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

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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 (Ba), fluorite (F), and niobium (Nb). REE are critical minerals and are critical to the functioning of information-age technologies because of their unique properties, i.e., high electric conductivity, strong magnetism, fluorescence, and luminescence. Carbonatites are currently the principal source of REE in the world. Carbonatites in the Lemitar Mountains are light REE enriched and contain as much as ~1% total rare earth elements (TREE). While previously described, new analytical techniques have allowed for additional and more precise description, age, and model of their origin. The Lemitar carbonatites from both $^{40}Ar/^{39}Ar$ and U/Pb methods are ~515 Ma. Petrographic observations combined with whole-rock geochemical and isotope data indicate the Lemitar carbonatites are mantle-derived and related to the regional 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. However, drilling is required to determine if they increase in REE and Nb concentrations at depth (1.1% total REE in one sample is significant). Detailed geophysics are required to determine if the Lemitar Mountains could have a larger carbonatite emplaced in the subsurface.

INTRODUCTION

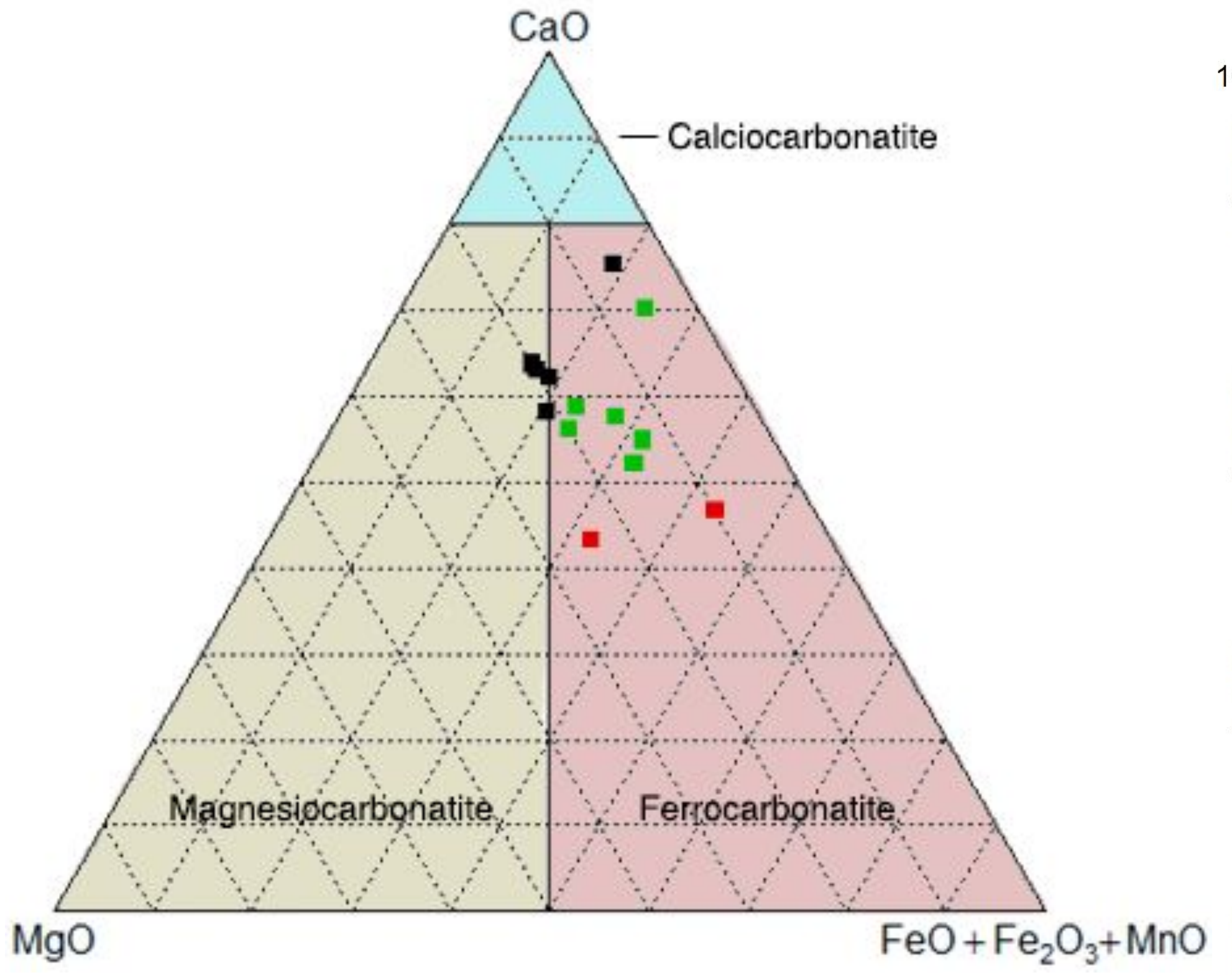
Carbonatites are igneous rocks of magmatic origin that are composed of more than 50% carbonate minerals, less than 20% SiO_2 (Streckeisen, 1980), and they can form economic deposits containing significant amounts of rare earth elements (REE), barite (Ba), fluorite (F), and niobium (Nb). Carbonatite magmas are associated with continental rift environments and have been attributed to either the subduction and subsequent melt of oceanic crust (Walter and others, 2008) or to the melt and partial differentiation or fractionation of lithospheric-mantle material (Jones, 2013; Stoppa and others, 2019; Ackerman and others 2021). Carbonatite intrusions are frequently surrounded by a halo of fenitization, a type of alkali metasomatism associated with carbonatites and alkaline igneous activity that involves the addition of potassium and/or sodium and depletion of silica (e.g., Andersen, 1989; Le Bas, 2008). Fenitized halos are typically larger than carbonatites themselves, so they frequently provide a substantial footprint in the field to aid in the exploration of carbonatites.

