GEOLOGY AND GEOCHEMISTRY
OF ORDOVICIAN CARBONATITE DIKES
IN THE LEMITAR MOUNTAINS,
SOCORRO COUNTY, NEW MEXICO

by

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ABSTRACT

Ordovician (449±16 m.y.) carbonatites intrude the complex Precambrian terrain in the Lemitar Mountains. They occur as dikes, stockworks, and veins and are not associated with any alkalic rocks or kimberlites. These radioactive carbonatites exhibit igneous textures and intrusive relationships with the country rocks and display the mineralogy and chemistry typical of such rocks. Sodic fenitization is present along some carbonatite dikes.

The Lemitar carbonatites can be grouped as 1) xenolith-bearing breccia and microbreccia silicocarbonatite dikes and 2) xenolith-free carbonatites. The xenolith-free carbonatites are subdivided into a) fine-grained calcitic to dolomitic silicocarbonatite dikes, b) sövite and rauhaugite veins, c) ankeritic-dolomitic carbonatite dikes, and d) stockwork carbonatites. Primary magmatic (with igneous textures) and replacement (with relict replacement textures) fine-grain calcitic to dolomitic silicocarbonatite dikes are differentiated. The Lemitar carbonatites consist of greater than 50% carbonate minerals with various amounts of magnetite, apatite, hematite, biotite/phlogopite, quartz, and numerous accessory minerals. These rocks are characterized by steep light rare-earth element enriched chondrite-normalized patterns, diagnostic of carbonatites. Similar carbonatites are found in the Chupadera Mountains, Socorro County and the Monte Largo area, Bernalillo County. The Lemitar carbonatites are enriched in uranium, thorium, rare-earth elements, barite, and fluorite; although the economic potential of these carbonatites is probably low.

The Lemitar carbonatites are similar in texture, emplacement, mineralogy, and chemistry to the mantle-derived carbonatites in the Wet Mountains, Colorado, which suggests that the Lemitar carbonatites have a similar origin. The strong fractionation and enrichment of light rare-earth elements of the Lemitar carbonatites and the chemical relationship between kimberlites and the Lemitar carbonatites would further support a mantle source. The Lemitar carbonatites probably represent the late phases of a carbonatite core which may exist at depth in the Lemitar-Socorro area.

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(in back pocket)

INTRODUCTION

The Lemitar Mountains are located approximately seven miles northwest of Socorro, New Mexico, along the western edge of the Rio Grande graben (figure 1). Most of the area is accessible throughout the entire year via dirt roads leading from the frontage road paralleling Interstate 25. The area is on the Lemitar 7½-min topographic map and is owned and administered by the Bureau of Land Management (BLM).

Radioactive calcareous basic dikes intruding the complex Precambrian terrain were first reported by Stroud and Collins (1954) and Anderson (1954, 1957). Since then a controversy has existed between geologists as to the nature of these dikes. Bonnichsen (1962) and Woodward (1973) identified them as lamprophyres of Precambrian or Tertiary age. McLemore (1980a, b, 1981) called them carbonatites. The economic potential of these dikes encouraged the New Mexico Bureau of Mines and Mineral Resouces to undertake additional detailed geologic mapping and petrographic, mineralogic, and geochemical studies to determine the nature and extent of these dikes and associated mineralization.

The study of carbonatites has recently become important due to their economic potential, their relationship to alkalic and kimberlite complexes, and their relationship to the nature and origin of silica-poor rocks. Carbonatites may be economically enriched in rare-earth elements (Mountain Pass, California), U, Th (Wet Mountains, Colorado), Nb (Iron Hill, Colorado), Fe (Iron Hill, Colorado), Cu, Ti, Mn, Zr, Sr, and Ba (Magnet-Cove, Arkansas). The Palabora complex, a unique carbonatite-alkalic complex in South

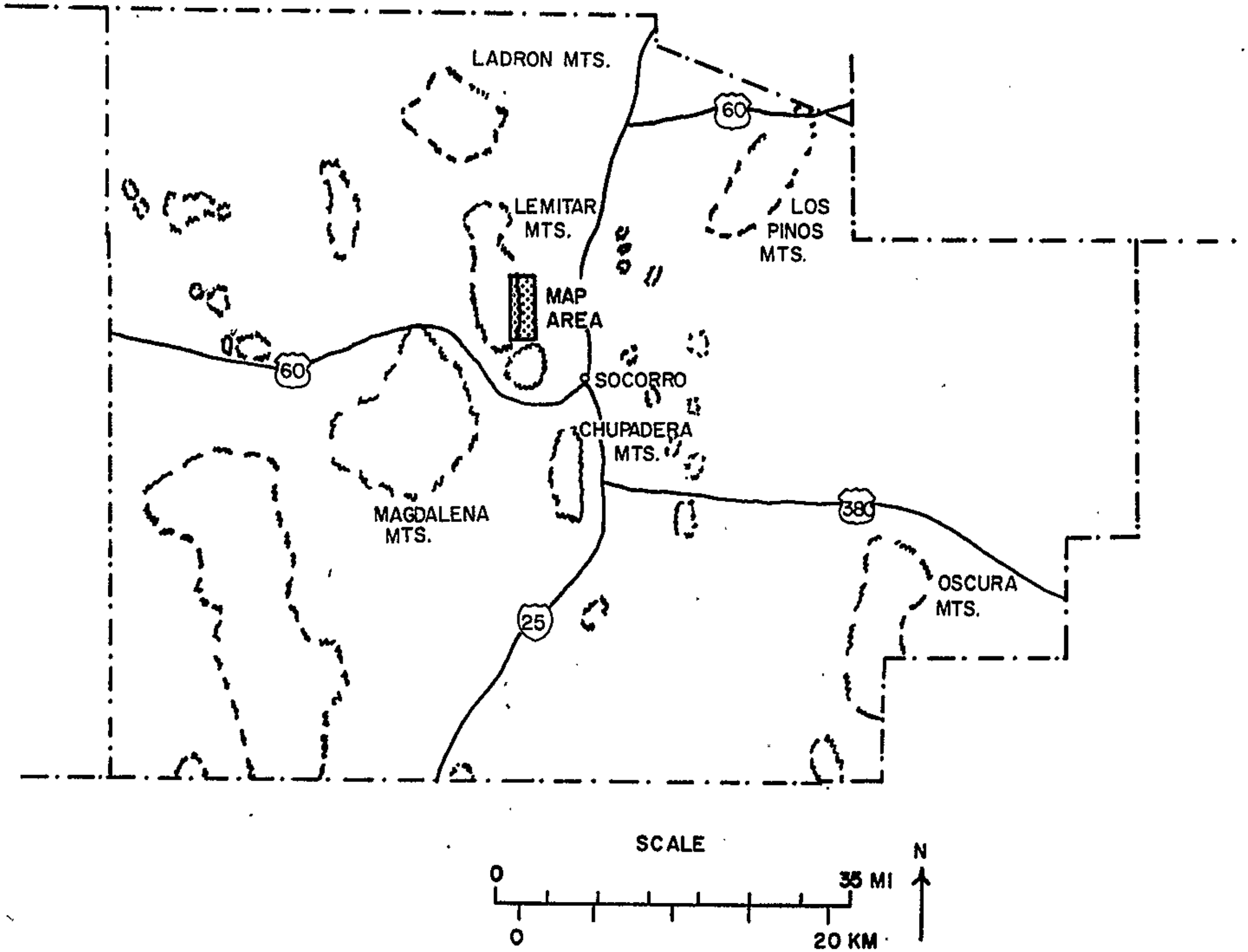

Figure 1 - Map of Socorro County showing area of study.

Africa, is currently producing copper ore and a number of by-products, including magnetite, baddeleyite, vermiculite, apatite, and uranothorianite. The relationship between carbonatites and kimberlites may delineate potential areas for the discovery of diamonds and may provide clues for the origin of these and other alkalic and silica-poor rocks.

Field work in the Lemitar Mountains began during the summer of 1978 and continued through August, 1979 as part of a master's thesis project (McLemore, 1980a, b). Work resumed in September, 1980 after the author joined the staff of the New Mexico Bureau of Mines and Mineral Resources.

Previous Work

The general geologic setting and the Precambrian rocks of the Lemitar Mountains are described by Darton (1928), Lasky (1932), Bonnichsen (1962), Woodward (1973), Chamberlin (1976, 1978a, b), Condie and Budding (1979), and McLemore (1980a, b). Woodward (1973) and Chamberlin (1978a) mapped the rocks of the Lemitar Mountains, while McLemore (1980a) mapped in detail the Precambrian rocks in the eastern Lemitar Mountains. Lasky (1932), Williams and others (1964), Williams (1966), and McLemore (1980a) describe the various fluorite, barite, and minor sulfides deposits in the Lemitar Mountains. The occurrence of uranium in the "calcareous basic" dikes was first reported by Stroud and Collins (1954) and Anderson (1954, 1957). The first mining claims for uranium, fluorite, and sulfides were filed in 1954 (Socorro County courthouse records) and the U.S. Bureau of Mines investigated several of these claims for their uranium potential during 1952 through

1955 (unpublished U.S. Bureau of Mines report).

In 1956, the U.S. Atomic Energy Commission conducted an airbourne radiometric survey over the Lemitar Mountains to specifically detect these radioactive dikes (Collins and Smith, 1956). The results were negative and the radioactive dikes were not detected due to turbulent air conditions and a high radioactive background of the Tertiary volcanics. As a part of the U.S. Department of Energy's NURE (National Uranium Resource Evaluation) program, an aerial radiometric and magnetic survey (ARMS) and a hydrogeochemical and stream-sediment reconnaissance (HSSR) survey were conducted over the 1 by 2 degree Socorro quadrangle (map scale 1:250,000), including the Lemitar Mountains area (Geodata International, Inc., 1979 and Planner and others, 1980). Radiometric anomalies were detected west of the Rio Grande in the Lemitar-Socorro area and anomalously high uranium concentrations were detected in stream sediments from the Rio Grande east of Lemitar. However, these surveys were conducted over a large area and it would be difficult to attribute these anomalies to the Lemitar carbonatites. Finally, in a more recent NURE report, Pierson and others (1980) indicated that the radioactive dikes in the Lemitar Mountains were unfavorable for significant uranium deposits.

Methods of Study

This project started as a master's thesis project in 1978 and continued until early 1980 (McLemore, 1980a, b). A detailed outcrop geologic map of the southern half of the Precambrian terrain in the eastern Lemitar Mountains was compiled at a scale of 1:6000 (McLemore, 1980a). Mineralogic and chemical studies of eight samples of carbonatites were completed at that time (appendix A).

During the summer of 1980, rare-earth elements and several additional trace elements (appendix A) were obtained by Steve White and Phil Allen (New Mexico Institute of Mining and Technology) by neutron activation methods. In September, 1980, the entire Precambrian terrain of the eastern Lemitar Mountains was mapped at a scale of 1:12,000 (plates 1 and 2). Plate 1 is an outcrop geologic map of the Precambrian rocks of the eastern Lemitar Mountains, while plate 2 is a simplified interpretative geologic map which also shows the trends of carbonatite and mafic dikes, differentiates the various types of carbonatite dikes, shows the dips and radioactivity of the carbonatite dikes, and shows the sample locations. Cross sections are shown on plate 3. Additional mineralogic and chemical analyses, not previously reported, are included in appendix A; analytical procedures are described in appendix B. A sample of a silicocarbonatite dike, number 80-11-1, was sent to Geochron Laboratories for an age determination. These results are given in table 1.

A geometrics gamma-ray scintillometer, model GR-101A, was used during the mapping in 1980 to determine radioactivity, shown on plate 2. The field work during 1980 was supported by the New Mexico Bureau of Mines and Mineral Resources.

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Definitions and Classifications of Carbonatites

Various definitions of carbonatites have been proposed by many different authors, but the simplest, most concise definition is by Heinrich (1966, p. 13): "a carbonatite is a carbonate-rich rock of apparent magmatic deviation or descent". This definition may be considered too broad since it includes carbonate deposits formed by hot fluids, many of which are different from the "classical" carbonatite complex. Therefore other factors should be considered in defining a carbonatite complex. Most carbonatites are associated with kimberlites, alkalic rocks, or alkaline igneous provinces; however, there are exceptions to this association (Moore, 1973; Heinrich, 1966). A distinct mineralogy and chemistry characterizes carbonatite complexes--greater than 50% carbonate minerals and varying amounts of apatite, magnetite, and pyroxenes which result in the enrichment of CaO, total iron, CO_2, and P_2O_5 and the depletion of SiO_2 relative to other igneous rocks. A variety of accessory minerals, including bastnaesite, fluorite, rutite, biotite, phlogopite, zircon, pyrochlore, vermiculite, and nepheline are common and reflects the concentrations of assorted trace elements. However, because of the diversity in mineralogy and chemistry in carbonatite complexes, they cannot be used alone in defining these rocks.

The idealized or "classic" geologic environment of carbonatite complexes is as one or more plugs or stocks surrounded by cone sheets or ring dikes of carbonatite and alkalic rocks, such as at Fen, Norway (Heinrich, 1966); Alnö, Sweden (von Eckermann, 1948); and Magnet Cove, Arkansas (Erickson and Blade, 1963). A halo of fenites generally surrounds the complex and may be adjacent to the cone sheets or ring dikes. Fenites are the product of a distinct alkalic metasomatic alteration, called fenitization, generally associated with most carbonatite, kimberlite, and alkalic complexes. Carbonitization, feldspathic, and argillic alteration may also be associated with carbonatite complexes.

Carbonatites also occur as dikes, stockworks, or sills without any exposed central plug or stock, such as at Wet Mountains, Colorado (Armbrustmacher, 1979). Generally, these carbonatites are also associated with kimberlites or alkalic complexes; although rare occurrences of carbonatite dikes, lenses, or sills have been documented at Strangways Range, Australia (Moore, 1973); Ravalli County, Montana; and Verity, British Columbia (Heinrich, 1966) without any associated alkalic rocks, kimberlites, or alkaline igneous province. Volcanic lava flows of carbonatite have been reported at Fort Portal, Uganda and Oldoinyo Lengai, Tanzania (Heinrich, 1966).

Carbonatites constitute only a small fraction of the earth's surface, but are found on every continent except Antartica. Over 300 known occurrences of carbonatites are reported and described in the literature. Carbonatite complexes range in age from Precambrian (2060 m.y., Palabora complex) to the present (active volcano, Oldoinyo Lengai, Tanzania). The general geology and distributions of carbonatites are described by Heinrich (1966), Gold (1966), Moore (1973), Le Bass (1977), and Nishimori and Powell (1980).

Various nomenclatures of different carbonatite bodies have been used by different authors in the past (Heinrich, 1966, p. 12); however, a simplified nomenclature has been adopted for the purposes of this report:

sövite--greater than 90% calcite;
rauhaugite--greater than 90% ankerite or dolomite;
silicocarbonatite--greater than 50% carbonate minerals
    plus various silicate minerals; and
carbonatite--greater than 50% carbonate minerals.

These terms may be prefixed by dominant accessory minerals.

Carbonatites within a complex have been grouped in various ways using different criteria. The carbonatites of the Wet Mountains complex, Colorado are grouped by Heinrich and Dahlem (1969) into three types based on the most abundant minerals present--calcite or dolomite carbonatite, carbonatite-potassium feldspar rocks and barite-fluorite-bearing carbonatites. Parker and Sharp (1970) grouped the carbonatites intruding the Gem Park complex, Colorado into mineralogic varieties--dolomite-pyrochlore, dolomite-apatite, dolomite-amphibole-pyrochlore, and dolomite-barite-monzonite. Carbonatites can be grouped according to their time of emplacement, chemical composition, or other distinctive geologic relationships.

A simple classification based on petrographic characteristics in thin section is proposed by Armbrustmacher (1979). Carbonatites can be differentiated as to primary magmatic or replacement carbonatites using texture and mineralogy as the primary criteria. Primary magmatic carbonatites exhibit primary igneous textures--

either hypidiomorphic-granular or porphyritic; whereas replacement carbonatites are characterized by fine- to coarse-grained carbonate partially or completely replacing relict phenocrysts of feldspars, pyroxenes, and amphiboles, thereby preserving the original texture of the rock. The presence or absence of replacement characteristics are not apparent in the field, however, some differences in mineralogy between primary magmatic and replacement carbonatites do occur (Armbrustmacher, 1979, p. 892).

The carbonatites in the Lemitar Mountains are grouped according to distinctive petrologic and mineralogic characteristics. This particular grouping of the Lemitar carbonatites is easy to use in the field and each group has a distinctive mineralogy, major and trace element chemistry, and time of emplacement.

Geologic Setting

The Lemitar Mountains form part of the eastern edge of the Rio Grande rift. The north-trending fault blocks which form the rift have exposed Precambrian rocks along two parallel ridges of the Lemitar Mountains. These Precambrian rocks consist of a sequence of metamorphosed and recrystallized arkoses and quartzites (the Corkscrew Canyon sequence) intruded sequentially by mafic dikes, a mafic intrusive body (the Lemitar diorite/gabbro), a granitic complex (Polvadera granite, altered facies, biotite granite, muscovite-biotite granite, and gneissic granite), and carbonatite dikes (plate 1). The Precambrian rocks exposed on the western ridge consist of granitic rocks similar in composition to the Polvadera granite (Chamberlin, 1978a). These rocks are overlain unconformably or in fault contact with Paleozoic sandstones and limestones and Tertiary volcanics and sediments (Chamberlin, 1978a). McLemore (1980a) mapped the Precambrian rocks in detail and includes descriptions and chemical analyses of the various types. Chamberlin (1978a) maps the general geology of the Lemitar Mountains, including good cross sections.

At least five periods of tectonic activity have affected the Lemitar-Socorro area:

1) Precambrian to Ordovician;
2) Mississippian to Permian (ancestral Rocky Mountains);
3) late Cretaceous to middle Eocene (Laramide orogeny);
4) Oligocene volcanism and cauldron formation (Datil-Mogollon volcanic field, Socorro cauldron); and
5) Tertiary volcanism and faulting (Rio Grande rift).

The reinforced northerly structural trends of the Precambrian rocks of the Lemitar Mountains are due to superimposed and overlapping faults and uplifts occurring during these five periods of tectonic activity. Precambrian, late Paleozoic, and Cretaceous to Eocene structures are partly reinforced and partly buried by volcanism and faulting during the formation of the Socorro cauldron and Rio Grande rift. Young rift-faults have rotated and tilted older features, further complicating the structural pattern. Further details of the tectonic setting of the Lemitar-Socorro area are described in McLemore (1980a), Woodward (1973), and Chamberlin (1976, 1978b, 1980, 1981).

GEOLOGY OF LEMITAR CARBONATITES

The Lemitar carbonatites occur as dikes, stockworks, and veins and are not associated with any alkalic rocks. Over one hundred carbonatite dikes intrude the complex Precambrian terrain in the Lemitar Mountains (plates 1 and 2) and range in thickness from less than a centimeter to over a meter. The dikes locally resemble weathered limestone in appearance, however, they generally form sharp intrusive contacts with the country rocks (figure 2). Alteration, shearing, and other physical deformation of the country rocks occurs adjacent to some carbonatite dikes. The carbonatite dikes exhibit variations in texture, mineralogy, chemistry, and distribution. Many dikes are homogeneous in that they lack any internal structure; but some brecciated and foliated dikes are preserved. Foliation or banding, formed by the mineralogic and textural differences within the carbonatite, parallels the dike margins (figure 3). Fine-grained chilled margins are locally present (figure 4), indication of an intrusive emplacement.

Although most carbonatite dikes are discontinuous along strike due to pinchouts, erosion, or faulting; a few dikes can be traced intermittently along strike for up to 600 meters (plate 2). Dikes locally form subparallel dike swarms with undisturbed country rock separating the segments; while other dikes grade into a system of carbonatite veins or stockwork.

The carbonatites strike dominantly north-south or east-west with variable dips, generally to the west or south (plate 2). Many of them have orientations similar to the direction of jointing and fracturing in the country rocks; while other

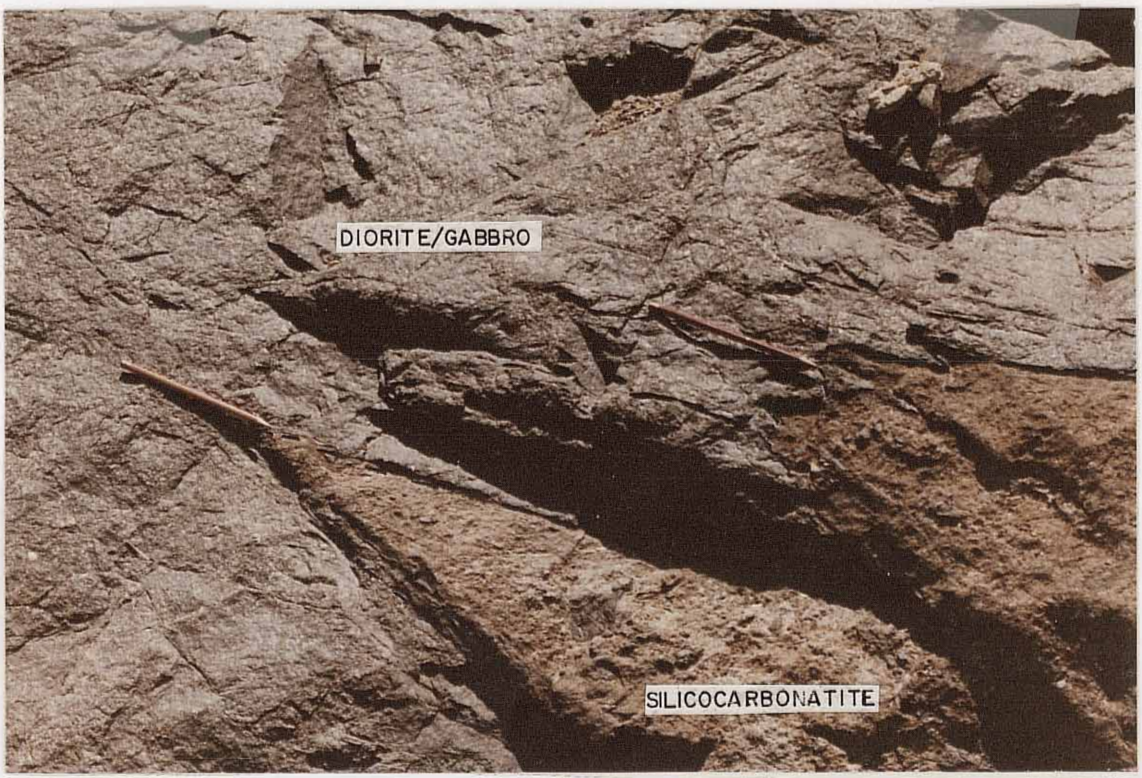

Figure 2 - Photograph of a xenolith-bearing breccia silicocarbonatite dike intruding the Lemitar diorite/gabbro (section 7, T. 2 S., R. 1 W.).

Figure 3 - Photograph of a foliated breccia silicocarbonatite dike intruding weathered Lemitar diorite/gabbro (near Hot Streak adit, section 5, T. 2 S., R. 1 W.).

