SLATT UNDERGRADUATE RESEARCH FELLOWSHIP
FINAL REPORT

SCHOLAR NAME:	Bennett Schmitt
FACULTY ADVISOR:	Dr. Antonio Simonetti
PROJECT PERIOD:	May 22nd, 2023 – July 28th, 2023
PROJECT TITLE:	Investigating Rare Earth Element Mineralization Within Fenite Alteration Zones
CONNECTION TO ONE OR MORE ENERGY-RELATED RESEARCH AREAS (CHECK ALL THAT APPLY):	**( ) Energy Conversion and Efficiency** **( ) Sustainable and Secure Nuclear** **(x) Smart Storage and Distribution** **( ) Transformative Solar** **( ) Sustainable Bio/Fossil Fuels** **( ) 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 in-situ Pb isotope compositions within samples	Using LA-MC-ICP-MS (laser ablation multi-collector inductively coupled plasma mass spectrometry), we were able to investigate the Pb isotope compositions of the dominant minerals in our samples (calcite, amphibole, and clinopyroxene) to better understand the petrogenetic history of the studied carbonatite complexes.	75
Examine in-situ Sr isotope compositions of calcite within samples	Using LA-MC-ICP-MS, we examined the Sr isotope compositions of calcite phases in our samples.	100
Investigate B concentrations of samples	We analyzed the B concentrations of our samples using high-resolution (HR) ICP-MS to inform understanding of the tectonic and geochemical mechanisms resulting in the formation of the carbonatite complexes studied.	100
Obtain bulk rock δ^{11}B (‰) isotope compositions	We obtained δ^{11}B (‰) isotope compositions of our samples in order to distinguish between varying types of open system behavior indicated by the variable in-situ Pb isotope compositions	75
Examine bulk rock and in-situ trace element analyses to explore rare earth element enrichment in samples	We juxtaposed whole rock and in-situ trace element data to understand the minerals controlling the rare earth element budget within our samples and to examine levels of rare earth element enrichment in the studied fenite and carbonatite samples.	100

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) 1) Notre Dame Summer Undergraduate Research Symposium; *Investigating Rare Earth Element Mineralization Within Fenite Alteration Zones*; July 26th, 2023; Notre Dame, IN 2) North American Workshop on Laser Ablation; *Investigating REE Mineralization at High-Spatial Resolution Within Fenite Alteration Zones Using LA-ICP-MS*; June 6th, 2023 – June 9th, 2023; Notre Dame, IN

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) Dr. Karl Cronberger, Materials Characterization Facility at the University of Notre Dame, We worked with Dr. Cronberger twice throughout the project to conduct electron microprobe analyses
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 summer research experience. The opportunity to work full time on my project prompted 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 mass spectrometry, petrography, isotopic geochemistry, 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 carbonatite samples from three of the world's largest REE deposits—Maonuiping-Dagudao, Bayan Obo, and Miaoya—we have been able to explore the petrogenesis of these complexes and gain insight into the similarities and differences in isotopic compositions and REE budgets between the fenites and their associated carbonatites.

Bulk-rock, solution mode isotopic investigations have revealed overlapping values between the studied fenites and their associated carbonatites, confirming a petrogenetic link between both rock types and supporting the hypothesis that the intruding carbonatitic magma is responsible for fenite alteration and at least partially controls observed REE enrichment in these alteration zones. Additionally, bulk rock analysis of multiple fenite samples has revealed extreme REE enrichment in the fenites relative to their associated carbonatites. Analogous in-situ data obtained via LA-ICP-MS for mineral phases dominating the bulk rock have shown that calcite controls the mass budget of light REEs, while amphibole and clinopyroxene command that of the heavy REEs (Figure 1).