Rare earth elements (REE), comprising atomic numbers 57-71 (lanthanum to lutetium) and yttrium (Y) and scandium (Sc) are generally considered critical minerals. REE are critical to the functioning of information-age technologies because of their unique properties, i.e., high electric conductivity, strong magnetism, fluorescence, and luminescence (Van Gosen et al., 2014). Carbonatites are currently the leading source of REE in the world.

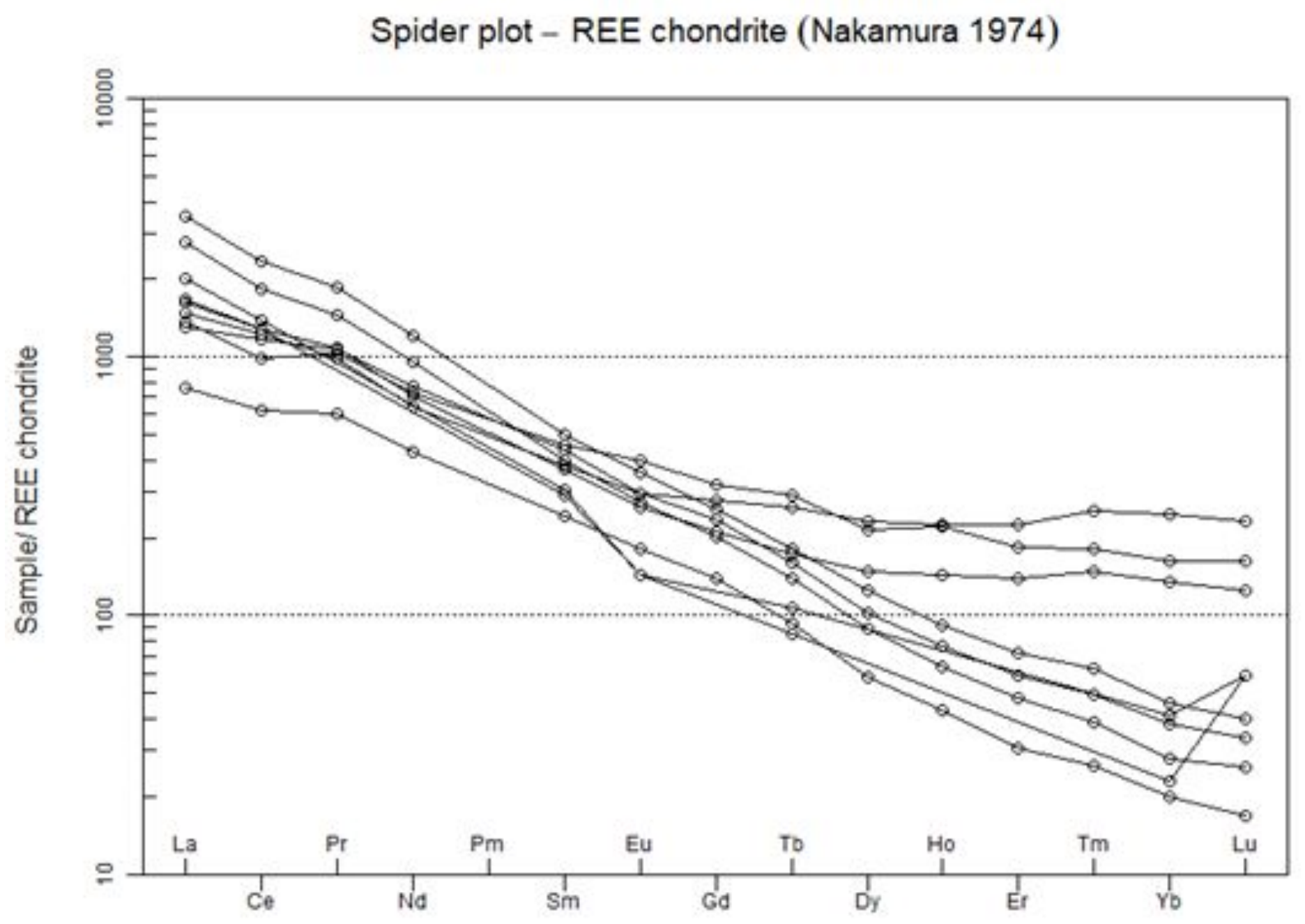
One area in New Mexico that has REE potential is the Lemitar Mountains north of Socorro in central New Mexico, which is part of a regional Cambrian-Ordovician belt of alkaline igneous rocks and carbonatites (Fig. 1; McMillan and McLemore, 2004; McLemore and others, 2020). Cambrian-Ordovician carbonatites are found as dikes and associated veins and stockworks in five areas in New Mexico: Lobo Hill, the Monte Largo area in the Sandia Mountains, Caballo Mountains (Perry, 2019), the Lemitar and Chupadera Mountains (Fig. 1; Woolley 1982; McLemore and others, 2020). Younger Oligocene carbonatite dikes also are found at Laughlin Peak in the Chico Hills (McLemore, 2015), but are not discussed in this report. Although the Lemitar carbonatites have been previously examined, this paper summarizes previous work as well as presents new geochronology, whole-rock geochemistry, and isotope data and tests a proposed model presented by Ackerman and others (2021).