Figure 4 - Photograph of a foliated fine-grained silicocarbonatite dike. Note darker chilled margin at lower left-hand corner. Scintillation counter reading is approximately 160 cps.

carbonatite dikes parallel or intrude along the margins of the mafic dikes. This evidence suggests that the emplacement of the carbonatite dikes may have been controlled by pre-existing fracture zones. Where these fracture zones did not exist, the carbonatite fluids appear to have shattered portions of the Polvadera granite forming a stockwork pattern of randomly orientated veins of carbonatite.

The carbonatite dikes do not appear to form any circular or elliptical patterns on the geologic map (plates 1 and 2); however, any interpretation of the attitude of these dikes depends upon how much the Lemitar Mountains were tilted since the intrusion of the carbonatite dikes. Unfortunately, this is not known for certain. If the tilting amounts to 60-70 degrees in the southern portion of the mapped area and 40-50 degrees in the northern portion--the average dip of the Paleozoic sediments--many of the carbonatite dikes attain an attitude of much lower dips, still to the west in many cases. However, other variables in which there are no known constraints such as the amount of tilting prior to the deposition of Mississippian and Pennsylvanian sediments and the numerous unmapped faults in the Precambrian terrain have to be considered. The best interpretation of the attitudes of these dikes possible is that a rotation of 60-70 degrees in the southern portion of the mapped area and 40-50 degrees in the northern portion has occurred.

AGE OF THE LEMITAR CARBONATITES

A K-Ar date was obtained on a biotite concentrate from a primary magmatic silicocarbonatite (sample number 80-11-1, plate 2) of 449±16 m.y. (table 1). This age date corresponds well with the range of late Precambrian to Mississippian times determined by field relationships (McLemore, 1980a, b). The Lemitar carbonatites intrude late Precambrian granites and mafic dikes and are not found intruding the Mississippian and Pennsylvanian sedimentary rocks. Other alkalic and carbonatite rocks were emplaced during late Precambrian to Ordovician times in New Mexico and Colorado (figure 5), further supporting this age date.

Some problems may exist with this K-Ar date. The brown biotite concentrate used for dating purposes was slightly contaminated by green phlogopite and may have altered the K-Ar date. The effect of fenitization by late-stage carbonatite activity or potassium metasomatism which occurred during Tertiary times (Chapin and others, 1978) on the biotite is unknown and may have altered the date. An increase in potassium would decrease the age, while an increase in argon would increase the age. It is doubtful that any substantial age difference would occur, although additional age determinations would provide a more precise age date.

TABLE 1 - K-Ar age and analytical data for a biotite concentrate from a primary magmatic silicocarbonatite from the Lemitar Mountains

(Decay constant K^{40} $\lambda\beta = 4.72 \times 10^{-10}$/yr.; $\lambda_e = 0.585 \times 10^{-10}$/yr.; $K^{40}/K = 1.22 \times 10^{-4}$g./g. Analysts Geochron Laboratories Division, Krueger Enterprises, Inc. Massachusetts).

Sample No.	Mineral analyzed	Ave. percent K	K^{40},ppm	Radiogenetic Ar^{40}, ppm.
80-11-1	biotite	7.549	9.209	0.2734

Radiogenic Ar^{40}/Total Ar^{40}	Age, m.y.	Location
0.929	449 ± 16	NW¼ sec. 7, T. 2 S., R. 1 W. (see plate 2)

NOTE: m.y. refers to millions of years

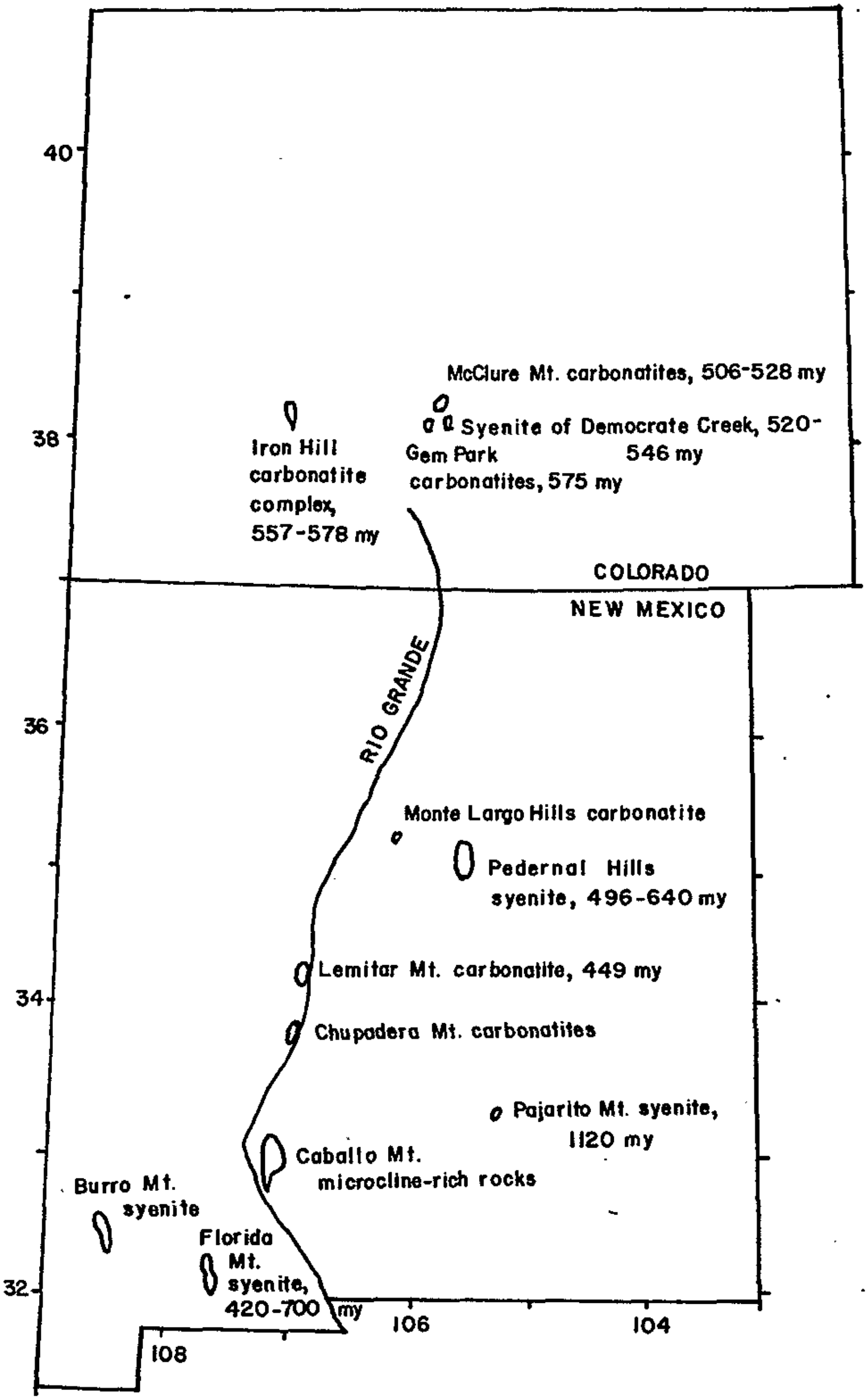

Figure 5 - Map of New Mexico and Colorado showing Precambrian-Ordovician carbonatite and alkalic complexes, including ages of each, if known. Dates from Brookins (1974 and 1980), Fenton and Faure (1970), Kelley (1968), Loring and Armstrong (1980), Olson and others (1977), and this report.

PETROLOGY OF THE LEMITAR CARBONATITES

One of the characteristics of the Lemitar carbonatites is the variations in texture, mineralogy, and chemistry between different dikes. In spite of these variations, the Lemitar carbonatites can be differentiated as:

1) xenolith-bearing breccia and microbreccia silicocarbonatite dikes, and
2) xenolith-free carbonatites.

The xenolith-free carbonatites can be further differentiated according to texture and mineralogic composition as:

a) fine-grained calcitic to dolomitic silicocarbonatite dikes;
b) sövite and rauhaugite veins;
c) ankeritic-dolomitic carbonatites; and
d) stockwork carbonatites.

The xenolith-bearing breccia and microbreccia silicocarbonatite dikes are light- to medium-gray and weathers to a medium- to dark-brown. These dikes resemble the fine-grained calcitic to dolomitic silicocarbonatites in appearance, texture, and composition; the only distinguishing feature is the presence of rock fragments (xenoliths) in the breccia and microbreccia silicocarbonatites. On a weathered surface, xenoliths and large phenocrysts may stand out in relief due to preferential weathering of the carbonatite matrix (figure 6).

The breccia and microbreccia silicocarbonatites occur in the central portion of the mapped area (sections 6 and 7, T. 2 S., R. 1 W., plate 2), where the best exposures of the carbonatites

Figure 6 - Photograph of a xenolith-bearing breccia silicocarbonatite dike.

are present. One of the breccia silicocarbonatite dikes is well-exposed in the bottom of an arroyo near the section line between sections 6 and 7, T. 2 S., R. 1 W. (plate 2). Here the silicocarbonatite dike has intruded the Lemitar diorite/gabbro and a mafic dike and is in turn intruded by a sövite vein (figure 7).

A porphyritic or hypidiomorphic-granular texture prevails in thin section (figure 8), indicating that these dikes are primary magmatic (Armbrustmacher, 1979). Resorption of phenocrysts is common in thin section, further evidence of the igneous origin of these dikes. The phenocrysts and xenoliths may be cracked and corroded or partially or completely replaced by carbonate.

These xenolith-bearing silicocarbonatite dikes consist of xenoliths (5-40%) and greater than 50% carbonate matrix (calcite and dolomite, determined by whole-rock x-ray diffraction). Minor and accessory minerals include 2-10% magnetite/ilmenite, 5-10% apatite, 5-15% biotite/phlogopite, less than 2% feldspar, and various trace amounts of purple fluorite, garnet, hornblende, muscovite/sericite, ankerite, chlorite, barite, hematite/goethite, garnet, galena, chalcopyrite, pyrite, pyrrhotite, sphene/leucoxene, quartz, zircon, sphalerite, and bastnaesite.

Xenoliths (figures 6 and 9) vary in size from less than a few millimeters (microbreccia) to a meter across (breccia). Xenoliths also vary in lithology, including fragments of the host rock (generally diorite/gabbro or mafic dike), foliated granites, foliated arkoses, quartzites, gray and green schist, gray phyllites, and red granitic fenites. Gray phyllites are the only xenolith

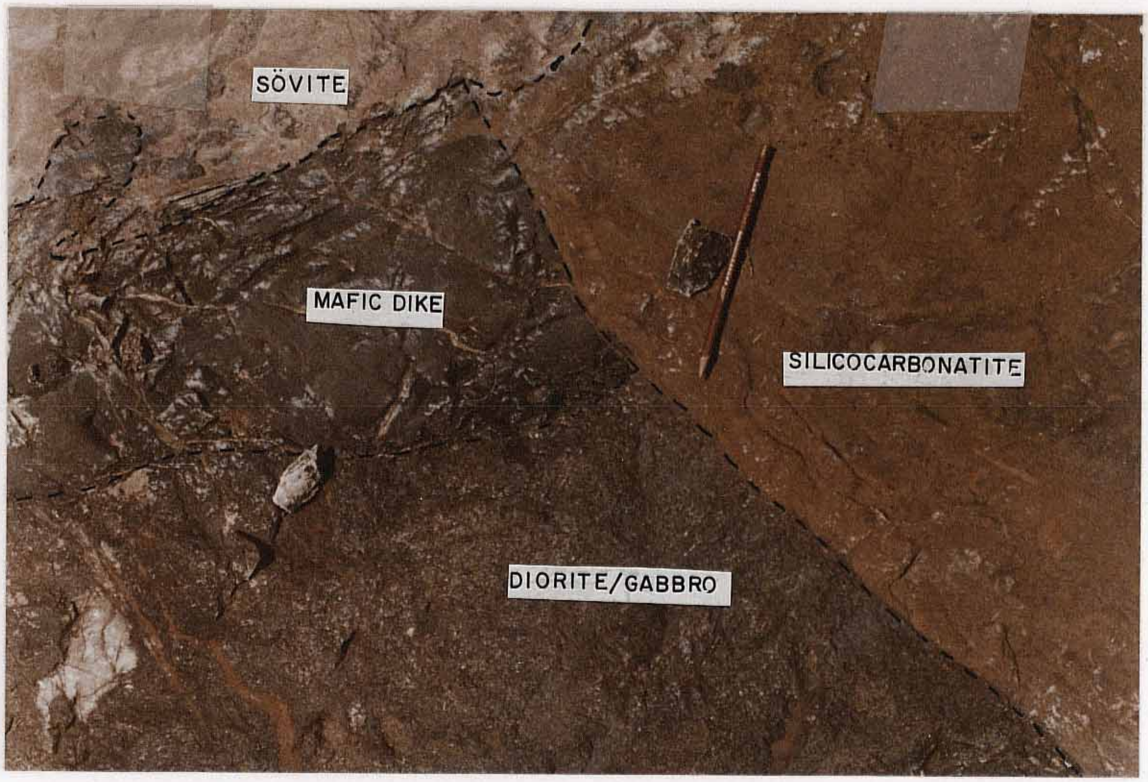

Figure 7 - Photograph of a breccia silicocarbonatite dike intruding a mafic dike and Lemitar diorite/gabbro. Note sövite vein cutting breccia silicocarbonatite dike.

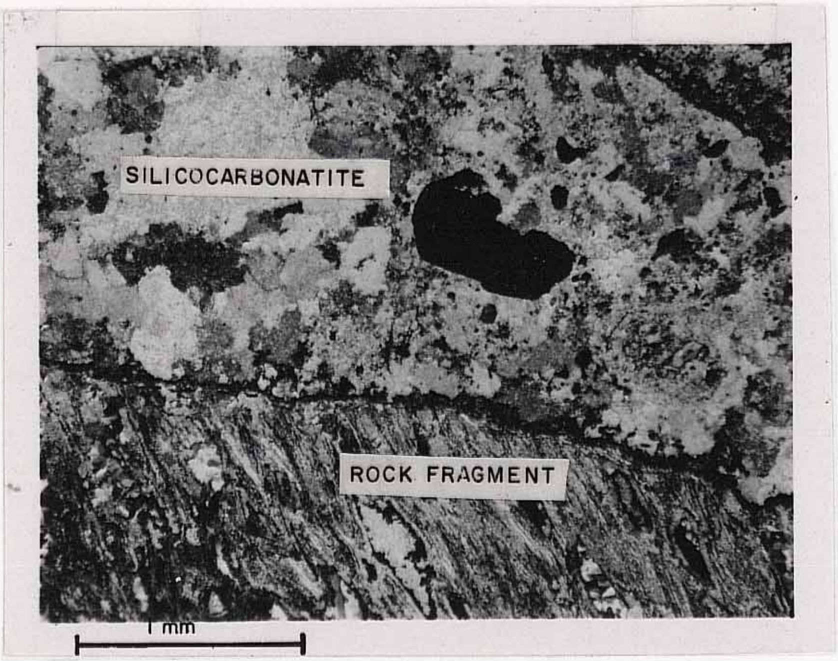

Figure 8 - Microphotograph (crossed nicols) of a primary magmatic silicocarbonatite. Note the reaction rim of mica surrounding the rock fragment (gneissic granite). The large dark grain in the center of the photograph is an apatite crystal.

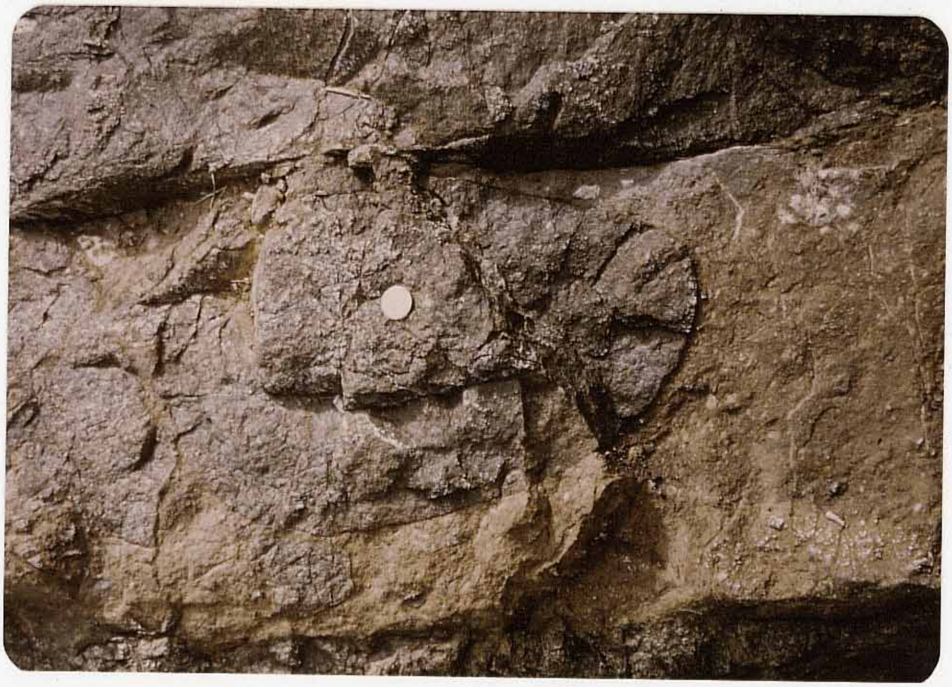

Figure 9 - Photograph of a rounded diorite/gabbro xenolith in a breccia silicocarbonatite dike.

not exposed in the Lemitar Precambrian terrain, although similar rocks outcrop in the Precambrian terrain exposed in the Chupadera Mountains (20 miles south of Socorro, figure 1), where they are mapped as pelitic schists (Sue Kent, unpublished geologic map of the Precambrian rocks in the Chupadera Mountains, 1980). Many granitic xenoliths resemble the Polvadera granite in appearance, texture, and mineralogic composition; whereas other granitic xenoliths are completely or partially altered to a red granitic fenite composed of K-feldspar and biotite or chlorite with little or no quartz or plagioclase. Many rimmed xenoliths exhibit well-rounded and spherical cross sections as a result of chemical reactions with the carbonatite fluids; but in some instances reaction rims are absent suggesting that rounding may be a result of collisions with each other and the surrounding wall rock. The variation of different sizes, shapes, and roundness of xenoliths within the same dike could be interpreted as representing a violent, explosive emplacement of these dikes.

Xenolith-free, fine-grained calcitic to dolomitic silicocarbontite dikes are light- to medium-gray and weathers to a brownish-gray outcrop that resembles weathered limestone in appearance. These dikes are distributed throughout the mapped area (plate 2) and may grade into breccia and microbreccia silicocarbonatite dikes or ankeritic-dolomitic carbonatite dikes. Most of these dikes are homogeneous (figure 10); however, foliation or banding may be preserved locally (figure 4). These silicocarbonatite dikes consist of greater than 60% carbonate matrix (calcite, dolomite), 5-15% magnetite, 10-20% mica (biotite, phlogopite,

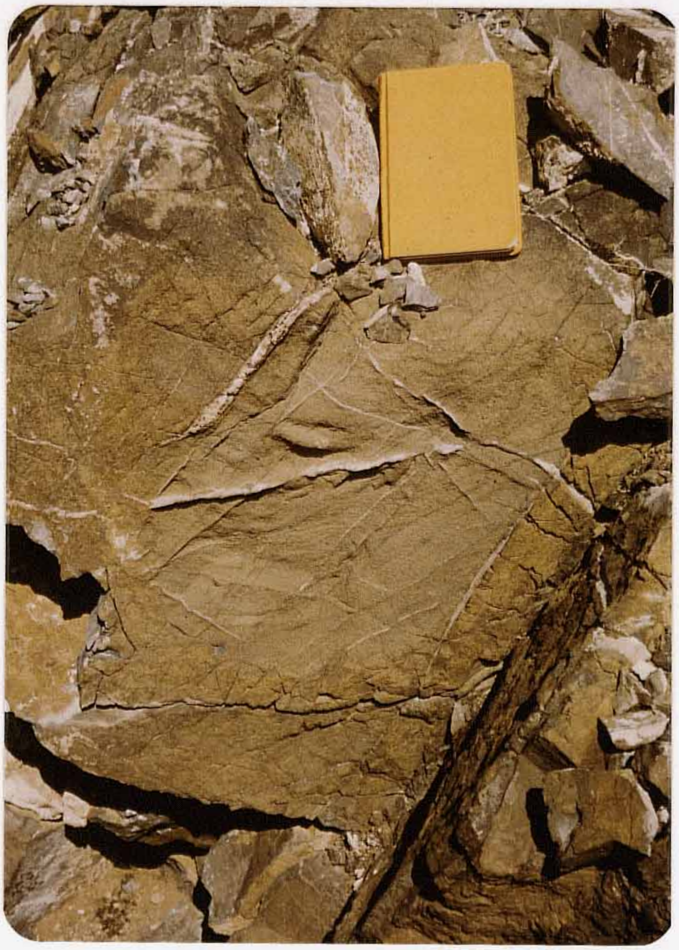

Figure 10 - Photograph of a fine-grained silicocarbonatite dike.

muscovite, sericite, chlorite), 5-10% apatite, and various amounts of purple and green fluorite, hornblende, quartz, feldspar, barite, ilmenite, hematite, pyrite, sphene/leucoxene, sphalerite, galena, pyrrhotite, quartz, and ankerite. One occurrence of a fine-grained silicocarbonatite dike (sample LEM-820, sec. 7, T. 2 S., R. 1 W., plate 2) contains thin veins of radioactive (3000 times background radioactivity) purple fluorite and various sulfide minerals. The uranium content of a sample of the vein is 0.25% U_3O_8; however, the uranium content of a sample of the purple fluorite is 0.025% (analyses from L. Brandvold, New Mexico Bureau of Mines and Minerals chemistry laboratory). This suggests that the uranium may occur in the sulfides.

In thin section, two types of textures dominate in the xenolith-free silicocarbonatite dikes--either a primary igneous texture (porphyritic or hypidiomorphic-granular) or a relict replacement texture. The porphyritic and hypidiomorphic-granular textures (figure 11) are similar to the textures observed in the breccia and microbreccia silicocarbonatite dikes (figure 8) and indicates a primary magmatic origin (Armbrustmacher, 1979). Two types of relict replacement textures are observed in the silicocarbonatite dikes; original, porphyritic or ophitic to subophitic textures are preserved by the partial or complete replacement of original feldspar and hornblende phenocrysts by carbonatite fluids (figures 12 and 13). The original rocks were mafic dikes, granites, or diorite/gabbro as determined by the preserved textures and minerals.

Figure 11 - Microphotograph (crossed polars) of a primary magmatic fine-grained silicocarbonatite dike (left-hand side) intruding the Lemitar diorite/gabbro. Note the veined magnetite crystal (dark) in the center of the slide.

