope data support the hypothesis that metasomatizing fluids emanating from carbonate/alkaline magmas played a significant role in the alteration of the surrounding rocks and in modulating the observed REE enrichment. However, B abundances and their corresponding $\delta^{11}B$ values reported here are difficult to reconcile with simple binary mixing between mantle-derived fluids and their host rocks. Binary mixing model calculations based on $\delta^{11}B$ values and $^{87}Sr/^{86}Sr$ indicate this hypothesis is only viable between a mantle-derived magma and a limestone-like member (high Sr, heavy $\delta^{11}B$ values) rather than typical, granite-like continental crust. The heavy $\delta^{11}B$ values for the fenites and mineralized carbonatites may also reflect fractionation incurred at varying and lower temperatures of formation relative to the higher temperatures associated with the mantle-derived fluids.

Together, through the juxtaposition of trace element analyses and isotopic investigations, we have been able to gain a better and more detailed understanding of the distribution of REEs between the fenites and their associated carbonatites, thus providing valuable insight into both the future use of B isotope signatures as a sophisticated prospecting tool, as well as the use of these complexes as reservoirs of economically and technologically critical elements.

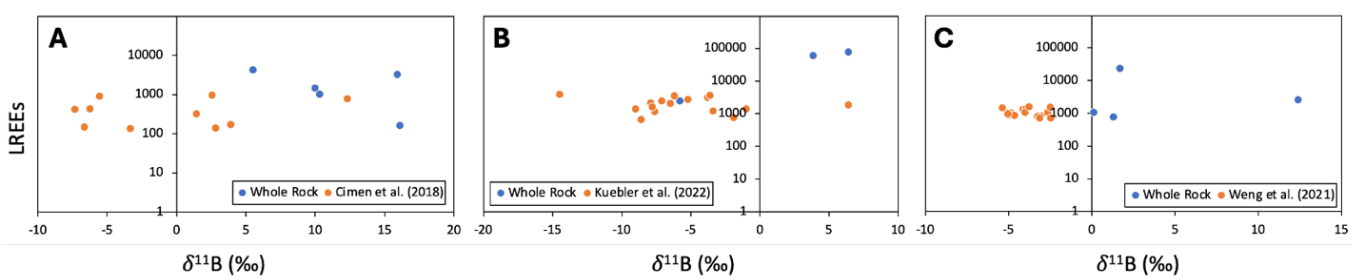

Figure 1. $\delta^{11}B$ values vs. light rare earth (LREE) abundances for (A) Miaoya, (B) Bayan Obo, and (C) Maonuiping-Dagudao.

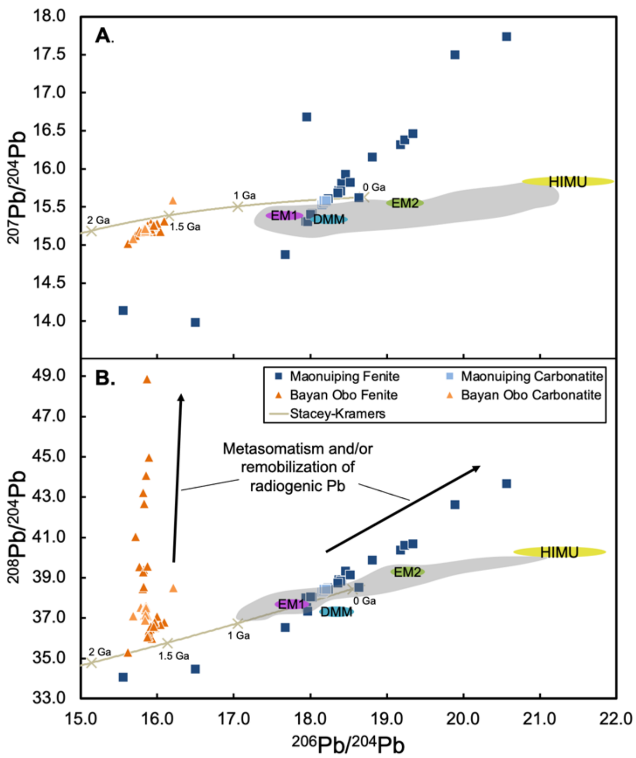

Figure 2. (A) $^{207}Pb/^{204}Pb$ and (B) $^{208}Pb/^{204}Pb$ vs. $^{206}Pb/^{204}Pb$ values for Bayan Obo and Maonuiping (this study) and young carbonatites (<200 Ma) worldwide (gray shaded area). Stacey and Kramers two-stage Pb evolution model is plotted, along with isotopic fields for HIMU, EM1, EM2, and DMM mantle