Geology of the Cambrian-Ordovician Lemitar Carbonatites, Socorro County, New Mexico: Revisited

Ethan B. Haft[1], Virginia T. McLemore[2], O. Tapani Rämö[3], and Jonas Kaare-Rasmussen[4]

[1]Department of Earth and Environmental Science, New Mexico Institute of Mining and Technology, Socorro, New Mexico, 87801

[2]New Mexico Bureau of Geology and Mineral Resources, Socorro, New Mexico, 87801

[3]Tapani Rämö, Department of Geosciences and Geography, Geology and Geophysics Research Program, University of Helsinki, Finland

[4]Department of Earth Science, University of California, Santa Barbara, California, 93106

ABSTRACT

Carbonatites are igneous rocks of magmatic origin that are composed of more than 50% carbonate minerals, less than 20% SiO_2, and they can form economic deposits containing significant amounts of rare earth elements (REE), barite, fluorite, and niobium. REE are critical minerals and are essential to the functioning of information-age technologies because of their unique properties, i.g., high electric conductivity, strong magnetism, fluorescence, and luminescence. In this respect, carbonatites serve as the principal source of REE on Earth. Carbonatites in the Lemitar Mountains are light REE enriched and contain as much as ~1.1 wt.% in total. While previously described, new analytical techniques have allowed for additional and more precise description, age, and model of their origin. The age of Lemitar carbonatites has been newly established at ~515 Ma using $^{40}Ar/^{39}Ar$ and U/Pb geochronological methods. Petrographic observations combined with whole-rock geochemical and isotope data indicate the Lemitar carbonatites are mantle-derived and that their origin is related to the Cambrian-Ordovician belt of alkaline igneous rocks and carbonatites in southern Colorado and New Mexico. The Lemitar carbonatites are not economic at the present time because of small tonnage and low grades. Nevertheless, further drilling is required to determine if the carbonatites increase in REE and Nb concentrations at greater depth (1.1% total REE in a surface sample is significant). Detailed geophysical surveys are required to determine if the Lemitar Mountains could contain a larger carbonatite body emplaced in the subsurface.

INTRODUCTION

The Lemitar Mountains (designated as the Lemitar Mountains mining district, McLemore, 2017) are formed by rocks ranging from Proterozoic granite, gneiss, diorite, gabbro, metasediments, arkoses, and pegmatites, Pennsylvanian limestone, Oligocene tuff and andesite, and Oligocene-Pleistocene fluvial and piedmont sediments. Rift extension and uplift have exposed the Proterozoic basement. The carbonatite dike swarm spanning the eastern half of the district is the product of Cambrian-Ordovician alkaline magmatism, a possible aulacogen (McMillan and McLemore, 2004; McLemore and others, 2020) that extends from southern Colorado into New Mexico. More than 150 carbonatite dikes and veins are found at the surface intruding igneous basement rock in the eastern foothills of the Lemitar Mountains. Mineral deposits found in the Lemitar Mountains district include Cambrian-Ordovician carbonatites, Tertiary barite-galena Rio Grande rift deposits, polymetallic veins, and carbonate-hosted replacement deposits.

Although the carbonatites in the Lemitar Mountains have been previously examined, this poster summarizes previous work as well as presents new data in terms of geochronology, whole-rock geochemistry, radiogenic, isotope data, and present a current model for the generation of Lemitar carbonatites proposed by Ackerman and others (2021).

MINING HISTORY

Mining in the district may have occurred as early as the 1600s (Benavides, 1630), but historic silver workings were first officially reported by the United States Mint in the late 1800s (Burchard, 1881). Prospecting in the early 1900s resulted in approximately 40 short tons of manganese production from the northern Lemitar Mountains (Howard, 1967). Lasky (1932) first mentioned small galena-barite fissure-filling veins in the Proterozoic rocks and in limestones along the unconformity between the Proterozoic rocks and Paleozoic sedimentary rocks in the district. Over 40 mines and prospects are found in the district; all extensive underground workings have been remediated. Total mineral production is estimated as $1000 worth of copper, lead, barite, silver, manganese, and uranium (Anderson, 1957; Howard, 1967; North and McLemore, 1986; McLemore, 2017).

Secondary carbonatite and sövite vein, Lemitar Mountains, Socorro County, New Mexico.