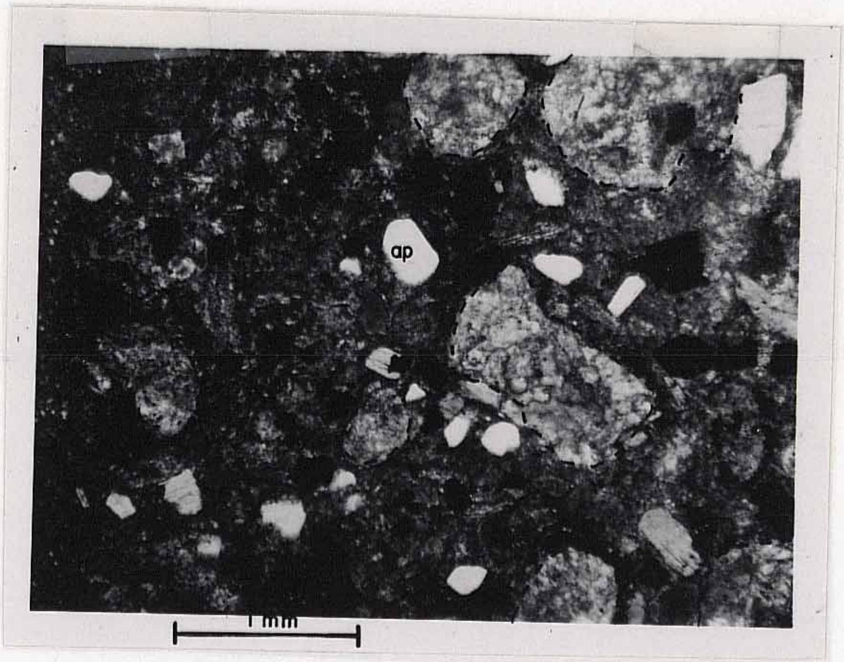

Figure 12 - Microphotograph (plane light) of a replacement silicocarbonatite dike exhibiting relict porphyritic texture. Carbonate has replaced the feldspar phenocrysts (outlined). The colorless crystals are apatite.

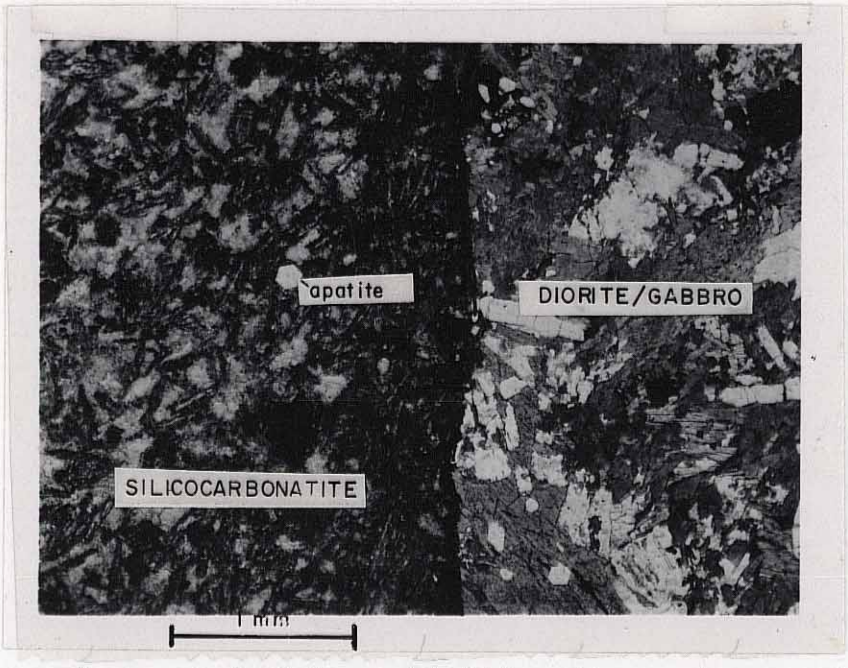

Figure 13 - Microphotograph (plane light) of a replacement silicocarbonatite dike exhibiting subophitic texture and in contact with the Lemitar diorite/gabbro (right-hand side). Note colorless hexagonal apatite grain near the center of the photograph.

A mineralogic difference exists between the primary magmatic breccia and microbreccia and fine-grained silicocarbonatites and the replacement silicocarbonatites. Apatite is more abundant in primary magmatic dikes, whereas magnetite is more abundant in replacement dikes; although apatite and magnetite may be present in either. The presence or absence of assorted accessory minerals varies. Fluorite, sulfides, pyrite, sphene, and quartz are more abundant in primary magmatic dikes, whereas hematite and magnetite are more abundant in replacement dikes. Similar differences in mineralogy between primary magmatic and replacement carbonatites are described from carbonatites in the Wet Mountains, Colorado (Armbrustmacher, 1979).

The replacement silicocarbonatite dikes are carbonatites in that they consist of greater than 50% carbonate minerals and are of magmatic derivation by their association with the primary magmatic silicocarbonatites. Various accessory minerals are present in these replacement dikes which are not typical of the replaced country rock (apatite, pyrrhotite, fluorite, barite, hornblende, and sulfides), further suggesting that these dikes are indeed carbonatites.

Thin sövite (greater than 90% calcite) and rauhaugite (greater than 90% dolomite) veins intrude many carbonatite dikes. Many of the sövite veins resemble caliche coatings in appearance, except that these chalk-white veins contain small inclusions of the wallrock (diorite/gabbro or mafic dike). Larger sövite veins (up to three or four centimeters thick) follow pre-existing fractures or along silicocarbonatite or mafic dikes and some are highly radioactive (up to 3000 times background). Box-work patterns of intersecting white sövite veins at many places intrude the diorite/gabbro (figure 14) and some are associated with thin barite veins. Many of these veins can be traced to a silicocarbonatite or ankeritic-dolomitic carbonatite dike, especially where exposed by prospect pits or trenches. Microscopically, sövite and rauhaugite veins crosscut the carbonatite matrix, xenoliths, and phenocrysts (figures 15 and 16). The carbonate in these microscopic veins is larger in grain size than the matrix and may contain inclusions of magnetite, quartz, biotite, hematite, and apatite. Clearly these veins represent periodic hydrothermal stages of carbonatite activity.

Ankeritic-dolomitic carbonatite dikes are dusky-red to moderate reddish-brown (on both fresh and weathered surfaces), fine- to medium-grained carbonatites (figure 17 and 18), ranging in size from a few centimeters to over a meter wide and up to 500 meters long. These dikes occur throughout the northern portion of the mapped area (plate 2). The dikes consist of varying amounts of ankerite, dolomite, calcite, quartz, barite, fluorite, hematite/goethite, and trace amounts of apatite, biotite/phlogopite, muscovite/sericite, chlorite, pyrite, hornblende, magnetite/ilmenite, galena, sphalerite, and molybdenite. These dikes are not radioactive although localized seritized granitic bodies associated with them may be slightly radioactive. Hematitization has obscured the textures and mineralogies of many of these dikes in thin section. However, both primary magmatic (hypidiomorphic-granular textures) and replacement (relict porphyritic or granitic textures) dikes

Figure 14 - Photograph showing box-work patterns of white sövite veins intruding the Lemitar diorite/gabbro.

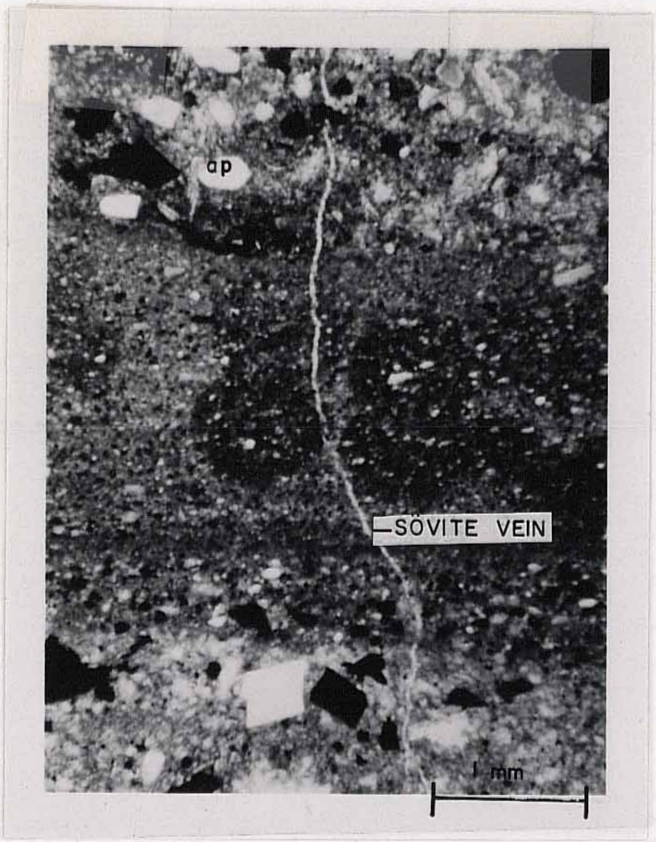

Figure 15 - Microphotograph (plane light) of a sövite vein intruding a replacement silicocarbonatite. Note the flow banding of the dark magnetite and colorless apatite crystals.

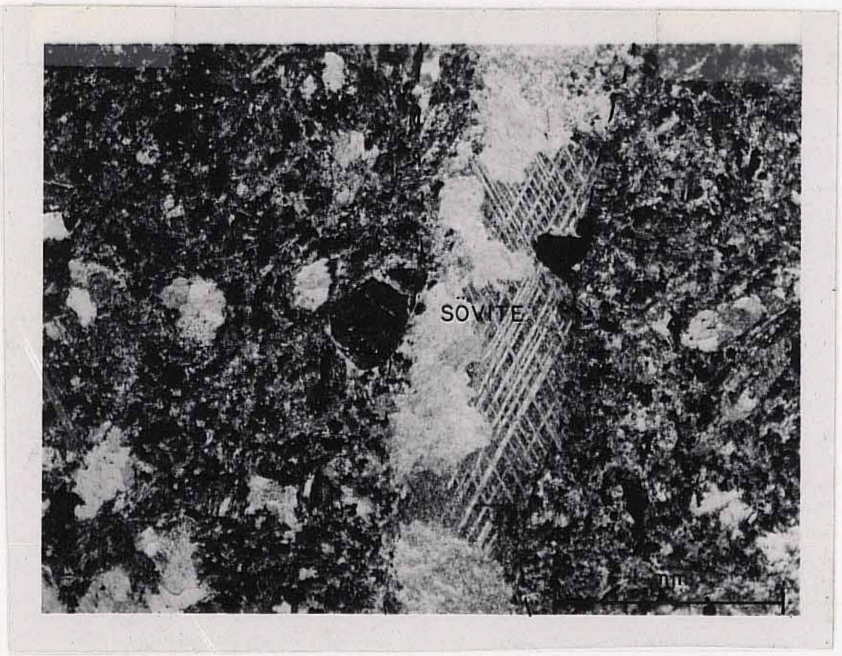

Figure 16 - Microphotograph (crossed nicols) of a coarse-grained sövite vein intruding a replacement silicocarbonatite.

Figure 17 - Photograph of a dusky-red ankeritic-dolomitic carbonatite dike intruding the Polvadera granite.

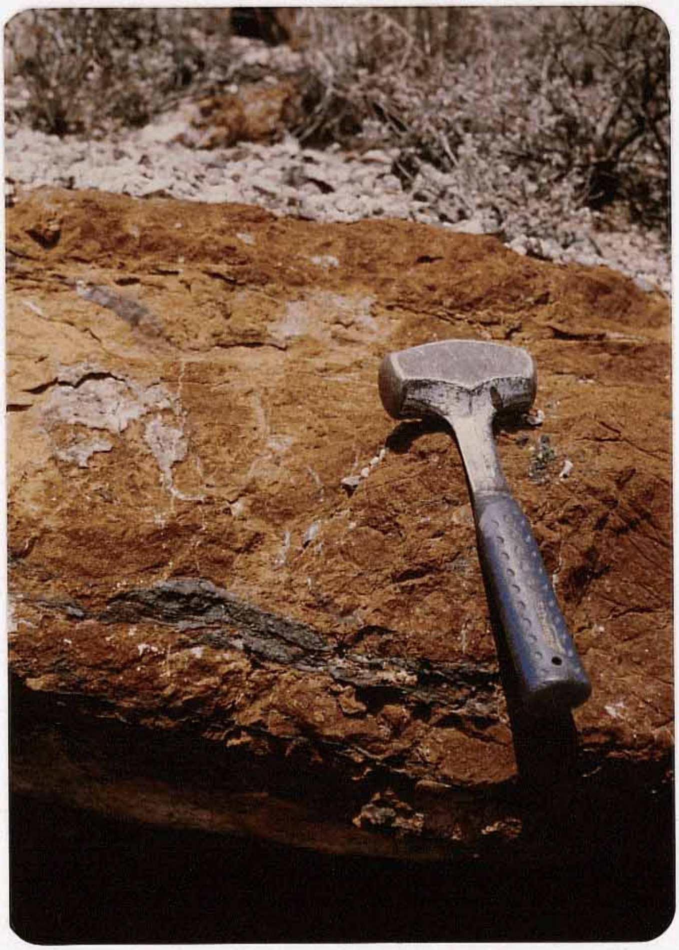

Figure 18 - Photograph of an ankeritic-dolomitic carbonatite dike intruding the Polvadera granite.

occur, although no systematic variations in appearance or composition appears to exist. These dikes intrude the fine-grained siliocarbonatites (figure 19) and are intruded by sövite and rauhaugite veins. Barite veins are commonly associated with the ankeritic dolomitic carbonatites.

Thin light-brown, randomly orientated dikelets or veins fill fracture systems in the Polvadera granite forming stockwork patterns (figure 20). The stockwork is at places associated with silicocarbonatite or ankeritic-dolomitic carbonatite dikes; although the stockwork may occur alone. These veins consist of varying amounts of ankerite, dolomite, calcite, hematite, biotite, feldspar, and a trace amount of quartz, apatite, and barite. Relict granitic textures and minerals are commonly preserved.

The ankeritic-dolomitic and stockwork carbonatites are carbonatites primarily because of their association with primary magmatic silicocarbonatite dikes. Other characteristics occur which further identify them as carbonatites:

1) their mineralogy and major element chemistry are typical of carbonatites;
2) they exhibit primary igneous textures or relict textures;
3) they display intrusive cross cutting relationships;
4) they are locally associated with granitic fenites (most of which are radioactive).

It is conceivable that these iron-rich carbonatites represent a hydrothermal stage of the carbonatite activity. It must be noted that these iron-rich carbonatites are similar in appearance and

Figure 19 - Photograph of a light brown ankeritic-dolomitic carbonatite dike intruding a fine-grained silicocarbonatite dike (gray).

Figure 20 - Photograph of stockwork carbonatite intruding the Polvadera granite.

composition to iron-rich veins common to Precambrian terrains and are difficult to distinguish from these more common veins. The Lemitar iron-rich carbonatites are thicker than the iron-rich veins and are associated with silicocarbonatite dikes.

MINERALOGY OF THE LEMITAR CARBONATITES

One of the most outstanding characteristics of carbonatite complexes is the mineralogic heterogenuity between the various carbonatite bodies and within single carbonatite intrusives. The Lemitar carbonatites are no exception; these carbonatites have been grouped partly on the basis of their mineralogic variations. The Lemitar carbonatites range from monomineralogic sövite and rauhaugite veins to multimineralogic silicocarbonatites which contains ten or more different minerals (appendix A). Some of the Lemitar carbonatites change mineralogic composition along strike or are mineralogically zoned. The differences in mineral composition between the various carbonatites in the Lemitar Mountains are shown in figure 21 and table 2.

The carbonate minerals (as determined by x-ray diffraction and thin-section studies) are the dominant mineral species in carbonatites. Many of the Lemitar carbonatites consist of fine-grained, homogeneous calcite and dolomite or dolomite and ankerite; whereas sövite and rauhaugite veins consist of coarse-grained calcite and dolomite. Bastnaesite, a rare-earth elements carbonate mineral, has been found in one silicocarbonatite dike (table 3).

Magnetite occurs in the primary magmatic and replacement silicocarbonatites, ankeritic-dolomitic carbonatites, and sövite and rauhaugite veins. Magnetite may have been originally present in the stockwork carbonatites but has been altered to hematite. The magnetite crystals form cubic shapes and occasionally cluster in flow bands (figure 15) or lenses of anhedral grains. Some magnetite crystals shows varying degrees of martitization (the

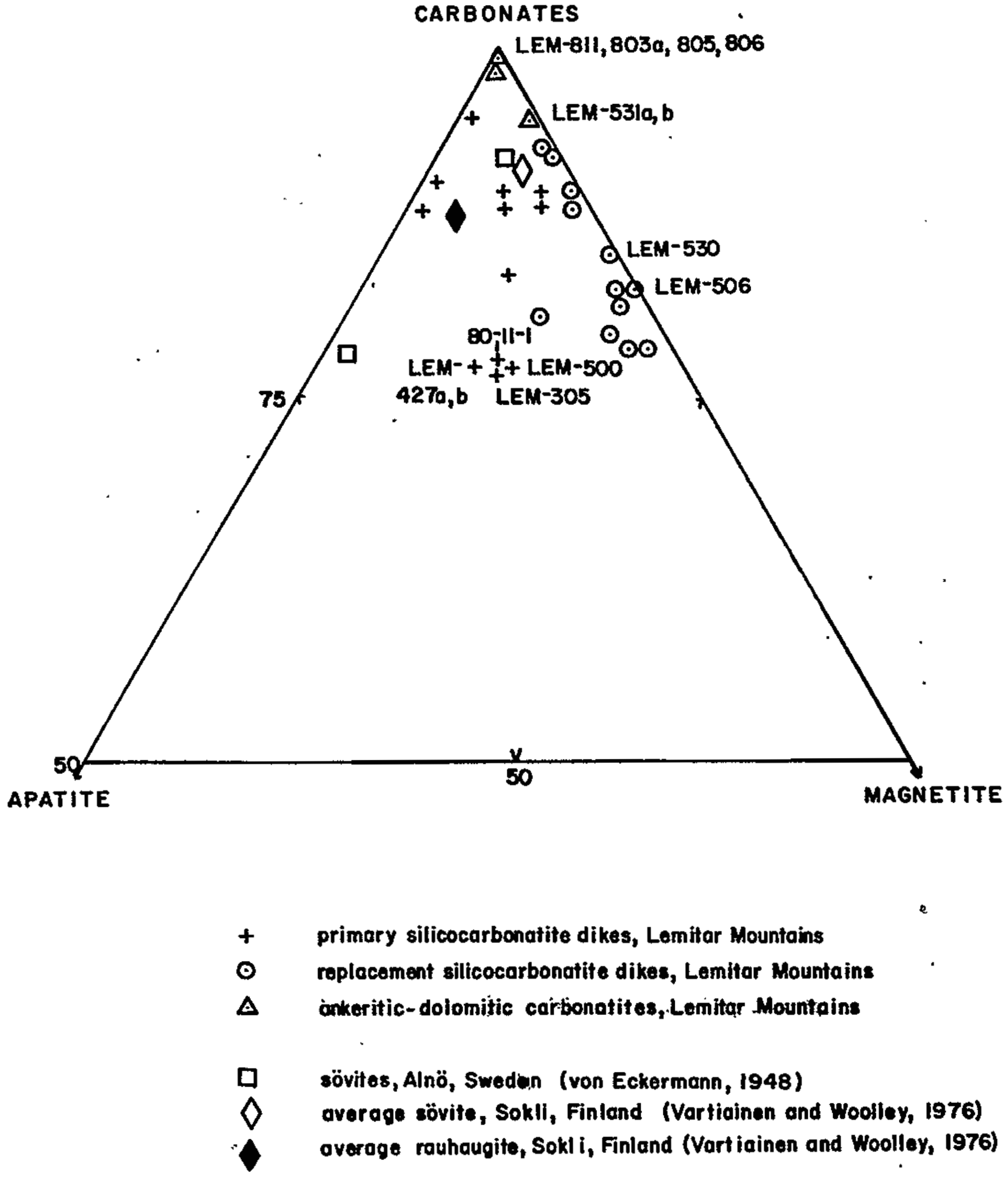

Figure 21 - Carbonates - apatite - magnetite plot of the Lemitar carbonatites.

TABLE 2

MINERALOGY OF THE LEMITAR CARBONATITES

Mineral	Primary magmatic silicocarbonatite[1]	Replacement silicocarbonatite	Sövite and rauhaugite veins	Ankeritic-dolomitic carbonatite	Stockwork carbonatite
calcite	e	e	e	e	e
dolomite	e	e	e	e	e
ankerite	vr	c	e	e	e
bastnaesite	vr	-	-	-	-
magnetite/ilmenite	e	e	r	r	-
apatite	e	c	r	vr	r
muscovite/sericite	r	c	-	-	-
biotite/phlogopite	c	c	r	r	c
zircon	vr	-	-	-	-
chlorite	c	c	-	r	-
sphene/leucoxene	r	vr	-	-	-
quartz	c	r	vr	c	r
pyrrhotite	vr	vr	-	-	-
fluorite	r	vr	-	c	-
pyrite	vr	vr	-	r	-
barite	r	r	-	c	r
hornblende	r	r	-	r	-
hematite/goethite	r	c	r	c	e
garnet	vr	-	-	-	-
feldspar	r	-	-	-	c
galena	vr	-	-	r	-
sphalerite	vr	vr	-	vr	-
chalcopyrite	vr	vr	-	-	-
molybdenite	-	-	-	vr	-

e - essential to all samples examined
c - common to many samples examined
r - rarely found in a few samples examined
vr - found in trace amounts in only one or two samples examined
\- - not found in any samples examined

[1] - includes breccia silicocarbonatites and primary magmatic fine-grained silicocarbonatites (without xenoliths)

TABLE 3

X-RAY DIFFRACTION LINES OF BASTNAESITE FROM THE LEMITAR MOUNTAINS

hKl	Lem 500		PDF	
	d	I	d	I
002	4.84	40	4.88	40
110	3.54	60	3.56	70
112	2.89	100	2.88	100
114	2.02	60	2.02	40
202	2.62	40	2.61	20
300	2.09	60	2.06	40
302	1.90	60	1.90	40

Lem 500 - heavy mineral separate from the Lemitar Mountains see plate 2 for sample location

P D F - Powder diffraction file (1972), card 11-340

Chemical formula of bastnaesite is $CeCO_3F$

process of alteration of magnetite to iron oxide, a pseudomorph after magnetite). Magnetite crystals are occasionally embayed and veined by carbonate and may contain inclusions of apatite, ilmenite, pyrochlore, or other accessory minerals.

Apatite is abundant and common to all five types of Lemitar carbonatites. The apatite crystals form hexagonal to ovoid shapes within the matrix (figures 8 and 11) or as prismatic inclusions within magnetite or biotite crystals.

The mica minerals--biotite, phlogopite, chlorite, muscovite, and sericite--occur in all five types of carbonatites in the Lemitar Mountains and may be difficult to distinguish from each other. Muscovite and sercite are rare and may be derived from the surrounding country rocks. Chlorite generally occurs as an alteration of biotite and phlogopite. The micas range in color from brown to green to yellowish-green to almost colorless and are generally pleochroic. They occur as intergrown disseminations or aggregates and may form flow bands.

