GEOLOGY OF THE PRECAMBRIAN ROCKS OF THE LEMITAR MOUNTAINS, SOCORRO COUNTY, NEW MEXICO

by

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ABSTRACT

The Precambrian rocks in the Lemitar Mountains consist of a sequence of sediments, the Corkscrew Canyon Sequence (5%), intruded sequentially by mafic dikes, a diorite/gabbro body (20%), granitic rocks (75%), and carbonatite dikes. The sediments consist of a Lower Unit composed of a massive arkose and an Upper Unit composed of interbedded and foliated arkoses, subarkoses, and quartzites. The sediments are high in SiO_2 (>62%) and have low SiO_2/Al_2O_3 ratios and K_2O/Na_2O ratios equal to or greater than one. The abundance of quartz and feldspar indicates a source area consisting of granite or gneiss, while bedding structures indicate a fluvial or deltaic environment in either a continental-rift or a rapidly rising continental-margin setting.

The Lemitar diorite/gabbro is a lithologically heterogeneous mafic unit ranging in composition from gabbro (>An50) and diorite (<An50) to quartz gabbro and quartz diorite (5-10% quartz). This lithologic heterogeneity could be accounted for by either late differentiation of a gabbroic magma or injection and mixing of granitic magmas with a gabbroic body. Three stages of mafic dikes are recognized - Stage I, II, and III (pre-diorite/gabbro, pre-granite, and post-granite). The mafic rocks plot in the

tholeiite field of an AFM diagram.

The granitic rocks are grouped into six variations of one or more plutons - gneissic granite, muscovite-biotite granite, biotite granite, leucogranite, Polvadera granite, and pegmatites and quartz veins. Age relationships between the granitic rocks are uncertain because the granites are not in contact with one another and probably are of a similar age. The granitic rocks fall into two groups - Group I (gneissic granite and biotite granite) characterized by low SiO_2 (66-70%) and high CaO (1.5-3%) and MgO (0.8-1.5%) and Group II (muscovite-biotite granite and Polvadera granite) characterized by high SiO_2 (73-76%) and low CaO (<1.5%) and MgO (<0.8%).

Carbonatite dikes intrude the earlier Proterozoic rocks and are composed of >50% carbonate (calcite, dolomite, and/or ankerite) and are rich in apatite (up to 10%), magnetite (up to 15%), and biotite/phlogopite (up to 15%). The carbonatites fall into two populations - low iron and high iron, related to the presence of ankerite and magnetite. Carbonatites are rich in phosphorus (up to 4% P_2O_5), and uranium (up to 0.1% U_3O_8). Normal sodic fenitization has altered the Lemitar diorite/gabbro adjacent to the carbonatite dikes as evidenced by the increase in sodium in plagioclases and the increase in K-feldspar.

Chemically, the igneous rocks fall into three distinct populations - the mafic rocks, the granitic rocks, and the carbonatites; no chemical trends are apparent between the groups. The bimodal nature of these rocks is consistent with a continental-rift setting.

The Precambrian rocks of the Lemitar Mountains have undergone successive periods of metamorphism prior to retrograde metamorphism and other alteration and are structurally complex, consisting of foliation, faults, shearing, and brecciation (most of which are Laramide or Tertiary structures). Mineral assemblages of the Proterozoic rocks are representative of the transition between the greenschist and amphibolite facies. Foliation of the Corkscrew Canyon sequence approximately parallels relict bedding and is distinguished by textural and color contrasts. A northeast-trending shear zone cuts across the sediments and ends at the intrusive contact with the muscovite-biotite granite. Shearing of the diorite/gabbro may be related to the emplacement of the granitic rocks.

Detailed mapping, petrographic, and geochemical studies indicate that the Proterozoic rocks are consistent with a continental-rift setting. The lack of any chemical trend between the mafic, granitic, and carbonatite groups suggests that there are three separate magma sources for the formation of igneous rocks in the Lemitar Mountains. However, contamination by crustal material and other magmas could be responsible in part for this lack of any chemical trend. An alkali province may have existed in New Mexico and southern Colorado, evidenced by the presence of 0.4 to 1.2 b.y. alkali rocks scattered throughout Colorado (Wet Mountains, Iron Mountains) and New Mexico (Monte Largo, Florida Mountains, Pajarito Mountain). The Lemitar Mountains would be part of this alkali province.