METHODS

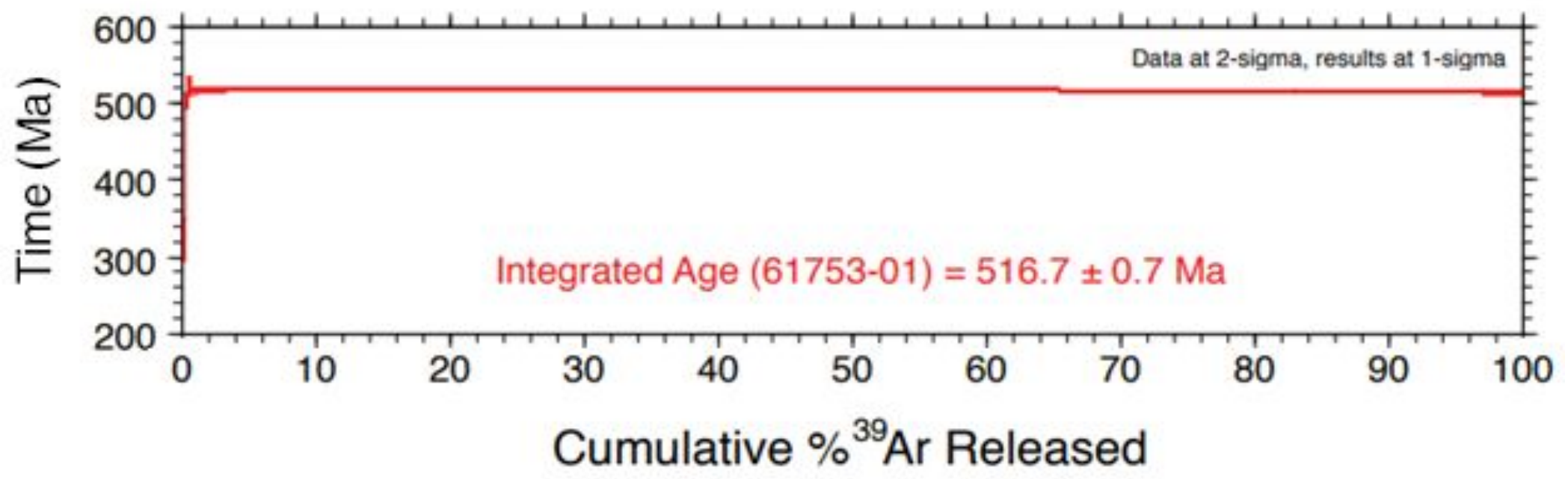
Carbonatites are igneous rocks of magmatic origin that are composed of more than 50% carbonate minerals, less than 20% SiO_2, and they can form economic deposits containing significant amounts of rare earth elements (REE), barite (Ba), fluorite (F), and niobium (Nb). REE are critical minerals and are critical to the functioning of information-age technologies because of their unique properties, i.e., high electric conductivity, strong magnetism, fluorescence, and luminescence. Carbonatites are currently the principal source of REE in the world. Carbonatites in the Lemitar Mountains are light REE enriched and contain as much as ~1% total rare earth elements (TREE). While previously described, new analytical techniques have allowed for additional and more precise description, age, and model of their origin. The Lemitar carbonatites from both $^{40}Ar/^{39}Ar$ and U/Pb methods are ~515 Ma. Petrographic observations combined with whole-rock geochemical and isotope data indicate the Lemitar carbonatites are mantle-derived and related to the regional 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. However, drilling is required to determine if they increase in REE and Nb concentrations at depth (1.1% total REE in one sample is significant). Detailed geophysics are required to determine if the Lemitar Mountains could have a larger carbonatite emplaced in the subsurface.