Hematite/goethite is rare in the silicocarbonatites, sövites, and rauhaugites, but common in the ankertic-dolomitic and stockwork carbonatites. It occurs as red to brown aggregates or as alterations of other minerals. As much as 20-25% hematite/goethite may occur in the ankeritic-dolomitic and stockwork carbonatites, obscuring the textures and mineralogy of these particular carbonatites.

Ilmenite, sphene, zircon, garnet, and pyrrhotite occur as small inclusions within magnetite or biotite crystals. Quartz occurs as ovoid grains, whereas feldspar and hornblende occur as prismatic crystals. Fluorite occurs as purple or green disseminations within the matrix. Pyrrhotite may form euhedral crystals. Leucoxene occurs as a white alteration of magnetite or sphene. Pyrite, galena, sphalerite, chalcopyrite, and molybdenite are rare and form euhedral to angular crystals or aggregates. Barite occurs in the carbonatite matrix. Minerals of the olivine, pyroxene, and amphibole (except hornblende) groups, common to many carbonatite complexes, are absent in the Lemitar carbonatites; only hornblende is present in some dikes.

GEOCHEMISTRY OF THE LEMITAR CARBONATITES

A representative suite of samples from the various carbonatite dikes was analyzed for major and trace elements (appendix A). A scintillation counter was not available during the initial sampling period; therefore, most samples were collected without any knowledge of the radioactivity content. A few of the carbonatites have major-element oxide sums of less than 100%; the difference can be accounted for by various additional elements that were not looked for. Sample locations are shown on plate 2 and the chemical procedures are described in appendix B. The mineralogy of the samples is shown in appendix A.

Major Element Chemistry

The Lemitar carbonatites are significantly depleted in SiO_2 and enriched in CaO and CO_2 relative to granitic and basaltic rocks (appendix A), but typical of carbonatites worldwide (Heinrich, 1966). The differences in CaO, MgO, and total iron among the Lemitar carbonatites reflects differences in mineralogical composition (table 4). K_2O exceeds Na_2O in all but a few samples, reflecting the dominance of mica and K-feldspar over plagioclase. The Lemitar carbonatites fall into two populations on the basis of their iron and phosphate contents (figure 22). The high iron, low phosphate group corresponds to the replacement silicocarbonatites and ankeritic-dolomitic carbonatites; whereas the low iron, high phosphate group corresponds to the primary magmatic silicocarbonatites. The differences between the two chemical groups can be attributed to differences in the amounts of magnetite, hematite, ankerite, and apatite (table 4). Similar chemical trends dis-

TABLE 4

Distribution of Elements in Carbonatites

OXIDE/ELEMENT	DISTRIBUTION
SiO_2	quartz, feldspar
TiO_2	Magnetite, sphene, garnet, pyrochlore, micas
Al_2O_3	feldspars, pyroxenes, amphiboles, biotite
Fe_2O_3,FeO	magnetite, ankerite, hematite, mica
MgO, CaO	carbonates, magnetite, biotite
Na_2O, K_2O	micas, feldspars, pyroxenes
MnO	carbonates, apatite
P_2O_5	apatite
LOI (H_2O, F, Cl)	mica, apatite, fluorite, bastnaesite

References: Olson and others, 1954; Russell and others, 1954; Erickson and Blade, 1963; Heinrich, 1966; Barber, 1974; Hurlbut, 1971; Nash, 1972.

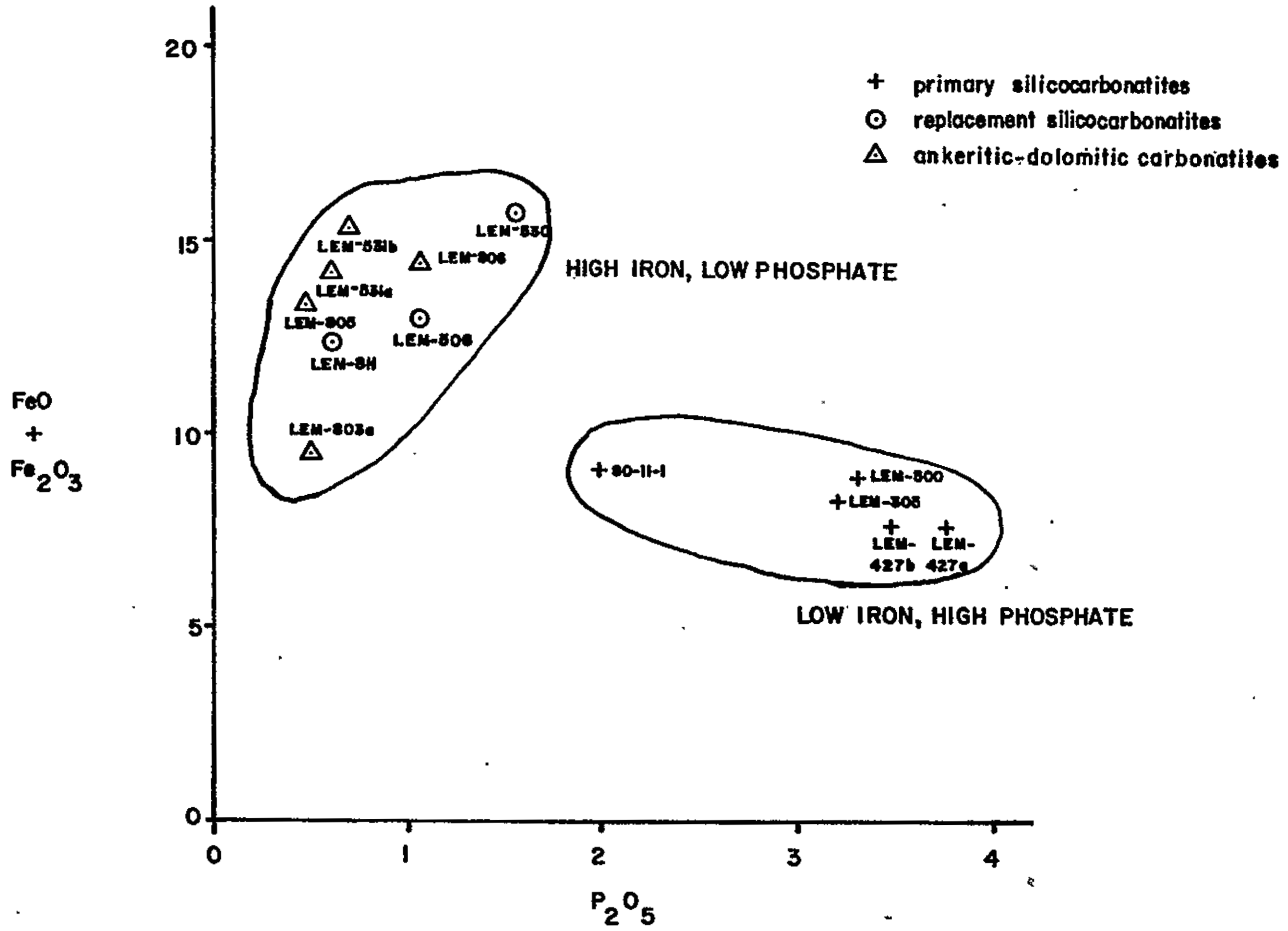

Figure 22 - Total iron (FeO + Fe_2O_3) - P_2O_5 plot of the Lemitar carbonatites showing high iron, low phosphate and low iron, high phosphate groups.

tinguish primary magmatic and replacement carbonatites in the Wet Mountains, Colorado (Armbrustmacher, 1979).

The Lemitar carbonatites are grossly similar in chemical composition to Heinrich's (1966) average carbonatite (table 5). The average Lemitar primary magmatic silicocarbonatite contains more MgO and P_2O_5 and less Al_2O_5, Na_2O, and K_2O than the average primary magmatic carbonatite from the Wet Mountains, Colorado; whereas the average Lemitar replacement silicocarbonatite contains more total iron, MgO, and P_2O_5 and less Al_2O_5, Na_2O, and K_2O than the average replacement carbonatite from the Wet Mountains (table 5). The average Lemitar ankeritic-dolomitic carbonatite is very similar in chemical composition to a rauhaugite from Iron Hill, Colorado (table 5) and contains less SiO_2, TiO_2, Na_2O, K_2O, and P_2O_5 and more total iron and CO_2 than the Iron Hill rauhaugite. These chemical differences can be attributed to the differences in mineralogic compositions, especially in the amounts of carbonates, apatite, micas, pyroxenes, and feldspars (table 4).

The Lemitar carbonatites are extremely different in major element composition from Pettijohn's (1957) average limestone (table 5).

Normal chemical variation diagrams used in the study of igneous rocks are not very useful in the study of carbonatites, because of the mineralogical and chemical heterogeneity of the carbonatites, and because of their unique chemical compositions. A variation diagram has been used by Dawson (1967) to show the chemical relationship between carbonatites and kimberlites. A plot of numerous chemical analyses of carbonatites from throughout the world

TABLE 5

Major Element Chemistry of Carbonatites

	1	2	3	4	5	6	7	8	9
SiO_2	12.5	24.2	8.27	10.3	15.0	20.6	14.6	>21.4	5.19
TiO_2	0.47	1.78	0.57	0.73	1.10	0.47	0.40	1.02	0.06
Al_2O_3	2.72	4.98	1.11	3.29	1.32	4.32	4.35	8.13	0.81
Fe_2O_3	3.74	7.68	6.78	3.46	6.53	1.91	7.72*	8.58*	0.54
FeO	4.63	6.87	6.49	3.60	3.13	8.92	-----	------	-----
MgO	8.23	6.80	7.29	5.79	7.04	9.47	3.15	5.47	7.89
CaO	31.5	17.2	30.4	36.1	30.4	20.3	>14.0	>14.0	42.6
Na_2O	0.34	0.75	0.02	0.42	2.28	0.24	1.75	4.45	0.05
K_2O	0.67	1.51	0.26	1.36	1.44	2.08	3.13	5.78	0.33
MnO	0.60	0.35	0.84	0.68	0.36	1.30	0.85	0.30	0.05
P_2O_5	3.16	1.32	0.23	2.09	2.33	1.97	1.37	< 0.46	0.04
CO_2	27.4	17.8	35.98^x	28.5	26.8	26.2	-----	-----	41.5
TOTAL$^+$	95.96	91.24	98.24	96.32	97.73	97.78	-----	-----	99.01

1 - average primary magmatic silicocarbonatite, Lemitar Mountains

2 - average replacement silicocarbonatite, Lemitar Mountains

3 - average ankeritic-dolomitic carbonatite, Lemitar Mountains

4 - average carbonatite (Heinrich, 1966)

5 - rauhaugite, Iron Hill, Colorado (Nash, 1972)

6 - biotite, ankeritic-dolomitic carbonatite breccia, Castigon Lake, Canada (Currie, 1976)

7 - average primary magmatic carbonatite, Wet Mountains, Colorado (Armbrustmacher, 1979)

8 - average replacement carbonatite, Wet Mountains, Colorado (Armbrustmacher, 1979)

9 - average limestone (Pettijohn, 1957)

$^+$ - does not include LOI

^{x} - includes LOI

* - Total iron calculated as Fe_2O_3

(miscellaneous analyses compiled by the author), defines a carbonatite field, which overlies the area between mafic carbonatites and kimberlites (figure 23). The Lemitar carbonatites fall nicely within this field, suggesting a chemical relationship with kimberlites. Kimberlites possibly are derived from the lower crust or upper mantle (Heinrich, 1966).

Trace Element Chemistry

The Lemitar carbonatites are further differentiated by various trace elements (appendix A). Primary magmatic silicocarbonatites contain more Ta, Th, and total rare-earth elements than replacement silicocarbonatites; similar chemical trends exist between primary magmatic and replacement carbonatites in the Wet Mountains, Colorado (Armbrustmacher, 1979). The Lemitar replacement silicocarbonatites contain more Ni, Sc, Cu, Ba, Cs, and Cr than primary magmatic silicocarbonatites and more Li, Sr, Cr, and total rare-earth elements than ankeritic-dolomitic carbonatites. Ankeritic-dolomitic carbonatites are depleted in Th, Ta, Li, Sr, and total rare-earth elements relative to primary magmatic and replacement silicocarbonatites.

In comparison with other carbonatite complexes in the world, the Lemitar carbonatites are depleted in Ba and Sr (table 6). The Lemitar carbonatites are enriched in Ni, Zn, and Co and depleted in U, Th, and Ta relative to Heinrich's (1966) and Gold's (1966) average chemical values for carbonatites (table 6); although the concentrations of these elements in the Lemitar carbonatites are within normal variations established for carbonatites by Gold (1966).

Several reasons may explain these differences in chemical

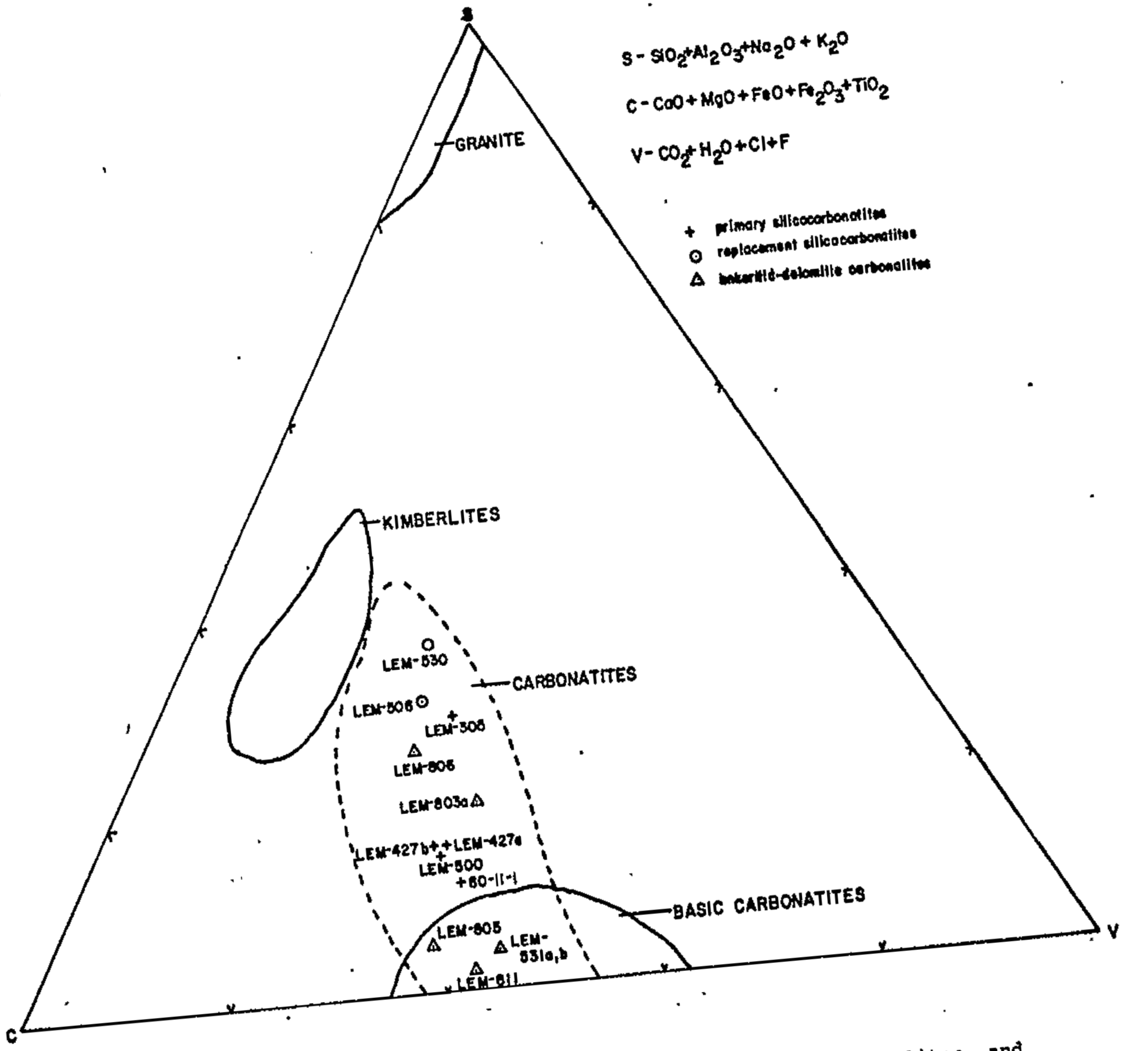

Figure 23 - Chemical plot showing relationship between carbonatites, kimberlites, and granites. Solid lines represent fields determined by Dawson (1967). Dashed line represents field determined by the author from miscellaneous analyses (greater than fifty) of carbonatites from throughout the world.

TABLE 6

Trace Element Chemistry of Carbonatites

	1	2	3	4	5	6	7	8	9	10
Li	29	<10	<5	-	15	-	-	-	-	-
Sc	11	24	9	-	10	-	-	-	-	-
Ni	38	286	-	8	32	-	51	200	85	53
Cu	12	63	28	2.5	88	10	43	39	51	50
Zn	218	275	194	-	160	-	-	-	109	-
Sr	368	355	71	-	9000	5000	3200	880	3200	2700
Ba	333	953	599	450-1120	4030	1000	15000	5300	830	15600
Cs	2.5	11	0.5	-	0	-	-	-	92	-
Cr	16	231	15	48	102	-	110	470	nil-13	65
Co	36	64	54	17	19	-	16	33	nil	18
Ta	26	11	0.9	-	560	-	-	-	-	-
Th	62	19	1.4	-	649	-	1500	130	-	47
U	7.5	8.4	3.2	-	57	10	26*	5*	-	11*

1 - average primary magmatic silicocarbonatite, Lemitar Mountains
2 - average replacement silicocarbonatite, Lemitar Mountains
3 - average ankeritic-dolomitic carbonatite, Lemitar Mountains
4 - average carbonatite (Heinrich, 1966)
5 - typical carbonatite (Gold, 1966)
6 - carbonatite, Magnet Cove, Arkansas (Erickson and Blade, 1962)
7 - average primary magmatic carbonatite, Wet Mts., Colorado (Armbrustmacher, 1979)
8 - average replacement carbonatite, Wet Mts., Colorado (Armbrustmacher, 1979)
9 - average of four sövites, Sokli complex, Finland (Vartiainen & Woolley, 1976)
10 - average Iron Hill carbonatite, Colorado (Armbrustmacher, 1980)

* radiometric equivalent U

composition:

1) differences in mineralogic composition;
2) mobilization of trace elements after crystallization;
3) crustal contamination;
4) original differences within the source material;
5) slightly different ages of intrusion;
6) injection of the main carbonatite source at different stages during its ascent through the crust;
7) feeder dikes tapping the main carbonatite source at different places;
8) different sources.

Many of the differences in chemical composition can be attributed to mineralogic composition; the concentrations of various accessory minerals containing the trace elements greatly affects the whole-rock chemistry. Trace elements are contained in major minerals as well. Ba and Sr probably occur in barite, calcite, dolomite, ankerite, and apatite; whereas, Cu, Ni, Co, Cr, and Zn probably occur in magnetite, pyrite, pyrrhotite, sphalerite, and various minor sulfide minerals. U, Th, and rare-earth elements probably occur in bastnaesite, apatite, fluorite, and phlogopite; Li probably occurs in phlogopite, biotite, and calcite (based on numerous studies of mineral separates by Barber, 1974; Quon and Heinrich, 1966; Heinrich, 1966; Russell and others, 1954; Erickson and Blade, 1963; Olson and others, 1954). Furthermore, the concentrations of trace elements in various minerals may be increased due to weathering (Erickson and Blade, 1963).

The depletion of Ba and Sr in the Lemitar carbonatites relative to average carbonatites may be due to additional factors other than mineralogic composition. Mobilization of these and other trace elements may have occurred since crystallization of the carbonatites; these elements may have been remobilized during any of the magmatic and volcanic events affecting the Lemitar Mountains since initial crystallization of the carbonatites. A late Tertiary potassic metasomatism is believed to have altered the Tertiary volcanic rocks in the Lemitar Mountains (Chapin and others, 1978) and the affect of this metasomatism on other trace elements is still unknown. Tertiary hydrothermal barite-fluorite-sulfide mineralization also may have caused the mobilization of these and other trace elements.

Crustal contamination of a carbonatite magma derived from the lower crust or upper mantle could dilute the chemical composition of the Lemitar carbonatites. Some of the Lemitar carbonatites contain xenoliths which could have a dilution affect on the trace element chemistry. Many of the replacement silicocarbonatites and ankeritic-dolomitic carbonatites were intruded into mafic and granitic rocks which were low in these trace elements (McLemore, 1980a, b), causing a depletion of them in the whole-rock chemistry of the Lemitar carbonatites.

The differences in chemical composition between the carbonatites may reflect differences in the source material or fractionation of the source material. Two or more magmas could have crystallized to form the Lemitar carbonatites or a single magma could have fractionated resulting in the different chemical compositions.

Rare-earth Elements

The Lemitar carbonatites are noticeably enriched in rare-earth elements (REE) and display steep, light REE enriched clondrite-normalized patterns (figure 24), patterns characteristic of carbonatites from throughout the world. The primary magmatic silicocarbonatites display steeper, more enriched REE patterns than the replacement silicocarbonatites and the ankeritic-dolomitic carbonatites. Furthermore, the REE patterns of the Lemitar carbonatites are more enriched in REE than that of a metamorphosed Precambrian limestone (figure 24).

However, the Lemitar ankeritic-dolomitic carbonatites are significantly depleted in REE relative to other Lemitar carbonatites and displays a relatively flat REE pattern (figure 24 and 25). This is especially unusual because late-stage carbonatites, such as the Lemitar ankeritic-dolomitic carbonatites are generally more enriched in REE than earlier stages (Heinrich, 1966); although there are documented carbonatites with depleted REE patterns (figure 25). This depletion of REE, especially the light REE (La, Ce, Sm, Eu), could be a result of hydrothermal alteration related to the Tertiary barite-fluorite-sulfides veins or to remobilization of the light REE. Another possibility is that the ankeritic-dolomitic carbonatites represent a depleted hydrothermal late-stage carbonatite; the REE patterns of hydrothermal carbonatites have not been studied. A third, less likely, possibility is that the ankeritic-dolomitic carbonatites are not related to the Lemitar carbonatites at all. Before this controversy can be resolved, additional REE analyses of ankeritic-dolomitic carbonatites in the Lemitar Mountains needs to be completed.