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Geology of the Precambrian Rocks of the Lemitar Mountains, Socorro County, New Mexico

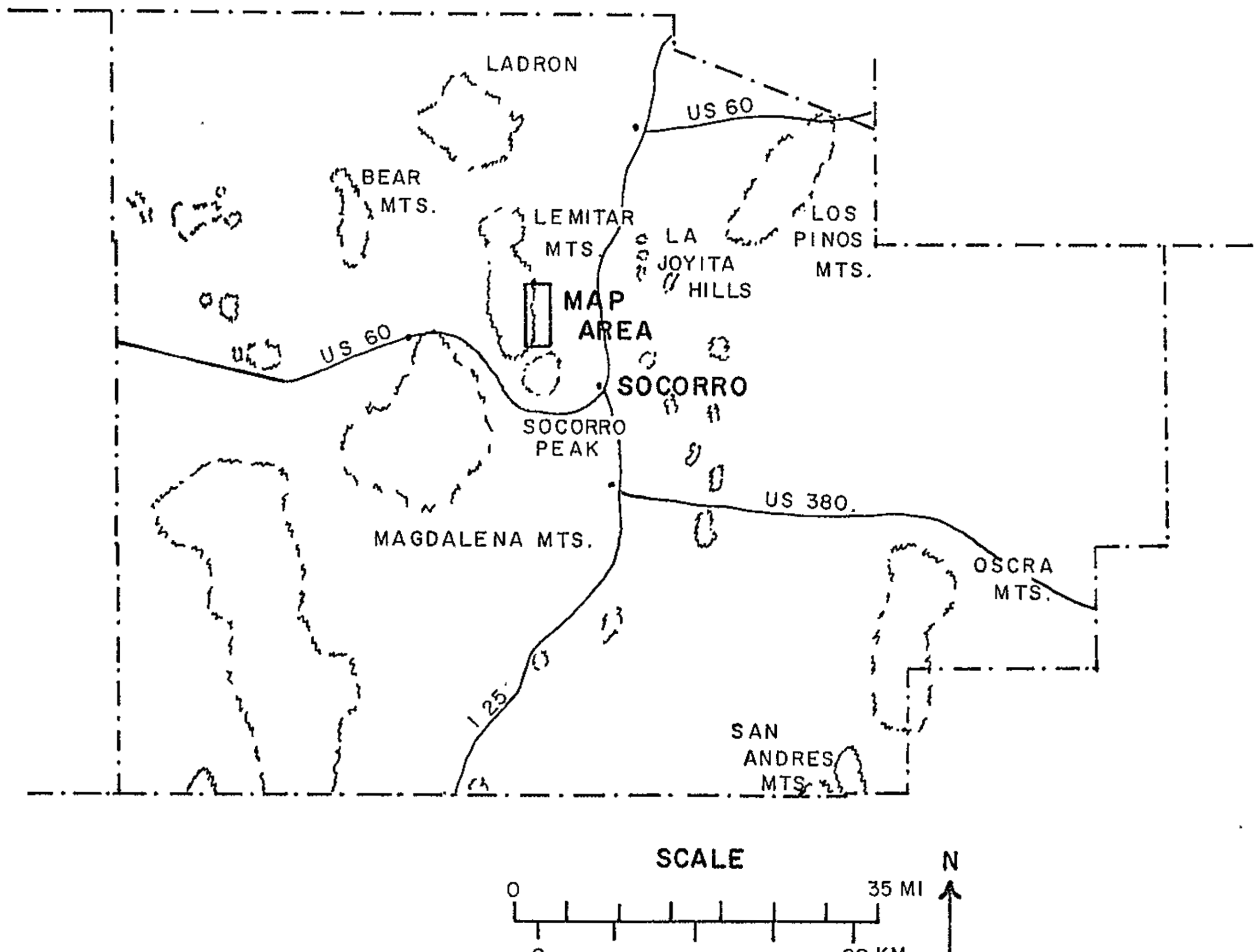
INTRODUCTION

The Lemitar Mountains are located approximately eleven km. northwest of Socorro, New Mexico (fig. 1). Several unpaved roads west of Lemitar, New Mexico, provide excellent access to the area by either two- or four-wheel-drive vehicles. Precambrian rocks crop out along the eastern flanks of the mountains.

The map area (fig. 2) extends from the southern limit of Precambrian exposure (near the section line between sec. 18 and 19, T.2S., R.1E.), northward to the microwave tower in sec. 32 (T.1S., R.1E.). The eastern and western boundaries of the field area are formed by the end of Precambrian exposure.