METHODS

- Compilation of previously published and unpublished data
  - Existing mines and prospects (This study; legacy mine land inventory)
  - Previous reported chemical analyses. (McLemore, Ackerman)
- Whole-rock channel and select sampling.
  - Geochemically quantified with inductively coupled plasma atomic emission spectroscopy (ICP-AES).
- Optical and reflected-light petrographic observations.
  - Characterization of thin sections and polished sections.
- Electron microprobe analyzer (EMPA) for mineralogy. (NMBGMR)
- Carbon (^{13}C) and oxygen (^{18}O) stable isotopes. (UNM-CSI)
- $^{40}Ar/^{39}Ar$ geochronology. (NMBGMR Argon laboratory)
- Zircon uranium/lead (U/Pb) geochronology. (UCSB)

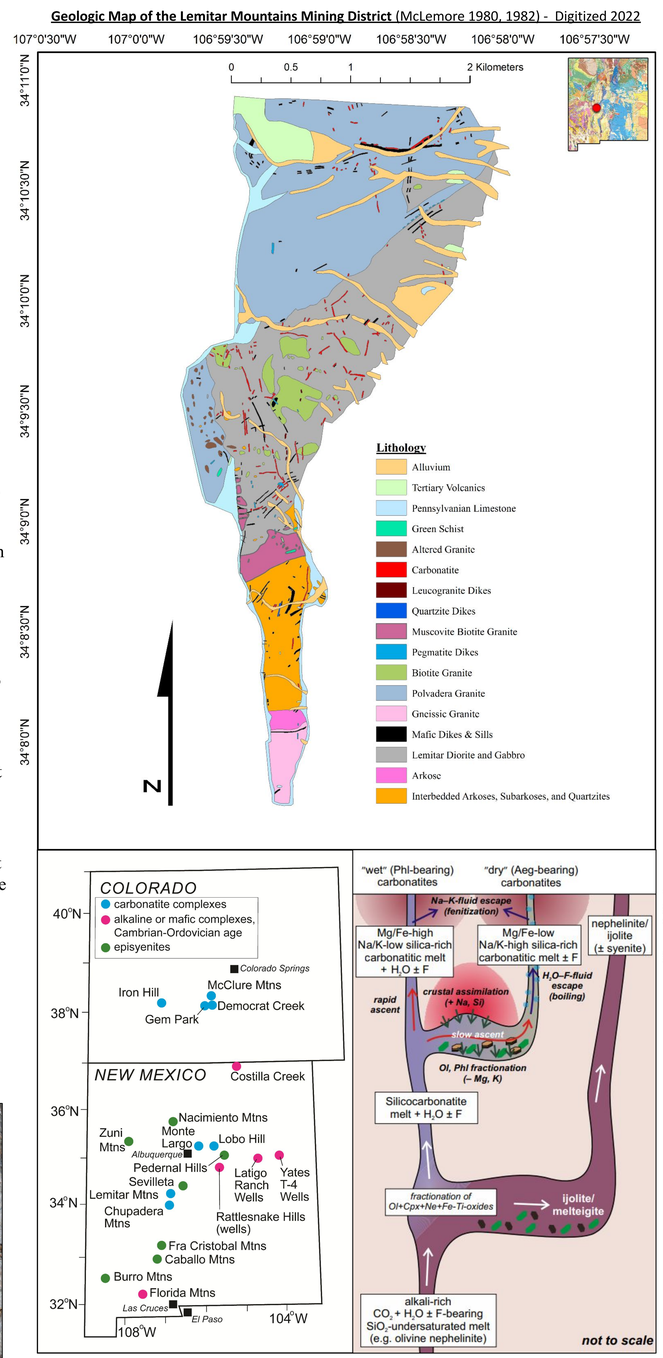
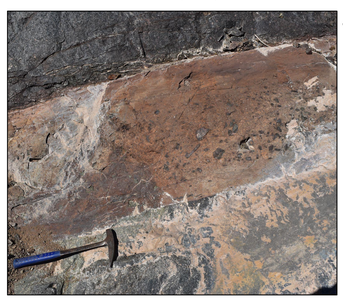


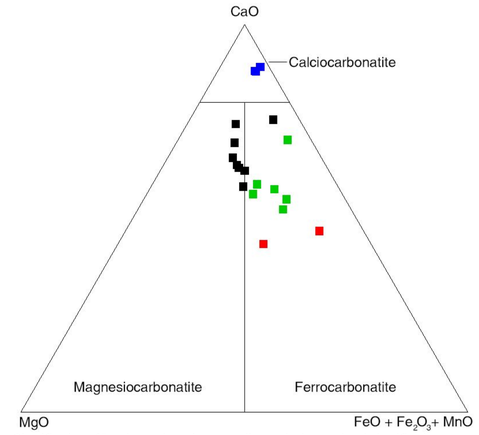
Fig. 1: Location of areas with Cambrian and Ordovician carbonatites, episyenites, and syenites in New Mexico and southern Colorado (from McLemore et al., 1999; 2018; McLemore, 2017).