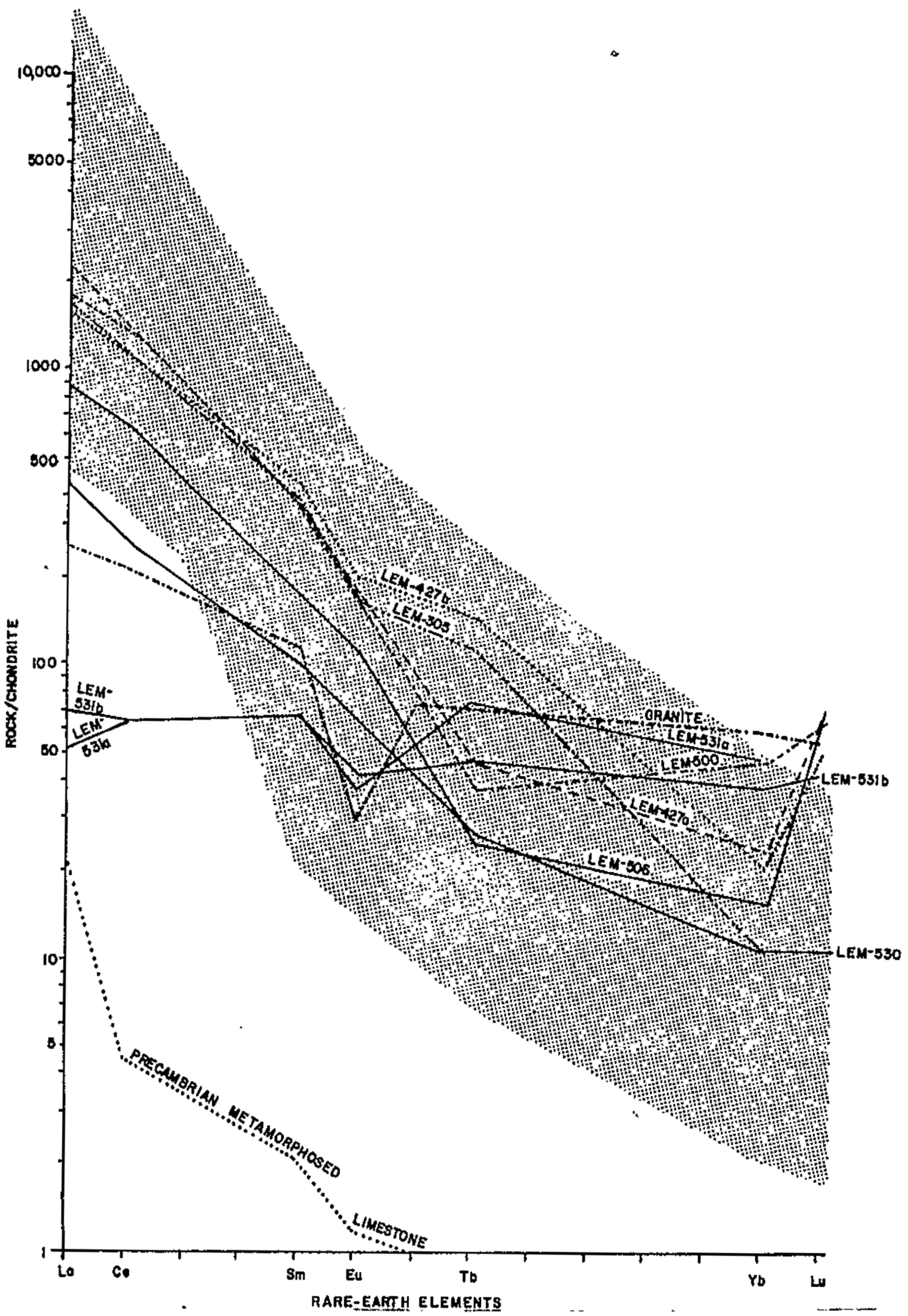

Figure 24 - Chondrite-normalized rare-earth element patterns of the Lemitar carbonatites. Shaded field represents an envelope of variation of carbonatites from throughout the world (miscellaneous analyses compiled by the author). Granite analysis (Precambrian Magdalena granite) from Condie and Budding (1979). Precambrian metamorphosed limestone analysis from Loubet and others (1972). There are eight samples from the Lemitar Mountains - Lem 305, 427 a, b, 500 (primary silicocarbonatites), Lem 506, 530 (replacement silicocarbonatites), and Lem 531 a, b (ankeritic-dolomitic carbonatite dikes). Note that the primary silicocarbonatites are higher in rare-earth elements than the replacement silicocarbonatites. Chondrite values from Haskins and others (1968).

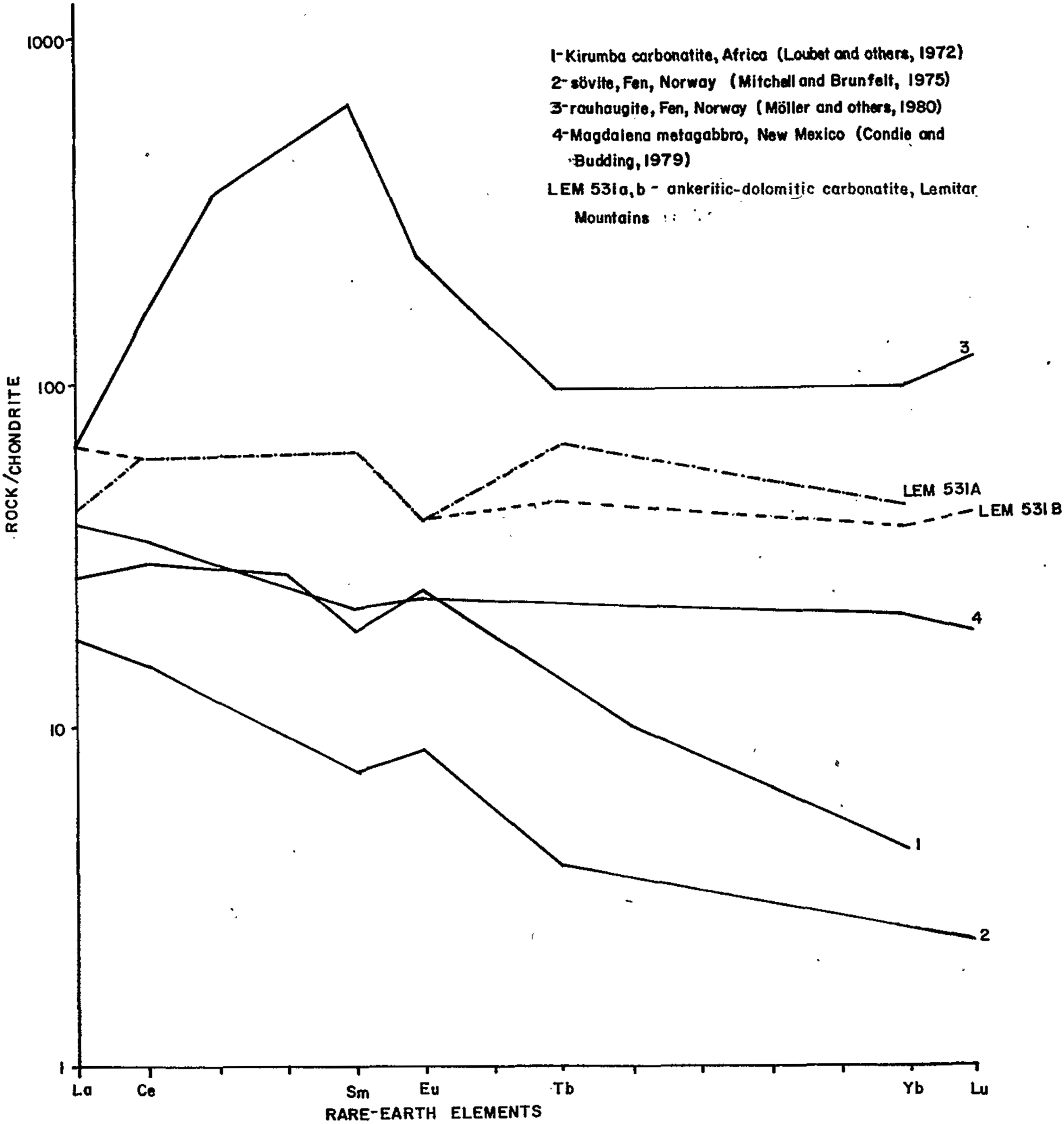

Figure 25 - Chondrite-normalized rare-earth element patterns of anomalous carbonatites, including the Lemitar ankeritic carbonatite dikes, indicating that these veins could be altered carbonatites as suggested. Chondrite values from Haskin and others (1968).

ALTERATION

The most common type of alteration associated with carbonatite complexes is fenitization, an in situ alkalic metasomatism resulting in desilication. Fenites can be classified as external fenites (along margins of the alkalic complex; along margins of dikes, or along fracture and joint systems outside of the main carbonatite complex), internal fenites (metasomatism of country rocks within the carbonatite complex), regional fenites, or fenitized xenoliths. Chemically, two processes of fenitization are recognized, regardless of mineralogy and petrology (table 7). One involves the addition of sodium and potassium (sodic or normal fenitization); the other involves the addition of potassium (potassic fenitization).

A multistage fenite halo of varying width and intensity of alteration surrounds most carbonatite and alkalic complexes; however, it is becoming apparent that fenites also occur as irregular bodies or zones along the margins of carbonatite dikes and along fracture or fault systems or as isolated bodies without any associated carbonatites. Fenitization occurs as a single stage of alteration or as superimposed periods of metasomotism which may be difficult to differentiate. Fenitization may precede the carbonatite intrusion and continue periodically during the various stages of intrusion of the carbonatite complex.

Argillic alteration, nephelinization, carbonatization, and feldspathization are additional common forms of alteration associated with carbonatite complexes (Heinrich, 1966). Hematization has been attributed to some carbonatite intrusions.

TABLE 7
CLASSIFICATION OF FENITES

(modified after Vartiainen and Woolley, 1976)

FENITE TYPE	FEATURES	EXAMPLE
1. Normal or Sodic Fenitization	Na and K added -- alkali pyroxenes and amphiboles	
a) Sodic type	strongly sodic	Sokli, Finland
b) Intermediate type	major Na and K	Alnö, Sweden
c) Potassic type	major K, minor Na	Amba Dongar, India
2. Potassic Fenitization	K added, no alkali pyroxenes or amphiboles, often phlogopite added	
a) Potassic type	K only	Bakusu, Uganda
b) Late stage K-Fenitization	K-fenitization superimposed on normal fenitization	Chilwa Island, Nyasaland, Africa Sokli, Finland

Hematite, calcite, pyroxene, and quartz veins may be common in the vicinity of carbonatite complexes.

Alteration of the Precambrian Rocks in the Lemitar Mountains

Alteration of the Precambrian rocks in the Lemitar Mountains due to the intrusion of the carbonatites is negligible; although external fenitization and carbonatization of mafic dikes is locally pervassive. Fenitization of the Lemitar diorite/gabbro is locally pronounced adjacent to some silicocarbonatite dikes, although a fenite halo is absent. Fenitization is generally absent in the metasediments and granitic rocks; however, red feldspathic fenites are developed locally in the Polvadera granite adjacent or near carbonatite dikes. The altered facies of the Polvadera granite may in part be a result of fenitization. The mafic dikes exhibit varying degrees of carbonatization and locally grades into silicocarbonatite dikes. Argillization locally affects some mafic dikes in the vicinity of some ankeritic-dolomitic carbonatite dikes or barite-fluorite-sulfide veins. Some hematite and carbonate veins intrude the Precambrian rocks which may be due to the early stages of fenitization; however, hematite and carbonate veins are common in Precambrian terrains. Nephelinization is absent in the Lemitar Mountains.

Fenitization of the Lemitar diorite/gabbro

Fenitization is poorly developed to absent in the Lemitar diorite/gabbro and a fenite halo is absent in the body. A thin discontinuous zone of fenitization is locally developed adjacent to some primary magmatic silicocarbonatite dikes. The fenitized zone is less than ten centimeters wide, although discontinuous zones of fenitization may occur along fractures or joints several meters away from the silicocarbonatite dikes. The fenite is characterized by large (several millimeters in length), orange-pink albite crystals (figure 26), as opposed to the normally white feldspars seen in the unaltered diorite/gabbro.

In thin section, extremely small disseminations of hematite "dusts" the feldspar phenocrysts, producing the red color. The feldspar phenocrysts are veined and outlined by hematite. This reddish color is a common feature of this type of alteration and is thought to be produced by the oxidation and exsolution of iron molecules originally within the feldspar lattice (von Eckermann, 1948, p. 29). This oxidation probably resulted from degassing of carbon dioxide from the carbonatite intrusive.

The plagioclase composition of the fenite reflects an increase in sodium by the chemical transformation of labradorite and andesine (An_{40}-An_{50}) to albite (An_5-An_{15}). The fenitized diorite/gabbro also appears to increase slightly in quartz and perthitic K-feldspar. Verwoerd (1966) describes a similar trend in fenitization from the Messum carbonatite complex, South West Africa, where four stages of fenitization in a gabbro are recognized (in order of increasing fenitization):

1) increase in albite content;
2) introduction of perthitic alkali-feldspar;
3) introduction of nepheline replacing plagioclase;
4) increase in orthoclase, nepheline, and ferrohastungsite.

Fenitization of the Lemitar diorite/gabbro appears to have

Figure 26 - Photograph showing fenitization of the Lemitar diorite/gabbro. Note the large, pink feldspar crystals above the penny.

progressed only as far as stage 2 of this particular sequence.

Five unaltered and two fenitized samples of the Lemitar diorite/gabbro were analyzed for eight major and two trace elements (appendix A). The fenitized samples show a significant increase in Na_2O and a decrease in CaO with increase in fenitization (figure 27), chemical trends characteristic of sodic-fenitization. Other chemical trends are summarized in table 8. The increase in sodium corresponds with an increase in normative albite (appendix A). These chemical differences with increase in fenitization can be attributed to loss of certain elements by the carbonatite to the fenite and to loss of other elements by the diorite/gabbro to the thin calcite and hematite veins intruding the diorite/gabbro and the carbonatite. Similar chemical trends are common in fenitized mafic rocks (table 9).

Red Feldspathic Fenites

Red feldspathic fenites have developed adjacent to some of the thicker fine-grained silicocarbonatite and ankeritic-dolomitic carbonatite dikes intruding the Polvadera granite (plate 2). These fenites have a characteristic red color produced by small disseminations of hematite occurring as inclusions within the feldspars and along fractures within the rock--similar to the fenitized diorite/gabbro. The red color is probably due to oxidation of iron molecules originally within the feldspar lattice. These feldspathic fenites consist of greater amounts of large plagioclase and K-feldspar crystals and lesser amounts of quartz than unaltered Polvadera granite and are also slightly radioactive (two to four times background). Hematite veins are common. Quartz

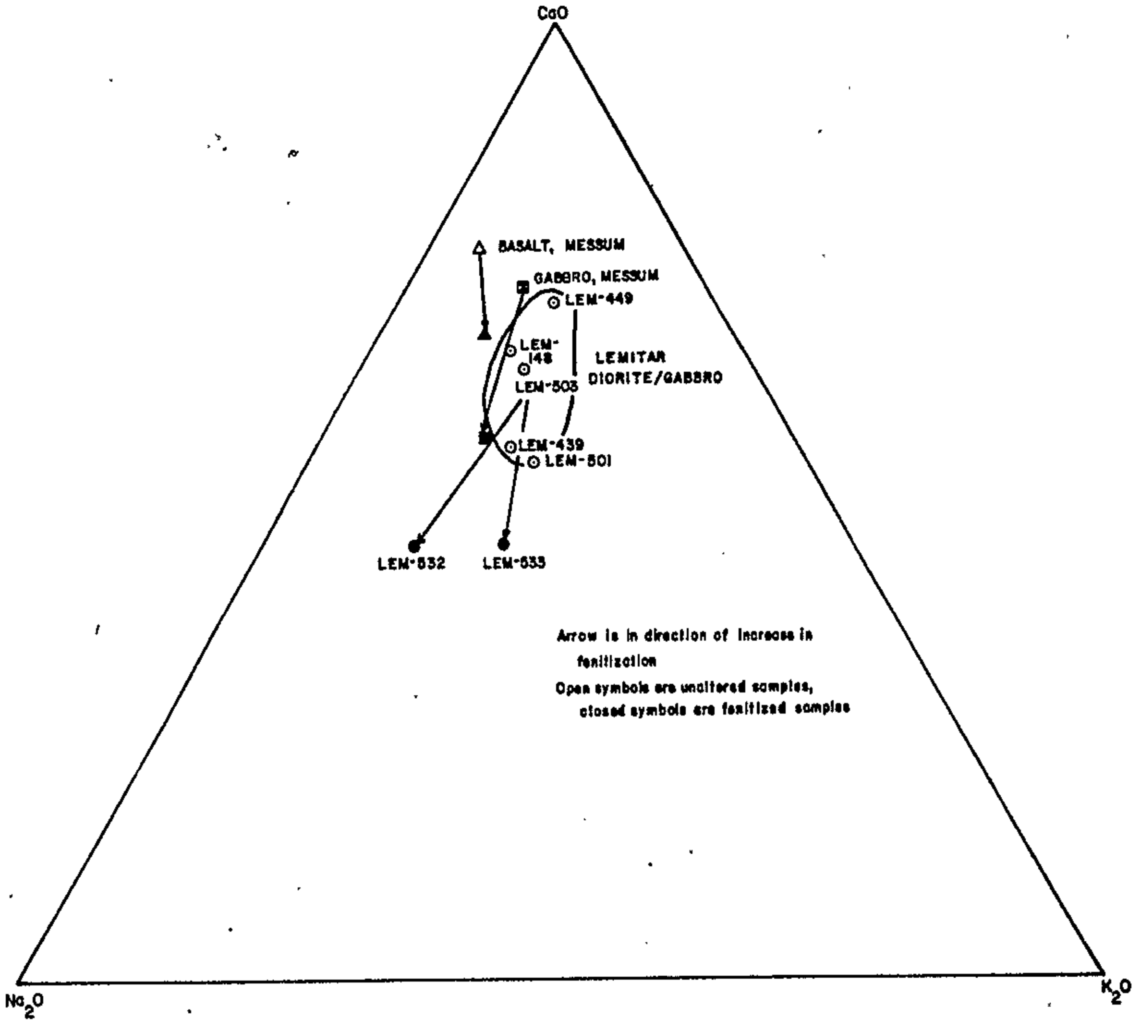

Figure 27- $CaO-Na_2O-K_2O$ plot of the effect of fenitization on the Lemitar diorite/gabbro. Trends of basalt and gabbro, near the Messum carbonatite, South-West Africa reported by Verwoerd (1966).

TABLE 8

SUMMARY OF CHEMICAL CHANGES OF
THE LEMITAR DIORITE/GABBRO DUE TO FENITIZATION

Significant increase	Na_2O
Significant decrease	CaO
Slight increase	Al_2O_3, MgO
Slight decrease	TiO_2, Fe_2O_3[1]
No significant trend	SiO_2, K_2O, Rb, Si

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[1] total iron calculated as Fe_2O_3

TABLE 9

COMPILATION OF CHEMICAL TRENDS OF FENITIZED MAFIC ROCKS

COMPLEX	FENITIZED ROCKS	GAINS	LOSSES	REF
Spitzkop ijolite, E. Transvaal	gabbro	Na, Ca, K, P, C	Mg, Si, Fe, Al	1
Messum syenite, S.W. Africa	basalt, dolerite, gabbro	Na, Al, H, K	Si, Ca Fe, C	1
Goudini carbonatite, Transvaal	norite	Na, CO_3, OH, Fe	Si, Al, Ca, Mg	1
Breivikbotn pyroxenite/carbonatite Soroy, Norway	metagabbro	Fe, Mn, Y, Zr, Nb	Al_2O_3	2
Blue Mountain syenite, Ontario	amphibolite	K_2O, Na_2O, Al_2O_3, H_2O, CO_2	CaO, Mgo FeO	3
Callander Bay carbonatite, Ontario	garnet amphibolite	Si, Al, Na, K, H	Ti, F, Mg, Ca	4
Seiland pyroxenite, Norway	gabbro (next to alkaline dikes)	Al, Ti, Fe, Ca, K, Mn	Mg	2
	gabbro (next to carbonatites)	Fe, Ca, K, Mn	Si, Al	
Mbozi syenite, S.W. Tanzania	gabbro	K, Na, Al, Si, P	Ca, Mg, Fe, Ti	5
Lemitar carbonatites, New Mexico	diorite/gabbro	Na, Al, Mg	Cu, Ti, Fe	6

1 -- Verwoerd, 1966

2 -- Robins and Tysseland, 1979

3 -- Payne, 1968

4 -- Currie and Ferguson, 1972

5 -- Brock, 1968

6 -- McLemore, 1980 a, this report

and feldspar veining may be present and at places intrude the carbonatite dikes, possibly as a result of rhemorphism. Original foliation is generally preserved. These fenites are not always restricted to the immediate vicinity of the carbonatite dikes, but locally forms small pods or lenticular bodies within the Polvadera granite (plate 2). These radioactive bodies are discontinuous and vary in size from a few centimeters to seven meters wide and up to ten meters long. Similar occurrences of feldspathic fenites are found associated with carbonatites in Wet Mountains, Colorado; Alnö, Sweden; Rufunsa Valley, Zambia; Tundulu, Malawi (Heinrich and Moore, 1970); Chilawa Island, Malawi (Garson, 1966; Heinrich and MOore, 1970); and Mbeya, Tanzania (Brown, 1964; Heinrich and Moore, 1970).

The altered facies of the Polvadera granite exposed in the western portion of the mapped area (plates 1 and 2) may represent an early stage of fenitization. At least two carbonatite dikes intrude this granite (plate 2) and one outcrop of this altered granite is radioactive (up to ten times background) and contains 0.01% U_3O_8. Some outcrops of this altered granite contain large red feldspar crystals, similar to many fenitized bodies within the Polvadera granite. A barite-silica vein has intruded this altered facies, suggesting that other factors have affected the alteration of this granite. More petrographic and geochemical work is needed to determine the nature of this alteration.

The general mineralogical tendencies during fenitization of granitic rocks are summarized below (in order of increasing fenitization; Heinrich, 1966 and Curro and Ferguson, 1972):

1) increase in ordering of K-feldspar and concentration of potassium into feldspars;
2) oxidation of Fe^{+2} to Fe^{+3} and its concentration into sodic pyroxenes and hematite, locally forming pyroxene and hematite veins;
3) conversion of plagioclase into albite plus calcite or calcium pyroxenes, locally forming calcite and pyroxene vines;
4) conversion of feldspar to microcline and continued formation of sodic and calcium pyroxenes;
5) elimination of quartz and possible formation of nepheline.

Fenitization of the Polvadera granite appears to have progressed only as far as stage 2 or 3, without the appearance of pyroxenes.

Fenitized Xenoliths

Alteration of xenoliths within silicocarbonatite dikes varies in intensity and deformation from little or no alteration or deformation to extensive alteration and assimulation of the rock fragment by the carbonatite. Many xenoliths exhibit light-colored reaction rims of carbonate, hematite, or biotite/chlorite, with decreasing alteration and deformation towards the darker center of the rock fragment. Some xenoliths exhibit mortor textures, generally not seen in the original unaltered rock. Original foliation is preserved in some xenoliths (figure 8); whereas, other rock fragments display warped and distorted schistosity generally not seen in the unaltered rock. Unaltered xenoliths may be adjacented to completely altered fenitized xenoliths.