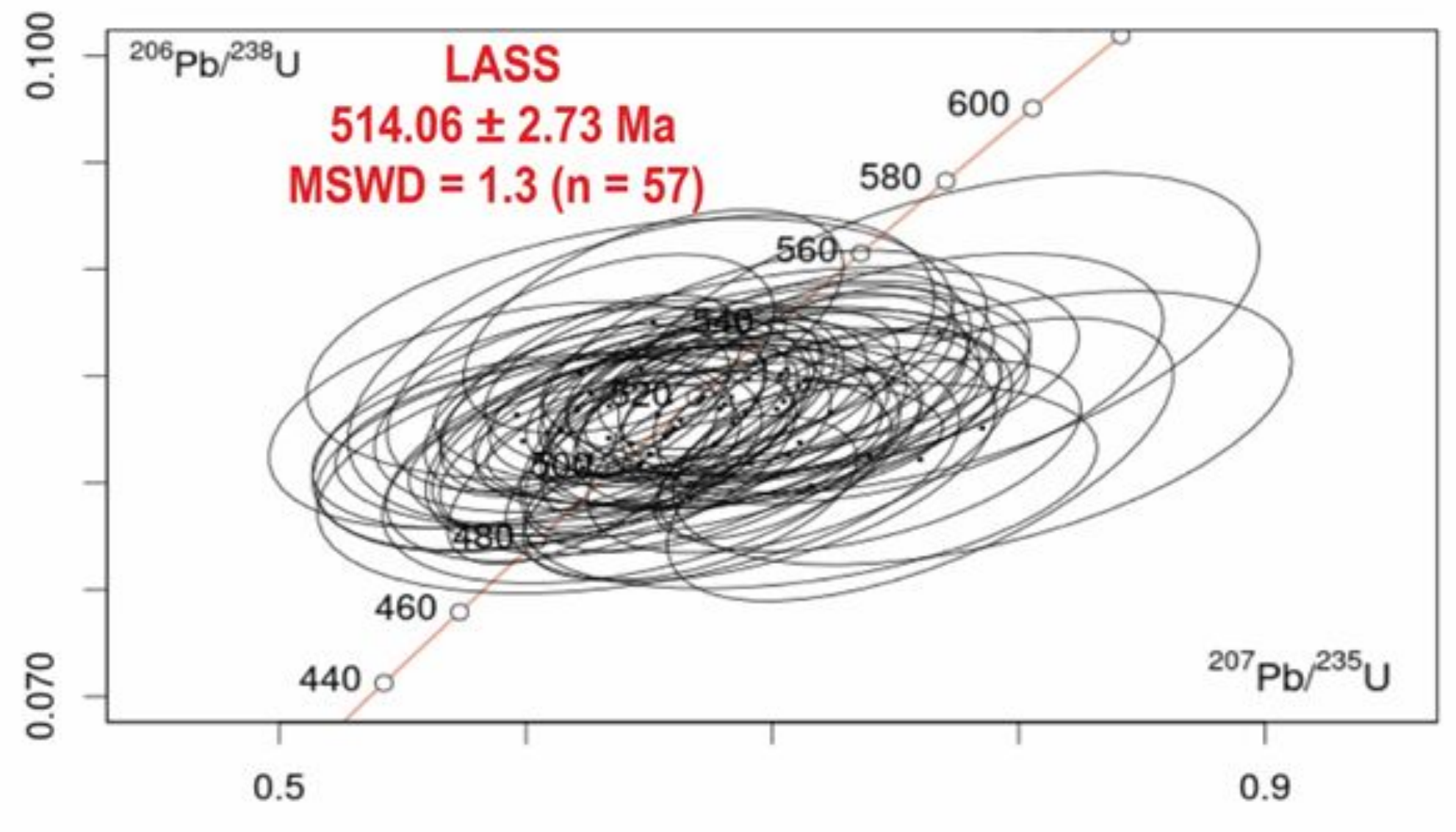
Classification of Lemitar carbonatites according to the international classification system (Woolley 1982; Le Maitre 2002). Black = primary carbonatite, green = secondary carbonatite, red = ankerite-dolomite carbonatite, previously known as rauhaugite