Fig. 2: A model proposed by Ackerman and others (2021) Details the separation of a mantle-derived CO_2-H_2O-F melt that fractionates to "wet" phlogopite-bearing carbonatites, "dry" aegirine carbonatites, and nephelinite/ijolite (i.e. syenite) alkaline rocks. Different magma compositions depend upon Si-Na-K-Mg contents, water activity, and melt ascent rate. More work is required to test this model. (from Ackerman et al. 2021)

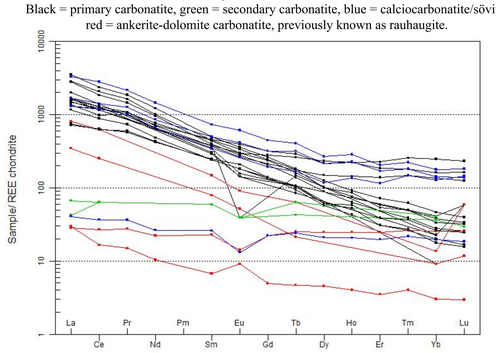


Primary carbonatite and white sövite intruding Proterozoic diorite, over a meter wide and elevated in REE, U, and Th. Lemitar Mountains, Socorro County, New Mexico.

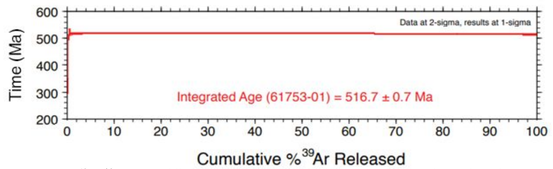
Primary carbonatite fenitizing diorite, note red phenocrysts. Plagioclase turned microcline+white phyllosilicate. Lemitar Mountains, Socorro County, New Mexico. Fenitization: $NaAlSi_3O_8 + K^+_{(aq)} \leftrightarrow KAlSi_3O_8 + Na^+_{(aq)}$



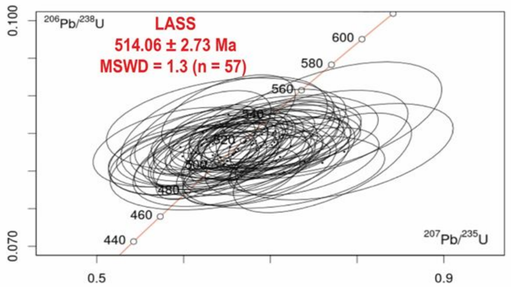
Classification of Lemitar carbonatites according to the international classification system (Woolley 1982; Le Maitre 2002).
Black = primary carbonatite, green = secondary carbonatite, blue = calciocarbonatite/sövite, red = ankerite-dolomite carbonatite, previously known as rauhaugite.



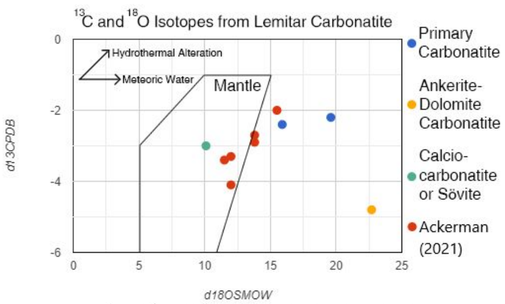
Chondrite-normalized REE spider plot of Lemitar carbonatites and veins using chondrite REE values from Nakamura (1974). Note enrichment in primary and calciocarbonatites.



$^{40}Ar/^{39}Ar$ spectral line plot indicating age of 516.7±0.7 Ma for Lemitar carbonatite. Captured from a primary carbonatite phlogopite crystal.



Wetherill Plot of U-Pb isotopic data collected from Lemitar carbonatite zircons. All analyses are concordant with an age of 514.06 ± 2.73 Ma (2 SD).



^{13}C and ^{18}O stable isotope scatter plot of Lemitar carbonatite.
Includes new data and recently reported data from Ackerman and others (2021).
Radiogenic isotope systems provide a means of differentiating carbonatite types.
^{13}C normalized to Pee Dee Belemnite (PDB)
^{18}O normalized to standard mean ocean water (SMOW).