The area south of Corkscrew Canyon (located along the section line between sec. 7 and 18) had been previously mapped by Chamberlin (1978 and 1980, in preparation) as Precambrian undifferentiated metamorphic rocks. This report divides the southern area into three mappable lithologic units (Map 1). Chamberlin (1978 and 1980, in preparation) also recognized deficiencies in the geologic mapping of the

FIGURE I - MAP OF SOCORRO COUNTY SHOWING AREA OF STUDY.



Precambrian rocks by Woodward (1973) in the area north of Corkscrew Canyon, but it was not his intention to remap the Precambrian rocks. As a part of this report, the area from Corkscrew Canyon northward to the intrusive contact of the Polvadera Granite has been remapped (Map 1).

Wherever possible, the names of particular lithologic units have been adopted or modified from the informal terminology used by Woodward (1973). In many cases, especially with the granitic rocks, new lithologic units were mapped by the author and assigned informal, descriptive names.

Several periods of metamorphism have affected the Precambrian rocks exposed in the Lemitar Mountains and the lithologic names should be prefixed with the term meta. However, the current trend among Precambrian geologists is to use the original lithologic nomenclature and leave off the prefix meta: that style is adopted for this report.

PURPOSE

The purpose of this report is to describe and determine the geologic history of the thick succession of Precambrian sediments and granitic, mafic, and carbonatite rocks exposed in the Lemitar Mountains. This study includes detailed mapping, petrographic studies, and major- and minor-element analyses of a representative suite of samples. Detailed chemical studies are included on eight carbonatite samples. From the results the following will be discussed:

(1) the sedimentary environment

(2) the sediment provenance

(3) the nature of the mafic and granitic magmatism, and

(4) the tectonic setting.

METHOD OF INVESTIGATION

The author, assisted by Larry Holt and James McLemore, spent approximately five months mapping the area (fig. 2) in detail at a scale of 1:6000. The U.S.G.S. Lemitar 7.5-minute quadrangle map was used as a base for geologic mapping. Areas of major outcrop are shown on the map. A scintillation counter was used to measure the natural radioactivity of the mafic and carbonatite dikes and other rocks in the field. Rock colors were standardized, using the rock color chart by Goddard, et al. (1975).

One hundred thin sections were examined with a Zeiss polarizing microscope to determine lithologic and textural variations. Twenty of the thin sections of carbonatites were on loan from Garry Morris, also studying these rocks. Many of the slides were stained to aid in the identification of K-feldspar. Plagioclase compositions were determined using the Michel-Levy method (Kerr, 1959).

Mineral identifications in carbonatite samples were determined from thin section study and by X-ray diffraction. Mineral separations were made with an acetic acid leach and a heavy mineral separation technique using tetrabromo-ethane (specific gravity of 2.96) and identified by X-ray diffraction. Analytical procedures are discussed in appendix A.

Several computer programs were used to calculate CIPW and MESO Norms (K. C. Condie, personal communication) and other petrologic parameters (Petcal by Bingler, et al., 1976). The editing mode of the DEC20 at New Mexico Tech enabled rapid revision of a semi-formated thesis text, while RUNOFF (a formater program at New Mexico Tech) was employed to obtain a completed version of the thesis text.

PREVIOUS WORK

The Precambrian rocks of the Lemitar Mountains were first briefly described by Darton (1928) and Lasky (1932). Lasky (1932) also mentioned small fissure-filling ore deposits along the western contacts of the Precambrian exposures. The occurrence of uranium in the calcareous basic dikes intruding the Precambrian rocks of the Lemitar Mountains was first reported by Stroud and Collins (1954) and Anderson (1954, 1957). The first mining claims for uranium, fluorite, and sulphides in the area were filed in 1954 (Socorro County Courthouse Records).

Bonnichsen (1962) made a general study of the Precambrian rocks in the Lemitar Mountains and the area was mapped by Woodward (1973) as part of a mapping project in the Lemitar Mountains. Condie and Budding (1979) describe the lithology and structural history of the Precambrian rocks in the Lemitar Mountains as part of a study of the Precambrian rocks in central New Mexico; Chamberlin (1978 and 1980, in preparation) remapped the Lemitar Mountains, including reconnaissance mapping of the Precambrian exposures.

SEDIMENTARY ROCKS

INTRODUCTION

A detailed composite Precambrian stratigraphic section of the Lemitar Mountains is difficult to determine because of poor exposures, faulting, shearing, and other deformation. Thicknesses may only be broadly estimated due to poorly exposed and faulted primary bedding structures. A diagrammatic sketch of the stratigraphic section is shown in fig. 3.