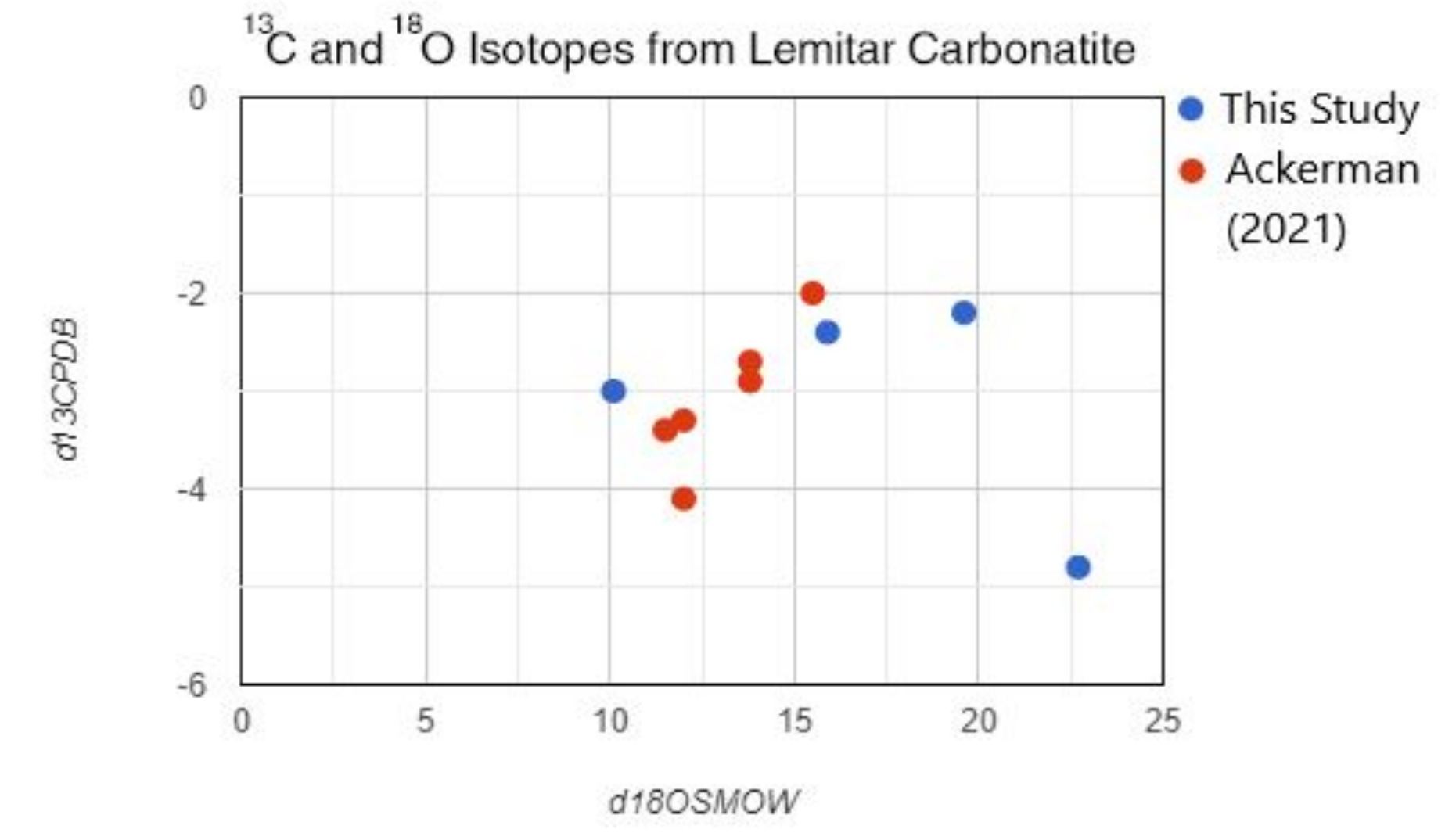
Chondrite-normalized REE spider plot of Lemitar carbonatites and veins using chondrite REE values from Nakamura (1974).