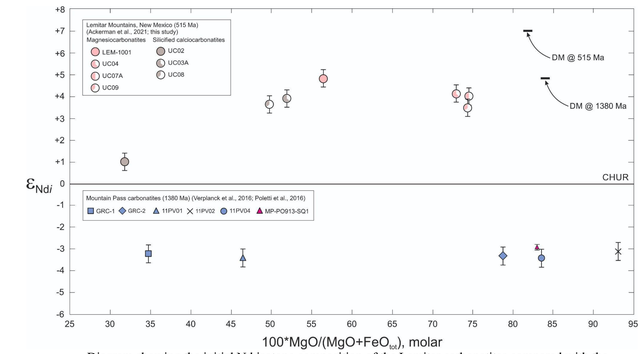


Diagram showing the initial Nd isotope composition of the Lemitar carbonatites compared with the Mountain Pass carbonatite (Verplanck and others, 2016; Poletti and others, 2016). DM is the depleted mantle of DePaolo (1981), with Nd shown at the two times of interest, CHUR is the Chondritic Uniform Reservoir of DePaolo and Wasserburg (1976). Error bars are 2 SD external

DISCUSSION

- Primary carbonatites were emplaced first, followed by secondary carbonatites, ankerite-dolomite carbonatites, and finally calciocarbonatites (sövite). Perry (2019) reported that at least four generations of calcite are present, therefore further studies on paragenesis are needed.
- Actinolite, sillimanite, titanite, and C – O isotope systematics in primary carbonatites indicate a mantle-derived magmatic origin with a crystallization temperature at or above 700°C (Hayden, 2008).
- Secondary (replacement) and ankerite-dolomite carbonatites (rauhaugites) reflect the most oxidized conditions of the Lemitar carbonatite system as hematite is the majority iron-oxide phase over magnetite.
- A hydrothermal environment persisted after initial carbonatite emplacement; indicated by alteration of biotite to hematite and chlorite. Nd isotopic data corroborates an open hydrothermal environment in comparison to the 'closed' Mountain Pass carbonatite in California.

CONCLUSIONS

- The Lemitar carbonatites are approximately 515Ma. Corroborated by $^{40}Ar/^{39}Ar$ geochronology and U/Pb age dating.
- While not economic at this time, further drilling is required to determine if Lemitar carbonatites increase in REE grade at depth. (1.1wt % total REE in surface sample LEM2000 is significant)
- The Lemitar carbonatites are magmatic, mantle-derived rocks that are enriched in REE and Nb (as shown by mineralogy, whole-rock chemistry and Sm – Nd isotopic systematics).
- Primary carbonatites and calciocarbonatites (sövites) contain the most REE and critical and energy minerals (Zr, F, Ba, Nb, U, Th)

ACKNOWLEDGMENTS

This work is part of ongoing research of the economic geology of mineral resources in New Mexico at NMBGMR, Nelia Dunbar, Director and State Geologist. We would like to thank William X. Chavez for his advice and insight in petrographic interpretation. Dave Kasefang, Mark Leo-Russel, and Brandon Dennis provided database and other computer support. This study was partially funded by the U.S. Geological Survey Earth MRI (Mapping Resources Initiative) Cooperative Agreement No. G19AC00258 and student grants from the New Mexico Geological Society and the New Mexico Tech Brightstar Scholarship. Thanks to Nicholas G. Harrison, Haley Dietz, Keith Diegel, Lochlan Vaughn, and Evan J. Owen for their assistance in collecting samples. Finally, Sarah Bennett spent many days in the field camping, sampling, and recording legacy mine workings. Samples were cataloged and archived at the NMBGMR for future examination.

REFERENCES

Ackerman, L., Rapprich, V., Polak, L., Magna, T., McLemore, V.T., Pour, O. and Cejkova, B., 2021, Petrogenesis of silica-rich carbonatites from continental rift settings: A missing link between carbonatites and carbonated silicate melts?: Journal of Geosciences, v. 66, p. 71-87.

Anderson, E.C., 1954, Occurrences of uranium ores in New Mexico: New Mexico Bureau of Mines and Mineral Resources, Circular 29, 27 p.

Benavides, A., Hodge, F. W., and Lummis, C. F., 1965, The memorial of Fray Alonso de Benavides, 1630. Albuquerque, N.M: Horn and Wallace, p. 18-19.