Corroded reaction rims may surround some xenoliths where the carbonatite matrix has partially digested the rock fragment. Feldspars within the xenoliths are partially or completely replaced by carbonate or altered to a red color. Biotite within the xenoliths is generally altered to chlorite, whereas quartz may be crushed forming mortar textures. Hematization of the rock fragments is common and hematite and biotite may form a rim around the xenolith (figure 8). Diorite/gabbro xenoliths are generally fenitized similar to the diorite/gabbro fenites; mafic dike fragments have undergone carbonatization. The metasediments exhibit minor alteration and maintain their original foliation and granitic xenoliths vary from little or no alteration to the formation of red feldspathic fenites.

Carbonatization of the Mafic Dikes

Carbonatization of the mafic dikes occurs adjacent to or in the immediate vicinity of silicocarbonatite and ankeritic-dolomitic carbonatite dikes. The altered mafic dikes exhibits various degrees of carbonatization from minor to extensive replacement of original minerals. The carbonate content is less than 50%, however, carbonatized mafic dikes do grade into replacement and primary magmatic carbonatite dikes.

A series of four thin sections along a mafic dike intruded by a primary magmatic fine-grained calcitic to dolomitic silicocarbonatite dike were studies. Adjacent to the carbonatite, the mafic dike was extensively altered; corroded magnetite, hornblende, and feldspar crystals are replaced by carbonate minerals (figure 28). Apatite was introduced into the generally apatite-free mafic

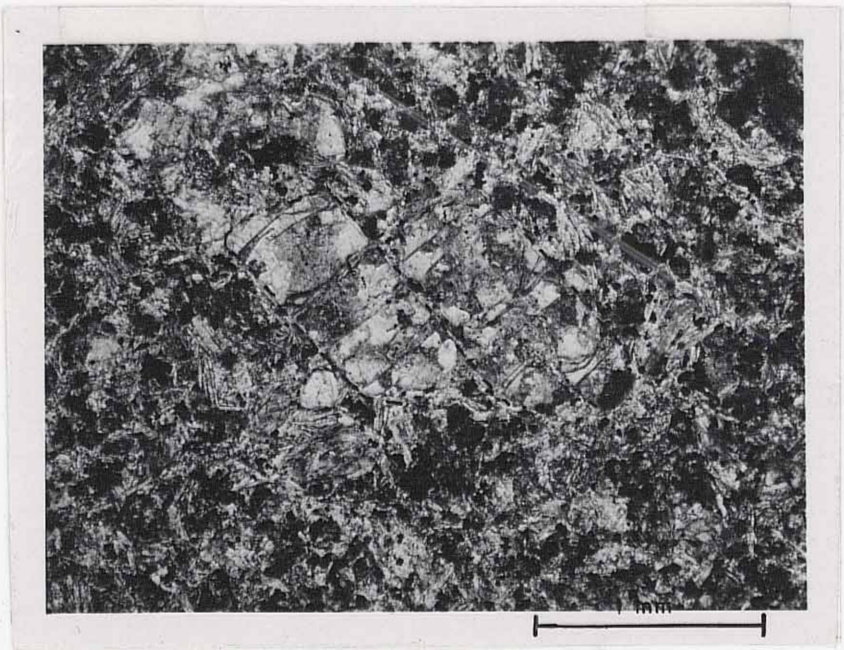

Figure 28 - Microphotograph (crossed nicols) showing extensive carbonatization of a mafic dike. Carbonate has replaced the relict feldspar crystals in the center of the photograph.

dike. Farther from the carbonatite, less alteration and replacement of original minerals by carbonate occurs; apatite is absent in the other three thin sections. In the thin section fartherest from the carbonatite, only minor replacement of magnetite, hornblende, and feldspar by carbonate occurs. Carbonatization of mafic dikes and lamprophyres adjacent to carbonatite dikes is common (Heinrich, 1966).

Discussion

The apparent lack of well-developed fenitization of the Precambrian rocks in the Lemitar Mountains is not uncommon. Little or no fenitization has affected the mafic rocks associated with the carbonatites at Magnet Heights, Transvaal (Verwoerd, 1966); Stjernoy, Norway (Verwoerd, 1966); Sokli, Finland (Vartiainen and Woolley, 1976); and Siilinjarvi, Finland (Puustinen, 1969). The only alteration seen in the Precambrian metamorphic rocks surrounding the carbonatite in Ravalli County, Montana are thin envelopes of altered amphibolite where hornblende has been converted to biotite (Heinrich, 1966). Most granitic rocks where intruded by carbonatites are fenitized resulting in desilication of the granite; this is contrary to what is observed in the Lemitar granites. The Polvadera granite has undergone feldspathization, locally forming red feldspathic fenites, but these zones are not continuous or extensive. The lack of fenitization of the Precambrian rocks is probably a result of some combination of the following factors:

1) pressure-temperature regime of the system;
2) mineralogic composition of the host rocks;

3) composition of the volatiles and of the fenitizing solutions;
4) permeability of the host rocks;
5) distance from the carbonatite magma chamber or source.

The pressure-temperature regime at the time of the emplacement of the carbonatites is an important factor affecting fenitization. Volatiles are held in solution by high temperatures and pressures; as the temperature decreases, so does the pressure and volatile content. The release of volatiles during cooling and crystallization of the carbonatites causes oxidation of the surrounding country rocks, as seen in the hematitic inclusions in feldspar phenocrysts. If the carbonatite intrusive cooled quickly, the volatiles and other fenitizing solutions may not have been able to escape, resulting in poorly developed fenitization. Furthermore, the pressure and temperature of the fenitizing solutions must be at optimum conditions to fenitize the previously metamorphosed rocks of the Lemitar Mountains.

The mineralogic composition of the host rocks must be compatible with fenitization. Vartiainen and Woolley (1976) determined that the stability of hornblende is such that it resists fenitization; the Lemitar diorite/gabbro consists of hornblende. The lack of abundant alkalies in the diorite/gabbro also partially explains the lack of fenites in the mafic rocks (Verwoerd, 1966).

The composition of the volatiles and of the fenitizing solutions is important in fenitization. If the fenitizing solutions are in equilibrium with the country rock, fenitization will not occur. If the volatile content is low, fenitization may not occur. The irregular and discontinuous distribution of the fenites in the Lemitar diorite/gabbro and Polvadera granite suggests that perhaps the volatiles were unevenly distributed in the carbonatite magma.

The permeability of the host rock must be such to allow fenitizing solutions and volatiles to migrate through the country rock. If the Lemitar metamorphic rocks were impermeable except for a few fractures, then fenitization would occur only along the contacts of the carbonatites. This is seen along the fringe zones representing earlier stages of fenitization at Sokli, Finland (Vartiainen and Woolley, 1976) and Callender Bay, Canada (Currie and Ferguson, 1971 and 1972).

As the distance from the carbonatite magma chamber or source increases, the pressure and temperature and volatile content decreases; therefore, fenitization decreases. Carbonatites outside of the main carbonatite complex may occur without any fenitization of the country rocks (Heinrich, 1966), as seen in the Lemitar Mountains.

ECONOMIC GEOLOGY

Uranium, thorium, and rare-earth elements

Anomalous radiometric readings, up to 7000 times background radioactivity, occur in the Lemitar carbonatite dikes and feldspathic fenites (plate 2). Numerous prospect pits, trenches, and one adit (Hot Streak adit, section 6, T. 2 S., R. 1 W.) expose these dikes. No uranium, thorium, or rare-earth element production is known to date.

Samples submitted to the New Mexico Bureau of Mines and Mineral Resources chemical laboratory (L. Brandvold, chemist) range from less than 0.001 to 0.25% U_3O_8 (table 10). The higher uranium analyses and corresponding high radiometric readings are in the silicocarbonatite dikes and some sövite veins. Only eight carbonatite samples were analyzed for thorium and rare-earth elements (appendix A); thorium ranges from 0.9 to 74 ppm and total rare-earth elements ranges from 81 to 1,946 ppm. The high thorium and rare-earth element analyses are in the silicocarbonatite dikes; additional thorium and rare-earth element analyses are required to adequately evaluate their potential.

Phosphate

Carbonatites in Africa, Brazil, Russia, and Canada are currently being economically mined for their phosphate content (Rovse, 1979). The phosphate in the Lemitar carbonatites is concentrated in apatite in the silicocarbonatite dikes (appendix A). The silicocarbonatite dikes average 5-10% apatite and range from less than 0.1% to 3% P_2O_5. Currently typical phosphate

TABLE 10

Uranium Analyses on Selected Lemitar Carbonatites and Feldspathic Fenites

SAMPLE	ROCK TYPE	U_3O_8%
Lem 305	primary magmatic silicocarbonatite	0.0023
Lem 427A	"	0.0033
Lem 427B	"	0.0019
Lem 500	"	0.0036
Lem 818	"	0.0021
Lem 819	"	0.0089
R - 1	"	0.08
R - 2	"	0.06
80-11-1	"	0.003
Lem 820	"	0.25
Lem 820A	fluorite from Lem 820	0.0025
Lem 506	replacement silicocarbonatite	0.045
Lem 530	"	0.0011
Lem 809	silicocarbonatite	0.004
Lem 810	silicocarbonatite	0.0032
Lem 821	sövite	0.056
Lem 531A	ankeritic-dolomitic carbonatite	0.0016
Lem 531B	"	0.0014
Lem 803A	"	0.008
Lem 804	"	0.004
Lem 805	"	0.003
Lem 806	"	0.002
Lem 811	"	0.002
Lem 800	red feldspathic fenite (Polvadera granite)	0.001
Lem 803B	"	0.001
Lem 813	"	0.001
Lem 815	"	0.001
Lem 817	"	0.0022
Lem 906	altered facies, Polvadera granite	0.01

Analyses by L. Brandvold, Bureau chemist.

Sample locations shown on plate 2.

resources in the United States ranges from 4 to 28% P_2O_5, suggesting that the Lemitar carbonatites would constitute a low-grade phosphate source.

Barite-fluorite-sulfides Veins

Barite-fluorite-sulfide veins (plate 2) occur 1) along the unconformible contact between the Precambrian rocks and Paleozoic limestones (Box Canyon prospects), 2) along fractures and faults in Paleozoic limestones and Precambrian granitic rocks (Jackpot and Western Silver and Gypsum prospects, Tom Smith, personal communication, August, 1980), and 3) along mafic and ankeritic-dolomitic carbonatite dikes (Western Silver and Gypsum prospects). Numerous pits, shafts, and trenches have exposed this mineralization. A small amount of lead-silver ore was produced from the Box Canyon prospects (Anderson, 1957) and an undetermined amount of barite was produced from the Jackpot and Western Silver and Gypsum claims during the summers of 1979 and 1980.

The mineralization at the Box Canyon prospects occurs in veins striking N. 30-40°W. and dipping nearly vertical. Three shallow shafts and several prospect pits have exposed these veins. Moderate-pink to white, medium- to fine-grained barite is mixed with disseminated fluorite, quartz, galena (generally altered), copper oxides, calcite, and wall rock fragments. Silicification and iron staining of the limestone is common within several feet of the veins. Mineralization has partially replaced the limestone and followed fractures and joints in the adjacent Precambrian granite and mafic dikes.

At the Jackpot prospects (sec. 5 and 6, T. 2 S., R. 1 W.), the barite-fluorite-sulfide mineralization occurs within a limestone fault block and along mafic and fine-grained silicocarbonatite dikes. Prospect pits and shallow shafts have exposed this mineralization. The mineralization within the limestone fault block occurs as veins and replacement deposits consisting of coarse, white to orange-pink barite mixed with trace amounts of galena, pyrite, chalcopyrite, calcite, fluorite, and sphalerite. The mineralization along the mafic and silicocarbonatite dikes occurs as crosscutting veins and lenses of coarse, white to moderate-pink barite mixed with galena and pyrite. Fissure-filling deposits of white barite occurs along joints and fractures within the diorite/gabbro adjacent to the silicocarbonatite and mafic dikes. The dikes strike N. 8-12°E. with a nearly vertical dip while the thin fissure-filling barite veins trend N. 70-80°E., dipping 20-30°E. The mineralization within both host rocks is discontinuous, forming pods or lenses. No continuous ore trend could be found between the two host rock deposits, although a prospect pit has been dug in hopes of finding a continuous trend. Minor iron staining is the only alteration noted along the mafic and silicocarbonatite dikes or within the diorite/gabbro. Calcite veins are common in the diorite/gabbro near the silicocarbonatite dikes. Silicification and iron staining of the limestone is common.

The ore at the Western Silver and Gypsum prospects (sec. 29, 31, and 32, T. 1 S., R. 1 W., plate 2) is intimately associated with ankeritic-dolomitic carbonatite and mafic dikes. Several prospect pits have exposed the mineralization. The barite is moderate-pink to grayish-pink to white and is mixed with quartz, galena, fluorite, and ankeritic-dolomitic carbonatite and mafic dike material. Silver and lead analyses from selected samples of galena are given in table 11. Molybdenite, chalcopyrite, pyrite, and sphalerite may occur as accessory minerals. Small orange crystals of wulfenite and vanadinite occur in a barite-fluorite prospect in SW¼ sec. 29, T. 1 S., R. 1 W. (identified by R.H. Weber, September, 1980), these veins and fissure-fillings occur in zones up to two feet thick, although most zones are less than one-half foot in thickness. None of these veins maintain their thickness for any substantial distance along strike and tend to form lense- and pod-shaped bodies. These veins are sometimes associated with the silicocarbonatite, ankeritic-dolomitic carbonatite, and mafic dikes; they also occur along fault zones. Smokey to milky white quartz veins in places crosscuts the barite veins and ankeritic-dolomitic carbonatite dikes. Localized sericitic and chloritic alteration may be present.

The apparent age of most of the barite-fluorite-sulfides mineralization is Tertiary and is similar to other low-temperature (less than 200 degrees C) barite-fluorite mineralization that occurs along the Rio Grande rift (Williams, 1966; Van Alstine, 1976; McAnulty, 1978). However, some of the barite-fluorite veins associated with the silicocarbonatite and ankeritic-dolomitic carbonatite dikes in the Western Silver and Gypsum prospects <u>may be</u> related to a final magmatic-hydrothermal stage of the carbonatite intrusion. Late-stage barite mineralization is commonly associated with ankeritic or sideritic carbonatites in the world (Heinrich, 1966; Le Bass, 1977). Three main types of barite mineralization

TABLE 11

Silver and Lead Analyses of Galena Samples from Western Silver and Gypsum Prospects

SAMPLE	Ag(Oz/ton)	Pb (percent)
1	0.62	19.4
2	1.48	45.7
3	0.30	2.56
4	0.50	15.6

Note: These samples are selected samples high in galena and fluorite.

(Analyses by L. Brandvold, Bureau chemist, November, 1980) associated with carbonatite complexes are identified by Heinrich (1966) as:

1) late barite replacement carbonatites;
2) veins and replacement bodies outside the main complex; and
3) residual barite accumulations developed by the weathering of carbonatite complexes.

The Lemitar Ordovician barite veins would represent an example of type 1 and 2; although the Lemitar barite veins are not high in rare-earth elements and thorium as is the case for many late barite replacement carbonatites (Heinrich and Dahlem, 1969; Olson and others, 1954). The only distinguishing features between the Ordovician barite veins and Tertiary veins are:

1) Ordovician barite veins occur only in the Precambrian terrain;
2) Ordovician barite veins are in close proximity with the silicocarbonatite, ankeritic-dolomitic, and mafic dikes;
3) Ordovician barite veins tend to be thicker and redder in color.

Mineralogical and isotopic studies need to be undertaken to determine if there are actually two ages of barite mineralization.

CONCLUSIONS

There is sufficient evidence supporting the view that the dikes, stockworks, and veins in the Lemitar Mountains are indeed carbonatites, as summarized below.

1) The Lemitar carbonatites were emplaced in an orderly sequence (figure 29) typical of magmatic events;
2) The Lemitar carbonatites exhibit field relationships (chilled margins on some dikes, cross cutting relationships, and xenoliths in some dikes) and textures (porphyritic or hypidiomorphic-granular) indicative of an igneous origin and are associated with replacement dikes and hydrothermal veins;
3) The mineralogy and major and trace element chemistry of the Lemitar carbonatites are characteristic of carbonatite complexes;
4) Steep, light rare-earth element enriched chondrite-normalized patterns diagnostic of carbonatite complexes characterizes the Lemitar carbonatites, although anomalous depleted rare-earth element patterns do occur;
5) Fenitization is rare, but sodic fenitization of the diorite/gabbro and Polvadera granite does occur locally adjacent to some carbonatite dikes.

Although the Lemitar carbonatites do not appear to be related with any kimberlites or alkalic rocks, a poorly defined alkaline igneous province may have existed during Cambrian to Ordovician times in

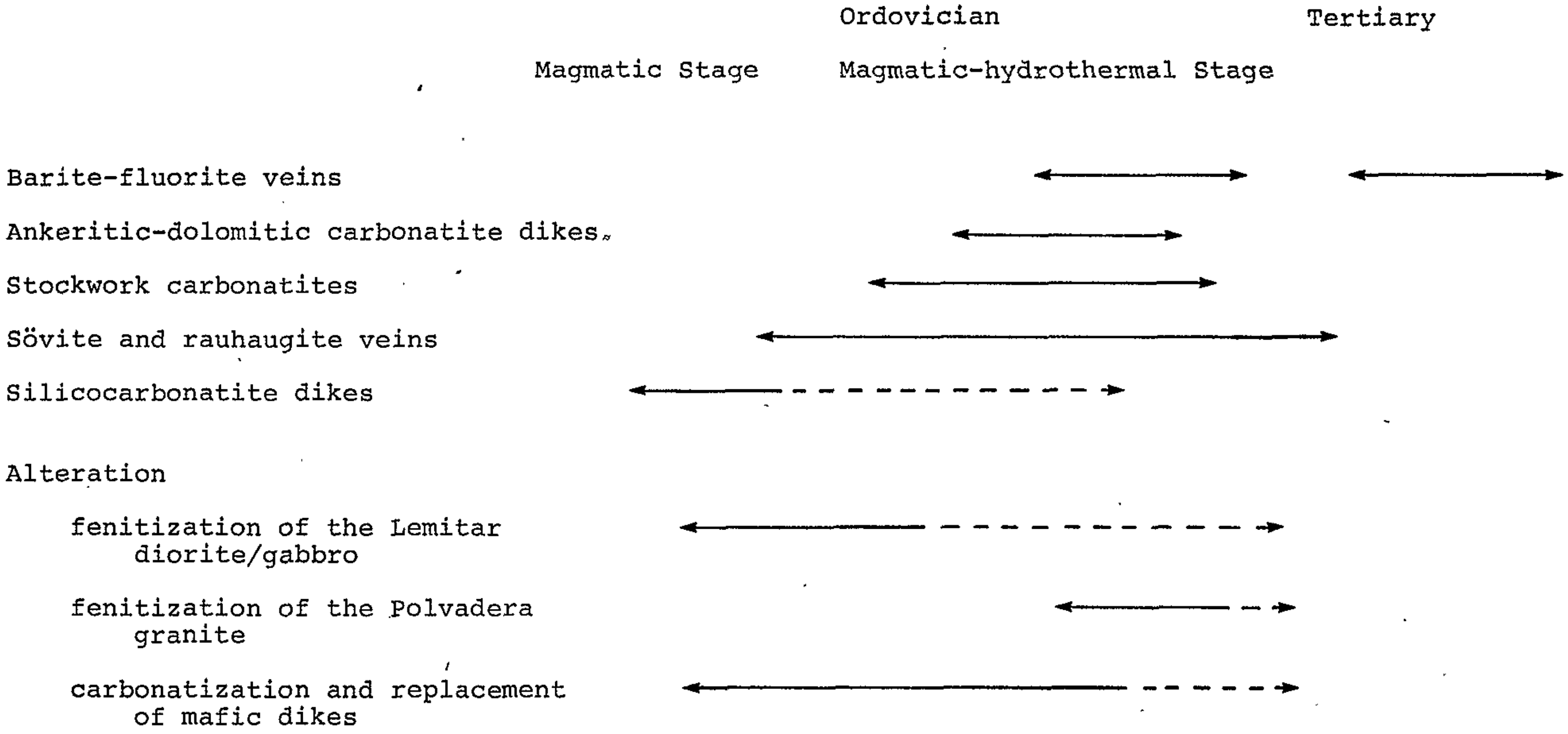

Figure 29 - Sequence of events relating to the intrusion of the carbonatites in the Lemitar Mountains

southern Colorado and New Mexico (figure 5). Carbonatites occur with alkalic rocks in southern Colorado (Armbrustmacher, 1979; Nash, 1972) and at Monte Largo, New Mexico (Lambert, 1961). Carbonatites similar in composition and texture to the Lemitar carbonatites occur in the Chupadera Mountains, Socorro County (figure 1) without any associated kimberlites or alkalic rocks. Alkalic rocks, generally syenites, of Cambrian to Ordovician age occur throughout New Mexico (figure 5) and may indicate the presence of an alkaline igneous province during this time period (Loring and Armstrong, 1980). However, this alkaline igneous province is not yet widely accepted and the Lemitar carbonatites may represent another example of the rare group of carbonatite complexes not associated with any kimberlites, alkalic rocks, or alkaline rock province (Heinrich, 1966; Moore, 1973).

Numerous origins of carbonatite complexes have been proposed by many different authors (summarized by Heinrich,1966) ranging from magmatic crystallization to hydrothermal replacement or precipitation to limestone assimilation. An origin of the Lemitar carbonatites by limestone assimilation can be eliminated for several reasons:

1) The Lemitar carbonatites exhibit textures and field relationships characteristic of an igneous origin, although replacement textures and hydrothermal veins are also common.
2) The Lemitar carbonatites are higher in P_2O_5, TiO_2, Mn, Ba, and rare-earth elements than typical sedimentary limestones and dolomites (Pettijohn,

1957; Weber, 1974; Loubet and others, 1972).

3) The Lemitar carbonatites display steep, light rare-earth element enrich chondrite-normalized patterns, that are quire different from the depleted rare-earth element patterns of limestones (Loubet and others, 1972).

This evidence may not be conclusive proof that the Lemitar carbonatites were not derived by limestone assimulation; however, it is easier to explain their origin by magmatic or magmatic-hydrothermal deviation.

The similarity in texture, emplacement, mineralogy, and chemistry between the Lemitar carbonatites and the Wet Mountains carbonatites, Colorado suggests that these carbonatites may have had a similar origin. Strontium, carbon, and oxygen isotope studies in the Wet Mountains carbonatites indicate that these carbonatites are derived from an upper mantle source and not from assimulation of marble, limestone, or granitic rocks (Olson and others, 1977; Fenton and Faure, 1970; Armbrustmacher, 1979). The strong fractionation and enrichment of light rare-earth elements of the Lemitar carbonatites and the chemical relationship between kimberlites (derived from the upper mantle of lower crust) and the Lemitar carbonatites would further support an upper mantle source. Experimental evidence confirms that melts with a variety of composition, compatible with an upper mantle source, can produce the wide variance in mineralogy and chemistry seen in the Lemitar carbonatites (Wyllie, 1966; Heinrich, 1966).