$^{40}Ar/^{39}Ar$ spectral line plot indicating age of 516.7±0.7 Ma for Lemitar carbonatite

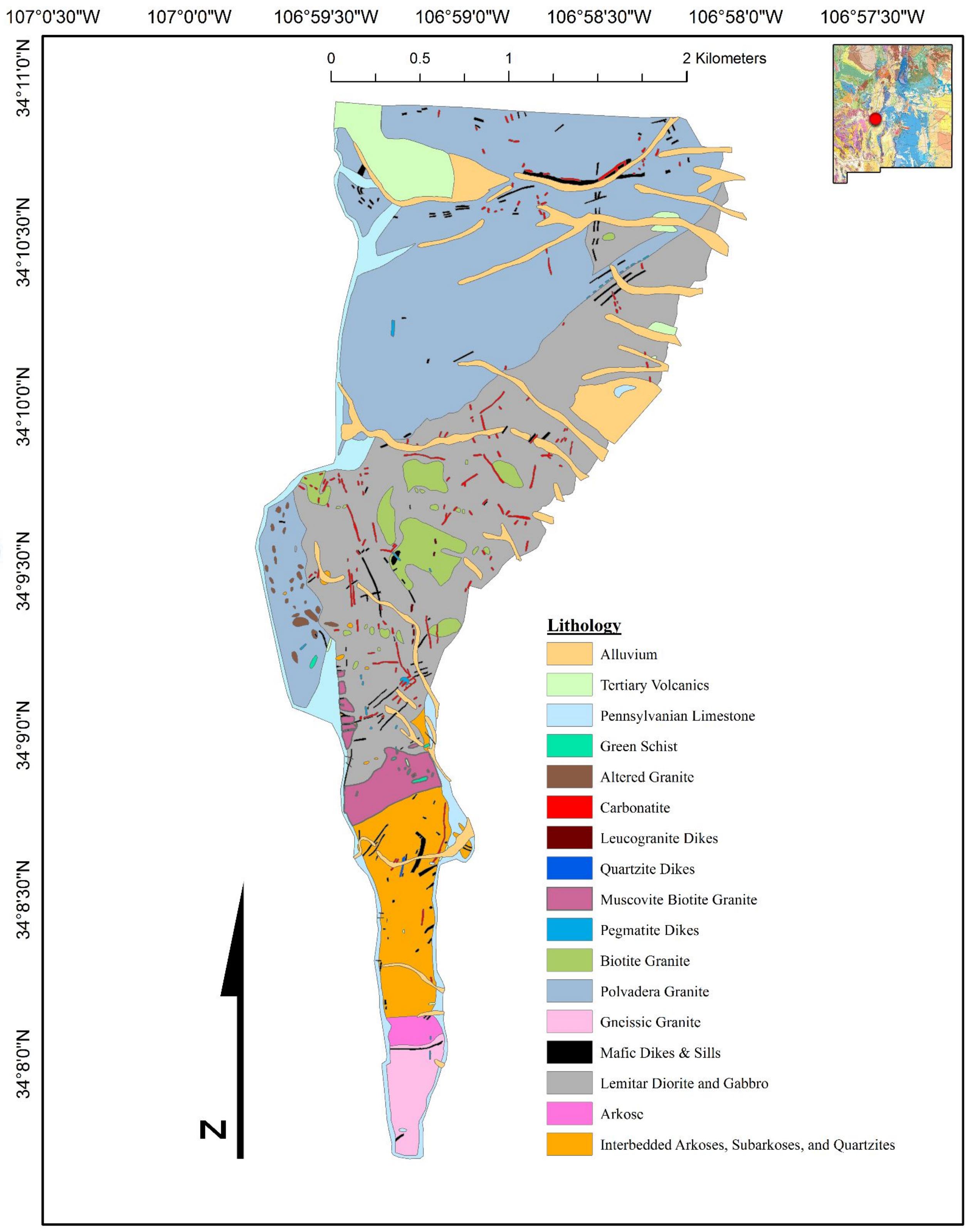


Wetherill Plot of U-Pb isotopic data collected from Lemitar carbonatite zircons. All analyses are concordant with an age of 514.06 ± 2.73 Ma (2 s.d.)



^{13}C and ^{18}O stable isotope scatter plot of Lemitar carbonatite; includes new data and data from Ackerman and others (2021). ^{13}C normalized to Pee Dee Belemnite (PDB) and ^{18}O is normalized to standard mean ocean water (SMOW).

Fig. 1: Geologic Map of the Lemitar Mountains Mining District (McLemore 1979, 1981) - Digitized 2022



Minerals Occurring in Lemitar Mountains Carbonatite

Mineral	**Composition**	**Description**
Quartz	SiO_2	Colorless euhedral crystals. Comb-forming veins to massive.
Albite	$NaAlSi_3O_8$	Magmatic phenocrysts in diorite xenoliths, polysynthetic twinning.
Sanidine	$KAlSi_3O_8$	Magmatic phenocrysts in diorite xenoliths and disseminated grains, diagnostic carlsbad twinning.
Microcline	$KAlSi_3O_8$	After albite, tartan twinning. Partially replaced by white phyllosilicate.
Perthite	$(Na,K)AlSi_3O_8$	Partially fenitized albite grains; microcline inclusions.
Biotite	$K(Mg,Fe)AlSi_3O_{10}(OH)_2$	One perfect cleavage, tan to dark brown, pleochroic.
Muscovite	$KAl_2(AlSi_3O_{10})(OH)_2$	Colorless to pleochroic pink. One perfect cleavage.
Chlorite var. Chamosite	$(Fe,Mg,Al)_6(Si,Al)_4O_{10}(OH,O)_8$	Yellow-purple-blue interference colors, acicular habit. Associated with hematite and magnetite, after biotite.
Phlogopite	$KMg_3(AlSi_3O_{10})(OH)_2$	After biotite, ragged, dark brown.
White Phyllosilicate	$KAl_2(AlSi_3O_{10})(OH)_2$	Commonly replacing feldspars, represents surficial weathering.
Hornblende	$(Ca,Na)_2(Mg,Fe,Al)_5(Al,Si)_8O_{22}(OH)_2$	Yellow-green to forest green euhedral crystals, amphibole cleavage, pleochroic.
Arfvedsonite	$Na_3(Fe,Mg)_4FeSi_8O_{22}(OH)_2$	Cyan to teal elongate lathes, amphibole cleavage, strong pleochroism.
Actinolite	$Ca_2(Mg,Fe)_5Si_8O_{22}OH_2$	Forms fine fibrous aggregates within miarolitic micro-cavities.