In-situ isotopic analyses obtained for the studied complexes indicate open system behavior that may be a result of metasomatic alteration and/or contamination by a crustal component (Figure 2). Appreciable spread in the isotopic compositions of different minerals within the samples evidences a complex petrogenesis that will be the focus of continued work in this area. Though ongoing, this project has confirmed the intimate relationship between carbonatites and their associated fenites and provided evidence that the latter rock type may represent an untapped reservoir of REE-bearing minerals that can help to accelerate the transition to a sustainable, clean-energy future.

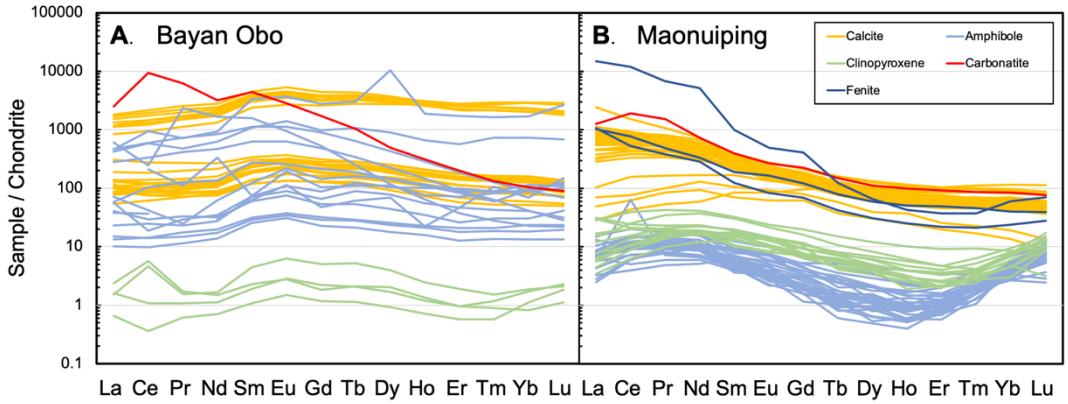

Figure 1. Bulk rock and in-situ chondrite-normalized REE profiles for samples from (A) Bayan Obo and (B) Maonuiping-Dagudao

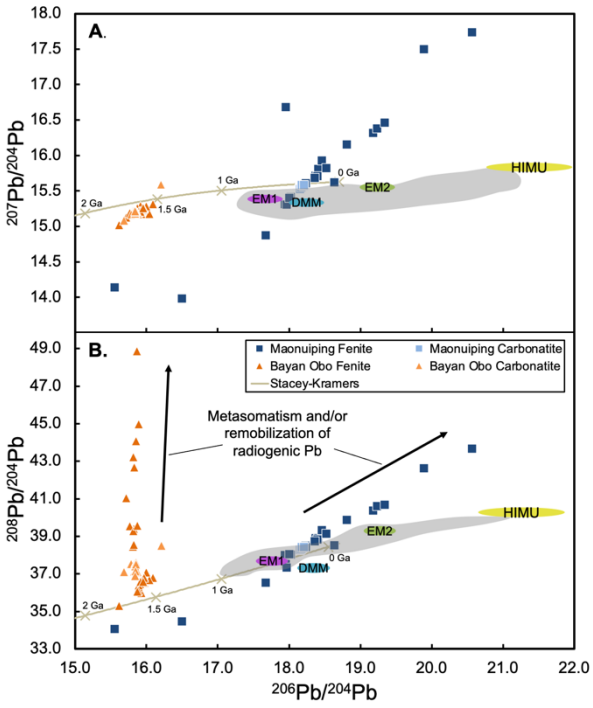

Figure 2. (A) $^{207}Pb/^{204}Pb$ and (B) $^{208}Pb/^{204}Pb$ vs. $^{206}Pb/^{204}Pb$ values for Bayan Obo and Maonuiping (this study) and young carbonatites (<200 Ma) worldwide (gray shaded area). Stacey and Kramers two-stage Pb evolution model is plotted, along with isotopic fields for HIMU, EM1, EM2, and DMM mantle reservoirs (Zindler and Hart, 1986).