It is conceivable that the carbonatite dikes, stockworks, and veins may represent the late phases of a carbonatite core which may exist at depth in the Lemitar-Socorro area, as evidenced by:

1) lack of a carbonatite stock or plug typical of most carbonatite complexes;
2) lack of a radial or conical pattern of the Lemitar carbonatites;
3) Lemitar carbonatites appear to follow pre-existing fractures or joints;
4) poorly developed fenitization;
5) dikes, stockworks, and veins are heterogeneous in composition, texture, and fabric;
6) replacement carbonatite dikes and hydrothermal veins are common;
7) presence of carbonatites similar in composition, emplacement, and texture to the Lemitar carbonatites in the Chupadera Mountains.

This evidence is characteristic of carbonatites occurring at a distance from the main carbonatite stock or plug (figure 30). However, rift-faulting of the Lemitar-Socorro area may have upthrown the block exposing the carbonatites away from the main carbonatite core.

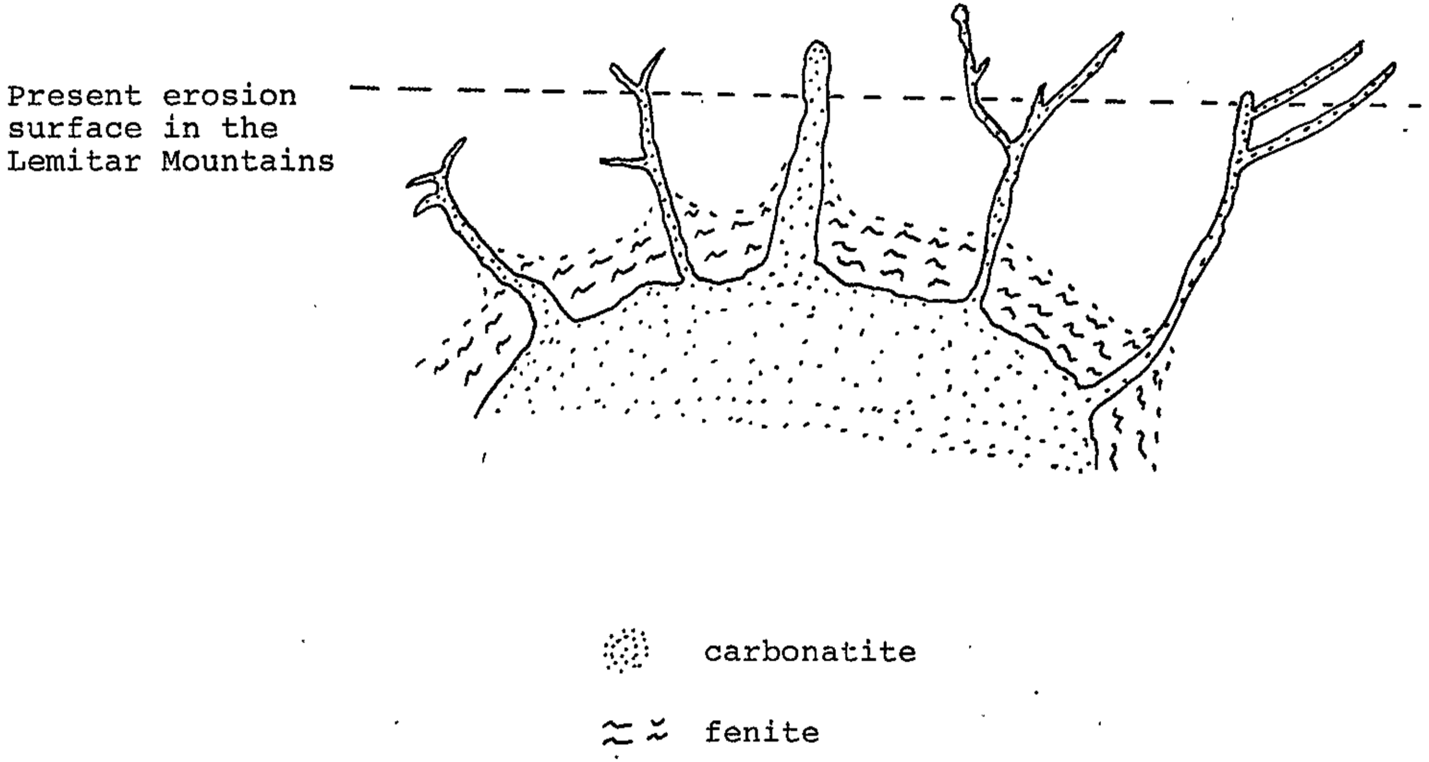

Figure 30 - Schematic diagram of a carbonatite complex illustrating the present erosion surface in the Lemitar Mountains.

APPENDIX A

MINERALOGY OF THE LEMITAR CARBONATITES*

Mineral	Lem 305[1]	Lem 427A[1]	Lem 427B[1]	Lem 500[1]	80-11-1[2]	Lem 506[3]	Lem 530[3]	Lem 531A[4]	Lem 531B[4]	Lem 811[4]	Lem 803A[4]	Lem 805[4]	Lem 806[4]
Biotite/phlogopite	X	X	X	X	X	X	X					X	
Chlorite	X	X	X		X	X	X						
Quartz	X	X	X	X		X	X	X	X		X		X
Fluorite	X	X		X		X	X	X					
Calcite	X	X	X	X	X	X	X	X	X	X		X	X
Dolomite	X	X	X	X	X	X	X	X	X	X	X		X
Ankerite							X	X	X	X	X	X	X
Magnetite/ilmenite	X	X	X	X	X	X	X						
Barite			X				X	X	X				
Bastnaesite				X									
Hematite/geothite								X	X			X	
Apatite	X	X	X	X	X	X	X						
Feldspar	X	X	X	X	X	X							
Sulfides					X	X	X			X			
Hornblende	X	X	X	X		X							

* Determined by whole-rock x-ray diffraction and thin-section analyses.

X - Mineral present

[1] - Primary magmatic silicocarbonatite

[2] - Primary magmatic silicocarbonatite, sample sent for age determination

[3] - Replacement silicocarbonatite

[4] - Ankeritic-dolomitic carbonatite

SAMPLE LOCATIONS SHOWN ON PLATE 2.

Major Element Chemistry of Lemitar Carbonatites (in percent)

Oxide	Lem 305[1]	Lem 427A[1]	Lem 427B[1]	Lem 500[1]	80-11-1[2]	Lem 506[3]	Lem 530[3]	Lem 531A[4]	Lem 531B[4]	Lem 811A[4]	Lem 803A[4]	Lem 805A[4]	806[4]
SiO_2	21.4	11.2	11.6	10.9	7.36	19.1	27.9	3.20	3.59	1.77	18.8	3.49	18.8
TiO_2	1.13	0.40	0.13	0.28	0.43	0.20	1.29	<0.10	0.46	0.34	<0.04	0.37	2.13
Al_2O_3	4.32	2.44	2.14	2.61	2.07	4.35	5.54	0.51	0.49	0.65	<0.05	1.25	3.74
Fe_2O_3	2.75	3.50	3.57	3.73	5.13	5.78	9.58	2.23	3.86	7.10	3.97	11.9	11.6
FeO	5.44	4.22	4.28	5.27	3.94	7.38	6.36	12.0	11.5	5.35	5.79	1.51	2.81
MgO	8.92	10.1	9.67	9.53	2.91	9.90	3.70	7.64	6.47	10.2	9.37	3.07	7.01
CaO	24.5	32.5	30.9	31.6	38.0	17.8	17.5	30.2	27.1	33.6	26.4	41.2	24.0
Na_2O	0.70	0.19	0.19	0.41	0.20	1.13	0.02	0.01	0.01	0.03	0.03	0.01	0.04
K_2O	1.45	0.22	0.47	0.37	0.82	2.20	0.83	0.10	0.10	<0.01	<0.01	<0.01	1.30
MnO	0.53	0.72	0.67	0.65	0.42	0.30	0.40	0.47	0.49	1.01	1.48	1.03	0.55
CO_2	22.7	29.1	29.0	26.3	29.8	18.1	17.4	36.6	34.8	---[5]	---[5]	---[5]	---[5]
P_2O_5	3.26	3.72	3.47	3.33	2.00	1.05	1.54	0.06	0.07	0.08	<0.05	<0.05	1.06
LOI	4.19	1.46	1.05	3.45	4.10	1.47	3.47	4.67	4.11	41.0	33.5	36.2	25.0
TOTAL	101.29	99.77	97.14	98.93	97.18	88.76	96.08	97.79	93.05	101.14	99.49	100.09	98.04

1 - primary magmatic silicocarbonatite

2 - primary magmatic silicocarbonatite, sample sent for age determination

3 - replacement silicocarbonatite

4 - ankeritic-dolomitic carbonatite

5 - CO_2 included in LOI

SAMPLE LOCATIONS SHOWN ON PLATE 2

Trace Element Chemistry of Lemitar Carbonatites (in ppm)

Element	Lem 305[1]	Lem 427A[1]	Lem 427B[1]	Lem 500[1]	80-11-1[2]	Lem 506[3]	Lem 530[3]	Lem 531A[4]	Lem 531B[4]	Lem 811[4]	Lem 803A[4]	Lem 805[4]	Lem 806[4]
Li	84	18	20	20	<5	61	19	7	7	<5	<5	<5	<5
Sc	11	9	9	14	--	23	24	10	8	---	---	---	---
Ni	51	33	60	31	<15	183	390	48	70	<15	<15	<15	<15
Cu	20	10	10	13	5	100	26	24	2	105	< 1	6	5
Zn	158	116	133	125	560	154	397	436	619	30	30	30	20
Sr	244	298	322	323	655	534	177	136	123	30	30	70	40
Ba	365	272	435	272	---	1250	672	913	285	---	---	---	---
Cs	1	2	---	4	---	14	8	---	0.5	---	---	---	---
Cr	20	10	24	10	---	64	398	25	5	---	---	---	---
Co	42	38	30	34	---	31	97	56	52	---	---	---	---
La	538	661	503	556	---	267	114	22	14	---	---	---	---
Ce	1008	1201	999	1122	---	535	218	55	55	---	---	---	---
Sm	70	62	76	59	---	30	16	12	12	---	---	---	---
Eu	12	11	13	11	---	7	4	3	3	---	---	---	---
Tb	5	4	7	5	---	3	1	3	2	---	---	---	---
Yb	2	5	5	9	---	3	2	9	8	---	---	---	---
Lu	---	2	2	2	---	2	0.4	---	1	---	---	---	---
Hf	14	13	16	28	---	22	10	1.2	---	---	---	---	---
Ta	32	16	37	18	---	16	6	5	1	---	---	---	---
Th	40	23	74	22	---	21	4	0.9	2	---	---	---	---
U	2.0	2.5	1.6	3.0	2.5	3.8	9.3	1.4	1.1	2.5	2.5	1.7	1.7
U_3O_8%	0.0023	0.0033	0.0019	0.0036	0.003	0.0045	0.0011	0.0016	0.0014	0.003	0.003	0.002	0.002

1 - primary magmatic silicocarbonatite
2 - primary magmatic silicocarbonatite, sample sent for age determination
3 - replacement silicocarbonatite
4 - ankeritic-dolomitic carbonatite

Chemical Analyses of Unfenitized and Fenitized Lemitar Diorite/gabbro

	UNFENITIZED					FENITIZED	
	Lem 148	Lem 439	Lem 449	Lem 501	Lem 503	Lem 532	Lem 533
SiO_2	51.2	54.5	51.0	59.1	51.0	54.2	58.9
TiO_2	2.88	1.46	2.29	1.17	2.99	1.17	1.30
Al_2O_3	11.1	12.1	9.26	11.8	10.6	11.8	13.1
Fe_2O_3*	18.2	17.7	21.1	15.9	18.6	17.0	12.2
MgO	3.08	1.01	2.58	0.98	3.12	2.94	2.06
CaO	7.63	6.10	7.97	5.34	7.43	4.30	4.42
Na_2O	2.43	2.83	1.73	2.53	2.43	3.75	3.16
K_2O	1.50	1.90	1.50	2.03	1.65	1.19	2.00
TOTAL	98.02	97.60	97.43	98.85	97.82	96.35	97.14
Rb	35	55	44	52	49	82	41
Sr	176	214	86	185	89	745	211
CIPW NORMS							
Q	6.4	9.7	9.1	17.3	6.2	8.8	16.6
Or	8.9	11.2	8.9	12.0	9.8	7.0	11.8
Ab	20.6	23.9	14.6	21.4	20.6	31.7	26.7
An	15.0	14.7	13.1	14.7	13.2	11.9	15.6
Di	19.5	13.7	22.8	10.3	20.2	8.0	5.4
Hy	17.4	17.0	18.5	16.7	17.0	19.8	13.4
Mt	6.1	5.9	7.0	5.3	6.2	5.7	4.1
Il	5.5	2.8	4.3	2.2	5.7	2.2	2.5

* Total iron calculated as Fe_2O_3.

SAMPLE LOCATIONS SHOWN ON PLATE 2

Q - quartz, Or - orthoclase, Ab - albite, An - anorthite, Di - diopside,
Hy - hypersthene, Mt - magnetite, Il - ilmenite

APPENDIX B

ANALYTICAL PROCEDURES

Thirteen samples of the carbonatites and seven samples of the diorite/gabbro were crushed in a rock crusher to silt-sized fragments. Ten grams of each sample (thirty grams of each carbonatite sample) were ground in an automatic mortar and pestle with acetone for thirty minutes. Briquettes were made for each sample for x-ray fluorescence and diffraction analyses. The remainder of each carbonatite sample was dried at 110 degrees C for one hour and then used for wet chemical analyses. An additional ten grams of each carbonatite sample were ground in an automatic mortar and pestle without acetone and set aside for neutron activation analyses.

Mineral identifications of the carbonatite samples were determined from thin-section study and by whole-rock x-ray diffraction. Mineral separates were made with an acetic acid leach and a heavy mineral separation technique using tetrabromoethane (specific gravity of 2.96) and identified by x-ray diffraction.

X-ray fluorescence data was obtained for the diorite/gabbro samples on a Norelco 8-position spectrograph. Ten thousand counts were collected for each briquette and a drift pellet was kept in position four of the spectrograph and counted each time. Count rates for each sample and standard were divided by the count rates for the drift pellet to correct for any drift. A computer program was employed for determining the ratio for each briquette (J.R. Renault, personal communication, Fall, 1979). The counting statistics are better than 2% for all elements except Na_2O and MgO, which are better than 4%. Calibration curves were constructed, employing a second computer program, using U.S.G.S. and intralab rock standards. The errors are summarized in table B-1.

Major and minor elements were determined for the carbonatite samples using atomic absorption, titration, colorimetric, gravimetric, and neutron activation methods (table B-2). A standard HF (hydrofluoric acid) dissolution process was used to decompose the samples for subsequent atomic absorption analysis (L. Brandvold, personal communication, Fall, 1979). Two dissoluations were made; one contained one-half to one gram of sample for the determination of Al, Fe, Mg, Ca, Na, K, Mn, and Zn and the other contained two grams for the determination of Cr, Co, Cu, Ni, Sr, Ba, and Li. The samples were analyzed using a Perkin Elmer 303 or Varian 1250 spectrometer. Standards were prepared from analytical grade reagents and calibration curves for each element were prepared. The relative error is within 5% for most of the elements; Cu and Ba are within 10% (L. Brandvold, personal communication, Fall, 1979).

Modified titration procedures and various colorimetric procedures were employed to determine FeO, CO_2, TiO_2, P_2O_5, and U_3O_8 (table B-2). The relative error for FeO, TiO_2, and P_2O_5 is approximately 1%. Two known standards were analyzed for CO_2 and were within 3% of the known CO_2 concentration. The relative error for U_3O_8 is within 5% (L. Brandvold, personal communication, Fall, 1979).

TABLE B-1

ERRORS FOR X-RAY FLUORESCENCE ANALYSES

ELEMENT	S	C	RMS % ERROR
SiO_2	0.4370	0.59	1.86
TiO_2	0.0206	4.66	4.59
Al_2O_3	0.1162	0.80	0.70
Fe_2O_3	0.2336	5.17	1.77
MgO	0.0230	9.92	1.96
CaO	0.0096	0.69	3.25
Na_2O	0.1079	2.24	2.81
K_2O	0.0238	0.73	3.47
Rb	0.82	1.15	7.40
Sr	0.58	0.35	7.25
Mn	17.19	7.39	4.45

s - standard deviation

c - coefficient of variation $= \dfrac{s}{\text{mean composition}} \times 100$

RMS % ERROR - relative error $= \dfrac{\sqrt{\sum_{i}^{n} \left(\dfrac{c_i - m_i}{m_i} \right)^2}}{n} \times 100$

c_i - calculated concentration of the ith element

m_i - measured concentration of the ith element

n - number of standards

TABLE B-2

Summary of Chemical Procedures for Analyses of Carbonatites

ELEMENT	METHOD	REFERENCE
SiO_2	gravimetric	Maxwell, 1968, p. 323-332 Jeffery, 1975, p. 35-39, 470-471
TiO_2	colorimetric	Maxwell, 1968, p. 379-381 Jeffery, 1975, p. 470-471
FeO	titration	Jeffery, 1975, p. 281, Pratt, 1894
CO_2	titration	Jeffery, 1975, p. 64-66, Shapiro, 1975, Grimaldi and others, 1966
P_2O_5	colorimetric	Jeffery, 1975, p. 382-385
LOI	gravimetric	Jeffery, 1975, p. 270
Note: LOI = loss on ignition - CO_2		
U_3O_8	colorimetric	modified from Yoe and others, 1953

Al, total Fe, Mg, Ca, Mg, K, Mn, Cr, Co, Ni, Sr, Ba, Li, Zn, and Cu were determined by atomic absorption analyses.

Na, Co, Cr, Cs, Ba, Hf, U, Th, Ta, Sc, and seven REE were determined by instrumental neutron activation analyses.

Fe_2O_3 = total Fe - FeO (titration)

Details of the analytical methods used for determining Na, Co, Cr, Cs, Ba, Hf, U, Th, Ta, Sc, and seven rare-earth elements by instrumental-neutron actiniation are described in Condie and Hunter (1976). U.S.G.S. rock standards BCR-1 and SY-1 were used as standards for these elements. Na, Ba, Co, Cr, and U were also determined previously (table B-2) and the results were comparable for all five elements except Ba. The Ba results reported in this report were determined by neutron activation analyses.

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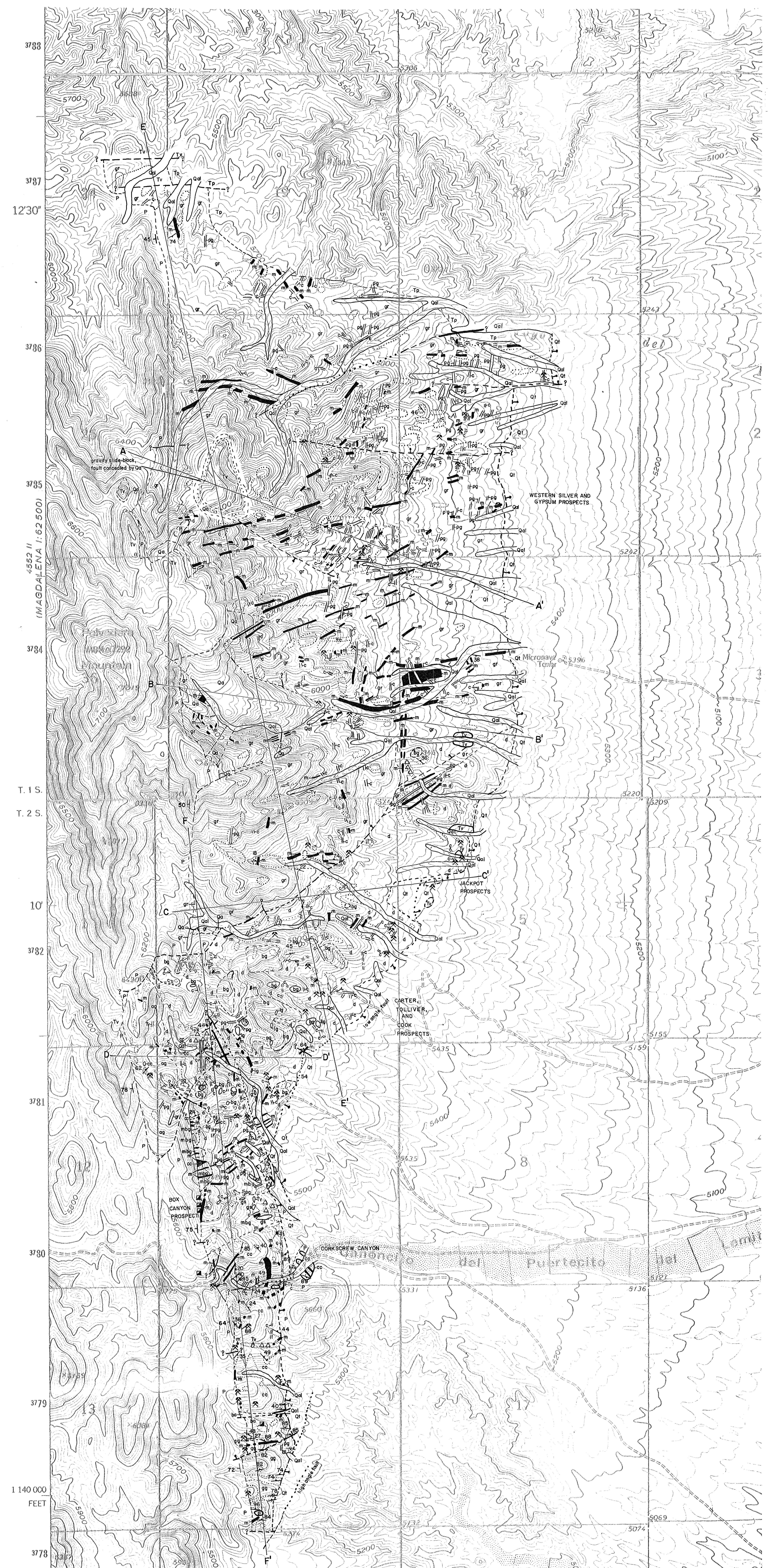
OPEN-FILE REPORT 158

PLATE 1

OUTCROP GEOLOGIC MAP OF THE PRECAMBRIAN ROCKS OF THE EASTERN LEMITAR MOUNTAINS, SOCORRO COUNTY, NEW MEXICO



base map from USGS Lemitar 7 1/2-min topographic map

geology and drafting by V. T. McLemore, 1978-1981

some geological interpretations from R.M. Chamberlin, 1978a

GEOLOGIC UNITS

QUATERNARY

Qa GRAVITY-SLIDE BLOCKS, SLUMP BLOCKS, LANDSLIDES

Qal ALLUVIUM, STREAM SEDIMENTS

Qt ALLUVIAL FAN FACIES, TERRACE DEPOSITS

TERTIARY

Tv VOLCANIC ROCKS, DIKES undifferentiated

Tp SANTA FE GROUP
Popotosa and Sierra Ladrons Formations

PALEOZOIC

P PALEOZOIC SEDIMENTS, undivided
Madera Limestone, Sandia Formation, Caloso Formation, and Kelly Limestone

?