Ferro-edenite	$NaCa_2Fe_5(Si_7Al)O_{22}OH_2$	Patchy acicular to tabular crystals in altered diorite xenoliths.
Aegirine	$NaFeSi_2O_6$	Light brown to verdant green hexagonal to elongate euhedra, cleavage at 56 and 124 degrees. Moderate pleochroism.
Enstatite	Mg_2SiO_3	Massive to prismatic crystals with first order gray-tan birefringence.
Epidote	$Ca_2(Al_2,Fe)(SiO_4)(Si_2O_7)O(OH)$	Colorless to pale green, very fine grains. Associated with fenitization.
Scapolite	$(Ca,Na)_4(Al_6Si_6O_{24})(SO_4,CO_3)$	Associated with aegerine, high relief, requires further EMPA to confirm.
Sillimanite	$Al_2(SiO_4)O$	Fibrolitic to acicular, very fine, after phlogopite. Vug-filling.
Titanite	$CaTi(SiO_4)O$	Tan to light peach sphenoidal crystals. Associated with rutile.
Zircon	$Zr(SiO_4)$	Fine subhedral grains with 4th+ order birefringence, often clustered.
Baddeleyite	ZrO_2	Coarse zircon phase in primary carbonatites.
Ilmenite	$FeTiO_3$	Associated with titanite, amorphous to irregular habit, in fenite xenoliths.
Rutile	TiO_2	Associated with magnetite, very fine platy to acicular crystals.
Magnetite	Fe_3O_4	Trigonal to hexagonal. Partially replaced by hematite.
Hematite	Fe_2O_3	Pervasive, red/dark brown to opaque. Irregular to cubic and acicular habit. After pyrite. Stockwork forming.
Calcite	$CaCO_3$	Coarse crystalline veins to massive sheets, 4th order birefringence.
Dolomite	$CaMg(CO_3)_2$	Dusty sheets and irregular grains associated with calcite.
Apatite	$Ca_5(PO_4)_3(F,OH)$	Very fine elongate euhedra present as disseminated inclusions within calcite and dolomite
Xenotime	YPO_4	Colorless to pinkish tan. Irregular crystallinity, high relief, anomalously high birefringence.
Pyrochlore	$(Na,Ca)_2Nb_2O_6(OH,F)$	Irregular form, likely metamict. No cleavage, light brown, isotropic.
Bastnaesite	$(Ce,La,Y)CO_3F$	Tabular, one perfect cleavage. Transparent, high relief, and anomalous birefringence. Silver-gray in reflected light.
Fluorite	CaF_2	Purple to dark purple/black, cubic, isotropic. Very rare.
Barite	$BaSO_4$	Coarse euhedral crystals with light yellow 1st order birefringence.
Pyrite	Fe_2S	Occurs in trace amounts. Near completely altered to hematite.