Burchard, H.C., 1881, Report of the Director of the Mint upon the statistics of the production of precious metals in the United States: Washington, D.C., U.S. Treasury Department, 341 p.

DePaolo, D.J. and Wasserburg, G.J., 1976, Nd isotopic variations and petrogenetic models: Geophysical Research Letters, v. 3, p. 249-252.

DePaolo, D.J., 1981, Neodymium isotopes in the Colorado Front range and crust-mantle evolution in the Proterozoic: Natur,e v. 291, p. 193-196.

Hayden, L.A., Watson, E.B, and Wark, D.A., 2008, A thermobarometer for sphene (titanite). Beiträge zur Mineralogie und Petrographie. 155: p. 529-540. doi: 10.1007/s00410-007-0256-y.

Howard, E.V., 1967, Metalliferous occurrences in New Mexico: Phase 1, state resources development plan: State Planning Office, Santa Fe, 270 p.

Le Maitre, R.W., 2002. Igneous rocks: A Classification and Glossary of Terms: 2nd Edition, Cambridge University Press, Cambridge, p 1–236.

McLemore, V.T., 1980, Carbonatites in the Lemitar Mountains, Socorro County, New Mexico: New Mexico Geology, v. 2, no. 4, p. 49-52.

McLemore, V.T., 1982, Carbonatites in the Lemitar Mountains, Socorro County, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Open-file report OF-158, 122 p., http://geoinfo.nmt.edu/publications/openfile/downloads/OFR100-199/151-175/158/of_158.pdf (accessed 5/14/2020)

McLemore, V.T., McMillan, N.J., Heizler, M., and McKee, C., 1999, Cambrian alkaline rocks at Lobo Hill, Torrance County, New Mexico: More evidence for a Cambrian-Ordovician aulacogen: New Mexico Geological Society, Guidebook 50, p. 247–253.

McLemore, V.T., 2017, Mining districts and prospect areas of New Mexico: New Mexico Bureau of Geology and Mineral Resources, Resource Map 24, 65 p., scale 1:1,000,000.

McLemore, V.T., 2018, Rare Earth Elements (REE) Deposits Associated with Great Plain Margin Deposits (Alkaline-Related), Southwestern United States and Eastern Mexico: Resources 2018, 7(1), 8; 44 p., doi: 10.3390/resources7010008; http://www.mdpi.com/2079-9276/7/1/8

McLemore, V.T., Smith, A., Riggins, A.M., Dunbar, N., Rämö, O.T., and Heizler, M.T., 2020, REE-bearing Cambrian-Ordovician episyenites and carbonatites in southern and central New Mexico, USA, in Koutz, F.R. and Pinnell, W.M., eds. Vision for discovery: Geology and ore deposits of the Great Basin: Geological Society of Nevada, 2020 Symposium Proceedings, p. 411-428.

McMillan, N. and McLemore, V.T., 2004, Cambrian-Ordovician magmatism and extension in New Mexico and Colorado. New Mexico Bureau of Geology and Mineral Resources, Bulletin 160, p. 1-12.

Nakamura, N., 1974, Determination of REE, Ba, Fe, Mg, Na and K in carbonaceous and ordinary chondrites: Geochimica et Cosmochimica Acta, v. 38, p. 757-775.

North, R.M., and McLemore, V.T., 1986, An overview of silver and gold in New Mexico; in Frontiers in geology and ore deposits of Arizona and the Southwest: Arizona Geological Society Digest, v. 16, p. 481-488.

Perry, E., 2019, Rare earth element signatures in hydrothermal calcite: Insights from numerical modeling, experimental geochemistry, and mineral deposits in New Mexico: Ph.D. dissertation, Colorado School of Mines, Golden, Colorado, 126 p.

Poletti, J.E., Cottle, J.M., Hagen-Peter, G.A. and Lackey, J.S., 2016, Petrochronological constraints on the origin of the Mountain Pass ultrapotassic and carbonatite intrusive suite, California: Journal of Petrology, v. 57, p. 1555-1598.

Verplanck, P.L., Mariano, A.N. and Mariano, A., Jr., 2016, Rare earth element ore geology of carbonatites: Reviews in Economic Geology, v. 18, p. 5-32.

Woolley, A.R., 1982, A discussion of carbonatite evolution and nomenclature and the generation of sodic and potassic fenites: Mineral Magazine, v. 46, p. 13–17.