PRECAMBRIAN

c CARBONATITE DIKES, VEINS

pg PEGMATITE DIKES

gr/ag/lg POLVADERA GRANITE
gr medium- to coarse-grained facies
ag altered facies
lg leucogranite

mbg MUSCOVITE-BIOTITE GRANITE

bg BIOTITE GRANITE

gg GNEISSIC GRANITE

m MAFIC DIKES

d LEMITAR DIORITE/GABBRO

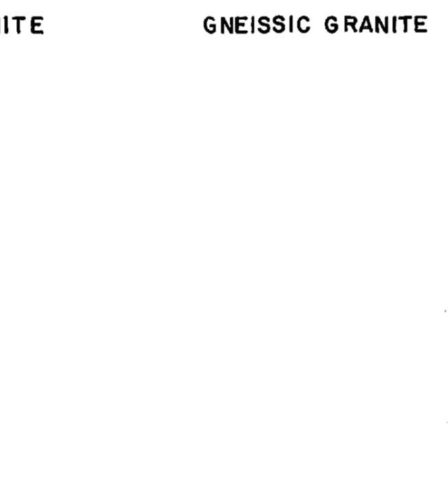
cc/ba CORKSCREW CANYON SEQUENCE
cc upper unit
ba lower unit

g GREENSCHIST

SYMBOLS

△△△	brecciation	? —— – – ?	fault, dashed where poorly exposed
⚒	prospect pit	—— – – –	contact, dashed where poorly exposed
◪	shaft	▨	zone of migmitization
⤙	adit	⬚	extent of outcrop, darker areas show major Precambrian outcrop, lighter areas show concealed Precambrian rock.
65	strike and dip of foliation		
70	strike and dip of beds		

N
12°



INDEX MAP

SCALE

1:12,000

0 1/2 1 MILE

0 1000 2000 3000 FEET

0 300 600 900 METERS

CONTOUR INTERVAL - 20 feet

OPEN-FILE REPORT **158**

PLATE 2

SIMPLIFIED GEOLOGIC MAP OF THE EASTERN LEMITAR MOUNTAINS, SHOWING THE DISTRIBUTION OF MAFIC AND CARBONATITE DIKES, MINERALIZATION, AND SAMPLE LOCATIONS

base map from USGS Lemitar 7 1/2-min topographic map

geology and drafting by V. T. McLemore, 1978-1981

GEOLOGIC UNITS

QUARTERNARY

Qt
ALLUVIAL FAN FACIES,
TERRACE DEPOSITS

TERTIARY

Tv
VOLCANIC ROCKS, DIKES
undifferentiated

Tp
SANTA FE GROUP
Popatosa and Sierra
Ladrons Formations

PALEOZOIC

P
PALEOZOIC SEDIMENTS, undivided
Madera Limestone, Sandia Formation,
Caloso Formation, and Kelly
Limestone

?

c
CARBONATITE DIKES
- t breccia silicocarbonatites
- c silicocarbonatites
- r sovite and rauhaugite veins
- a ankeritic-dolomitic carbonatites
- s stockwork carbonatites

PRECAMBRIAN

gr / ag / lg
POLVADERA GRANITE
- gr medium- to coarse-grained facies
- ag altered facies
- lg leucogranite
- f fenitized granite

mbg
MUSCOVITE-BIOTITE GRANITE

bg
BIOTITE GRANITE

gg
GNEISSIC GRANITE

m
MAFIC DIKES

d
LEMITAR DIORITE/GABBRO

cc / ba
CORKSCREW CANYON SEQUENCE
- cc upper unit
- ba lower unit

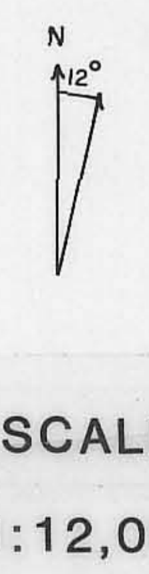
MINERALIZATION

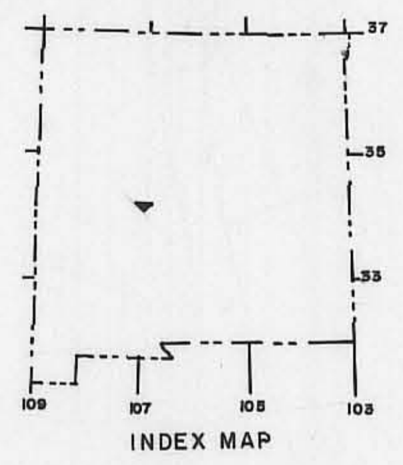
Cu	copper mineralization
b	barite mineralization
f	fluorite mineralization

SYMBOLS

△△△	brecciation	? —— – – ?	fault, dashed where poorly exposed
⚒	prospect pit	—— – – –	contact, dashed where poorly exposed
◪	shaft		
—<	adit		

x LEM-804	SAMPLE LOCATIONS
t 120 g 100	RADIOMETRIC READING IN COUNTS PER SECOND (cps) ON SCINTILLOMETER (GEOMETRICS MODEL GR-101A), BACKGROUND READINGS 30-60 cps
80	DIP OF CARBONATITE DIKE





INDEX MAP

SCALE

1:12,000

0 1/2 1 MILE

0 1000 2000 3000 FEET

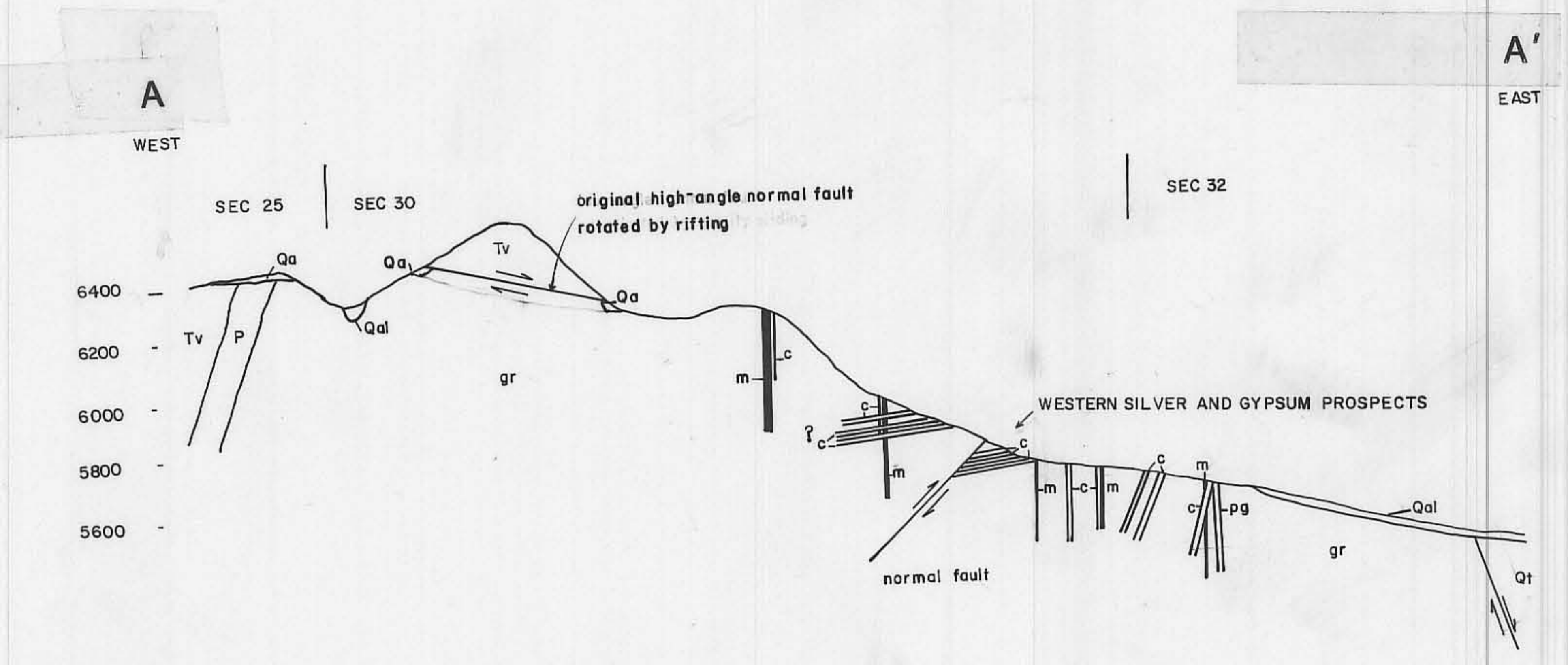
0 300 600 900 METERS

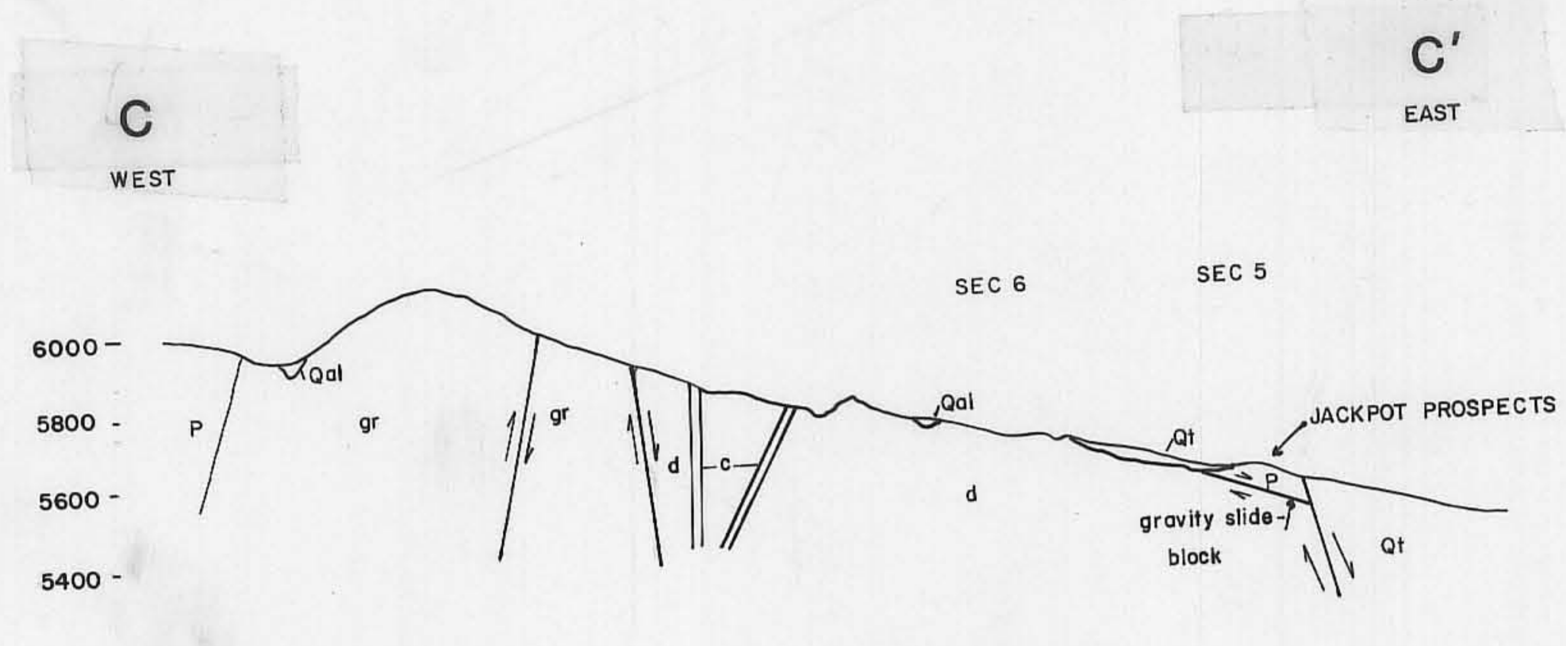
CONTOUR INTERVAL - 20 feet

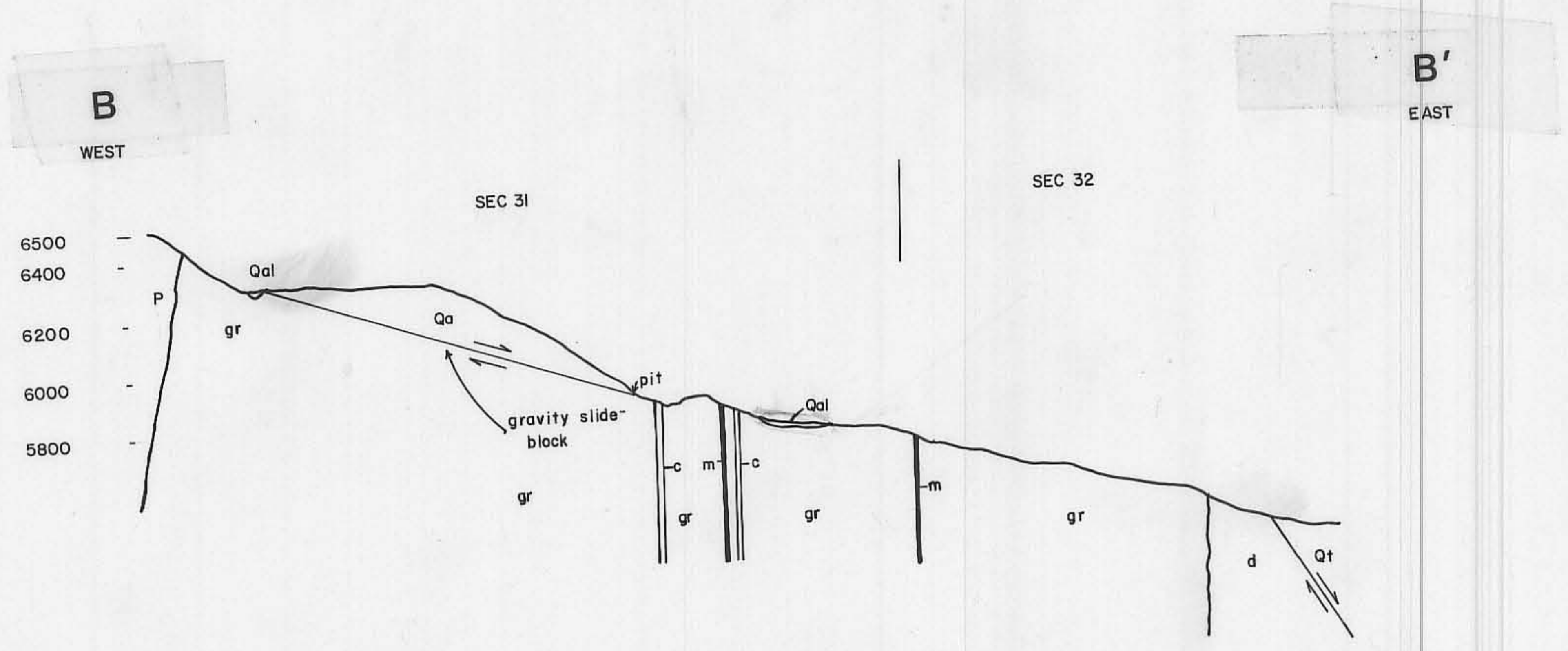
OPEN-FILE REPORT **158**

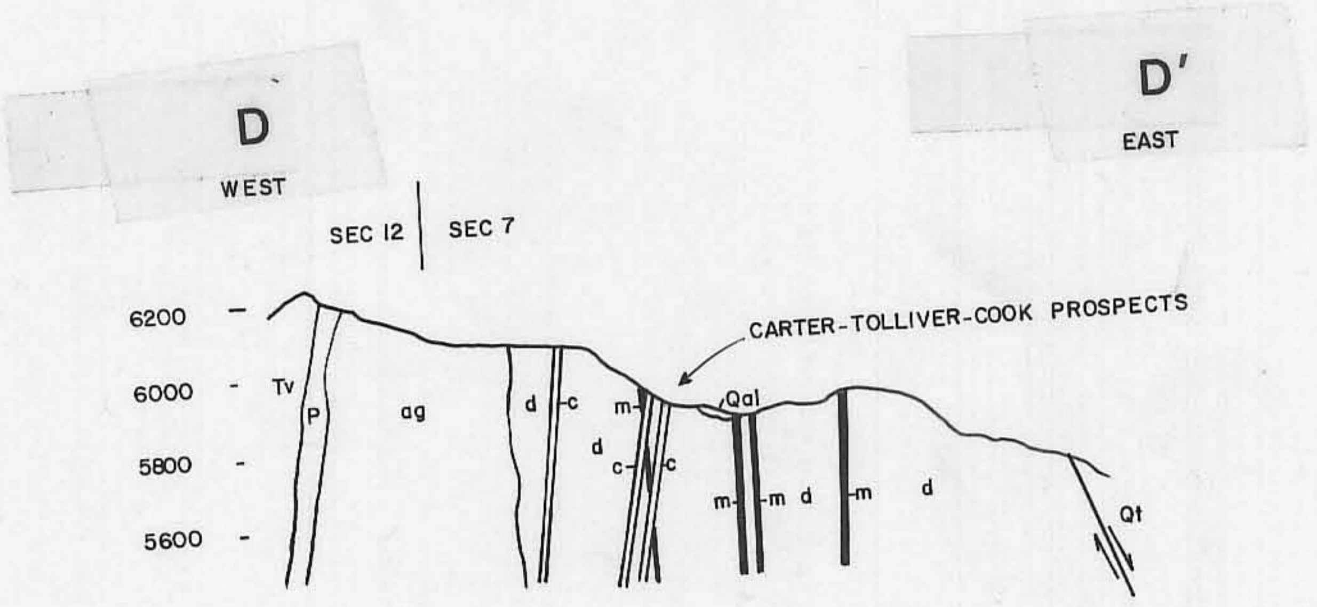
PLATE 3

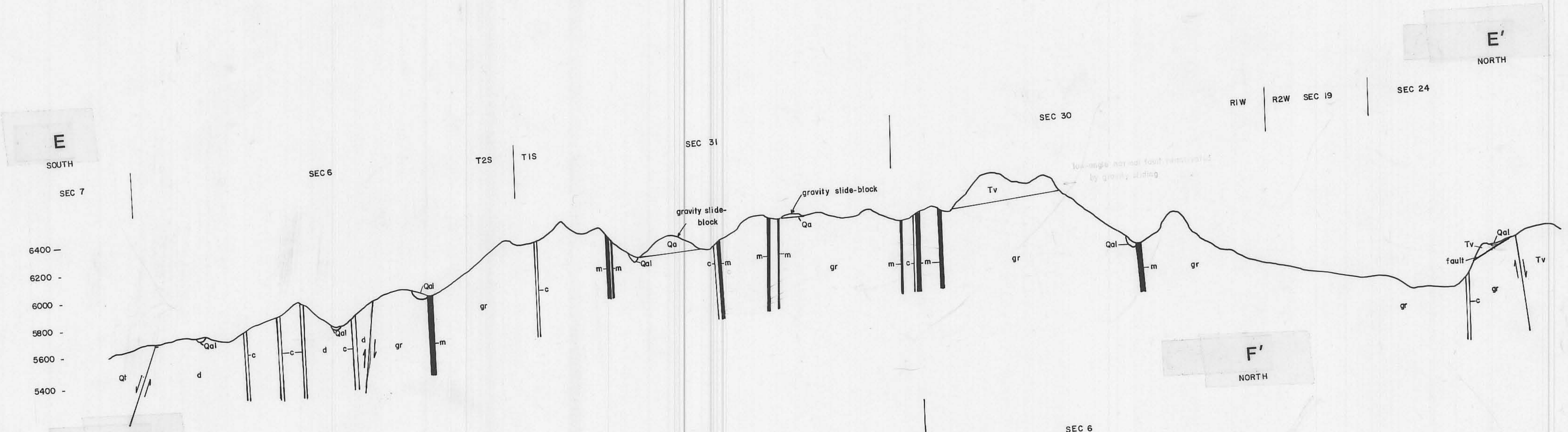
CROSS SECTIONS

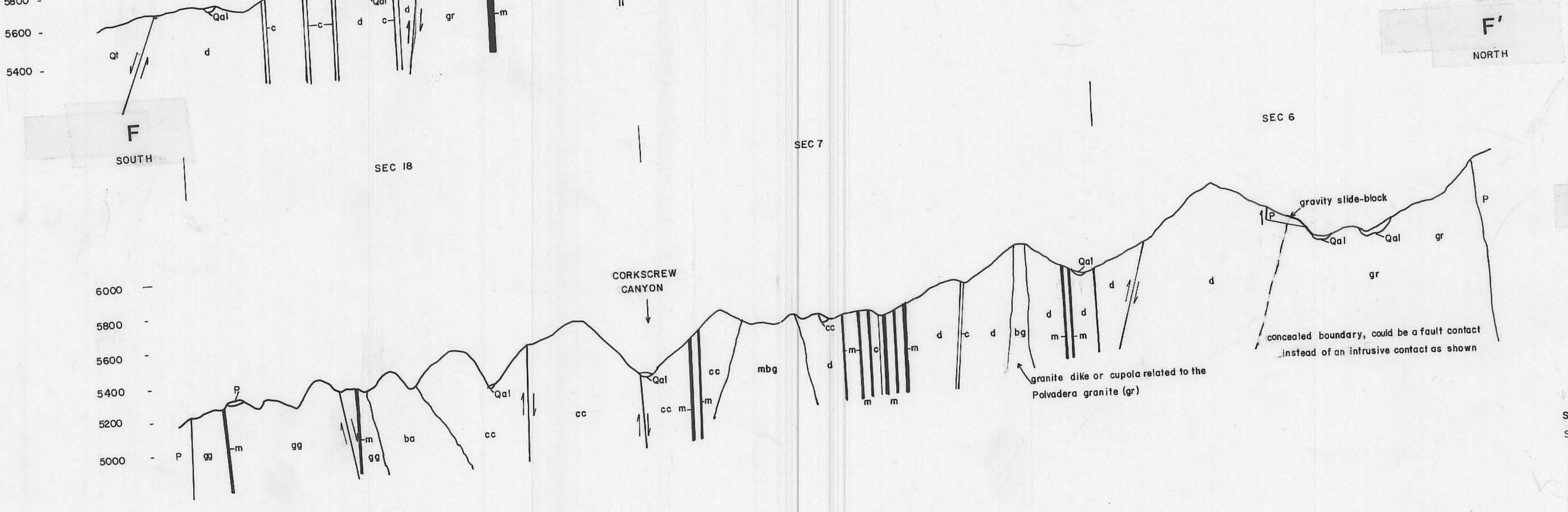












HORRIZONTAL SCALE

1:12,000

VERTICAL SCALE

1 in=500 ft

STRUCTURE MODIFIED IN PART FROM CHAMBERLIN, 1978a

SEE PLATE I FOR LEGEND

OF 158 3 of 3