DISCUSSION

Paragenetically, primary carbonatites were the first to be emplaced, followed by secondary/replacement carbonatites (both magnesiocarbonatite) and then by ankerite-dolomite carbonatites (ferrocarbonatite) and sövites (calciocarbonatite). Perry (2019) indicated that at least four generations of calcite occurred, therefore more study on the paragenesis is needed. Potassic fenitization follows magnesio- and ferrocarbonatite intrusions.

The presence of trace amounts of actinolite, sillimanite, and titanite in Lemitar primary carbonatite indicate a magmatic crystallization temperature at or above 700°C. Fenitization in country rock, arfvedsonite/aegirine mineralization, and successive generations of calcite and dolomite in Lemitar carbonatites show a hydrothermal environment persisted after initial carbonatite emplacement. Alteration of biotite to hematite and chlorite likely occurred as hydrothermal conditions cooled off (~500-300°C). Replacement carbonatites and rauhaugites (ankerite-dolomite carbonatite) represent the most oxidized portions of the Lemitar carbonatite system because of the predominance of hematite over magnetite.

A model proposed by Ackerman and others (2021) involves the fractionation of a mantle-derived CO_2-H_2O-F silicate melt that fractionates to “wet” phlogopite-bearing carbonatites, “dry” aegirine carbonatites, and nephelinite/ijolite (i.e. syenites) alkaline rocks. “Wet” carbonatites are found in the Lemitar and Chupadera Mountains, Monte Largo Hills, Caballo Mountains, Lobo Hills and Wet Mountains. “Dry” carbonatites are found in at Iron Hill and Wet Mountains, Colorado. Syenites, ijolites and other alkaline rocks are found at Iron Hill and in the Wet Mountains and Florida Mountains. The different magma compositions depend upon Si-Na-K-Mg contents, water activity, and melt ascent rate. More work is required to test this model.

CONCLUSIONS

- The Lemitar carbonatites are magmatic, mantle-derived rocks that are enriched in light REE and Nb (as shown by mineralogy, whole-rock chemistry, isotopic geochemistry).
- The age is about 515 Ma and indicates that the Lemitar carbonatite belongs to the Cambrian-Ordovician magmatic event in New Mexico and Colorado ($^{40}Ar/^{39}Ar$, U/Pb).
- The model presented by Ackerman and others (2021) provides a testable hypothesis for the origin of the Lemitar carbonatites and other magmatic and metasomatic rocks emplaced during the Cambrian-Ordovician magmatic event. Available Nd isotope data points to a relatively radiogenic primary source in the mantle beneath Mazatzal crust.
- The Lemitar carbonatites are not economic at the present time because of small tonnage and low grades. But drilling is required to determine if they increase in REE and Nb concentrations at depth (1.1% total REE in one sample is significant). Detailed geophysics is required to determine if the Lemitar Mountains could have a larger carbonatite intrusive in the subsurface.

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REFERENCES