Precambrian sedimentary rocks compose approximately 5% of the Precambrian exposure (fig. 2) and have been called the Corkscrew Canyon sequence (Woodward, 1973). They can be classified as quartzites (>90% quartz), subarkoses (75 - 90% quartz), and arkoses (<75% quartz). The Corkscrew Canyon sequence contains the oldest rocks exposed in the Lemitar Mountains.

Two stratigraphic units can be distinguished, an Upper and Lower Unit; and both units have been intruded by granitic rocks. The Lower Unit is a recrystallized, fine-grained arkose, and the Upper Unit consists of recrystallized, interbedded arkoses, subarkoses, and quartzites (fig. 4). Small lenses of green and gray schist

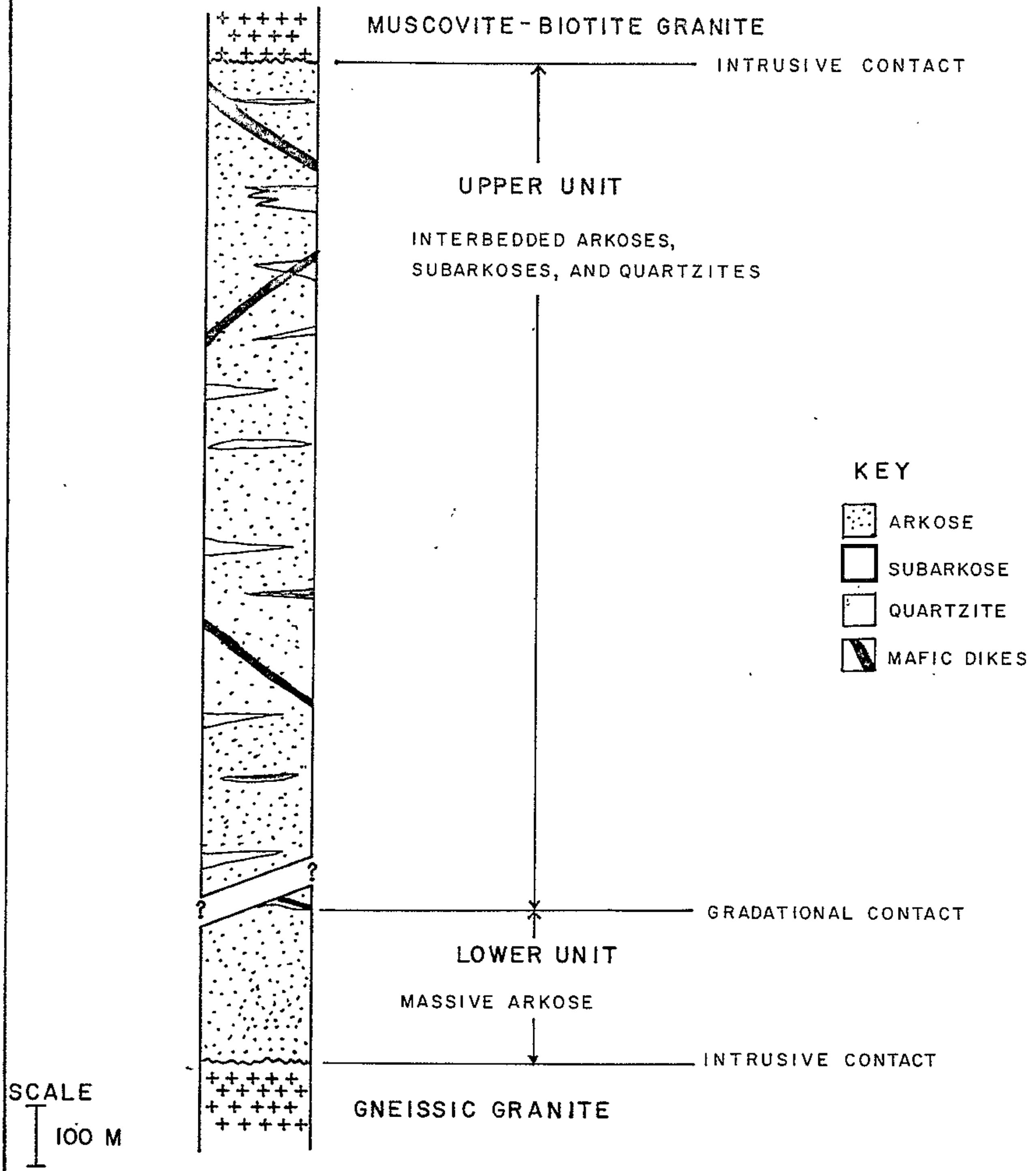


FIGURE 3-DIAGRAMATIC STRATIGRAPHIC SECTION OF THE PROTEROZOIC CORKSCREW CANYON SEQUENCE, LEMITAR MOUNTAINS

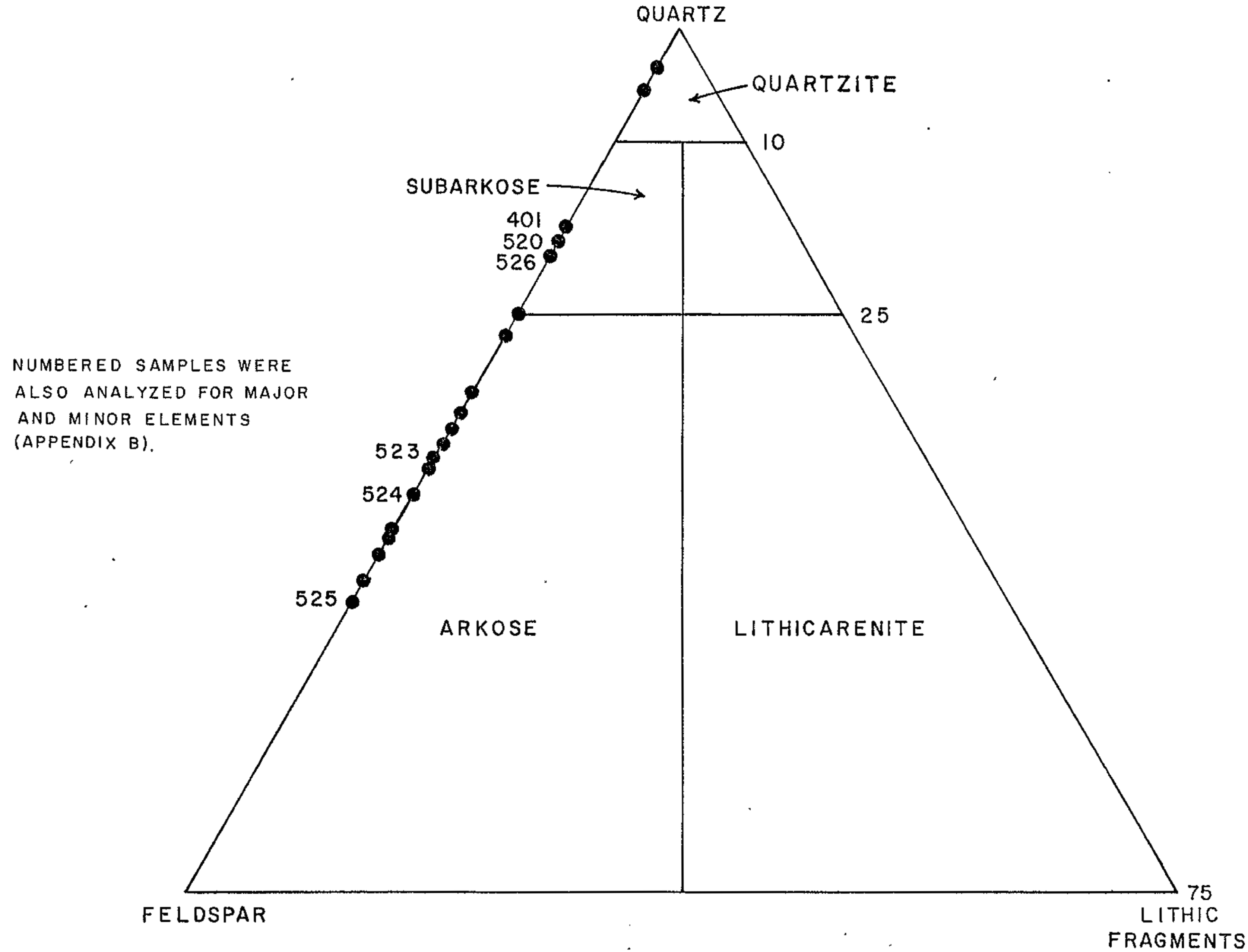


FIGURE 4- CLASSIFICATION OF SANDSTONES FROM THE CORKSCREW CANYON SEQUENCE (MODIFIED AFTER PETTIJOHN, 1957) BASED ON ESTIMATED MODAL ANALYSIS

are found locally throughout the sequence. The sequence is representative of the feldspathic quartzite and arkose association exposed throughout southern and central New Mexico (Condie and Budding, 1979).

Faint crossbedding and graded bedding are preserved in arkoses and subarkoses in Corkscrew Canyon, indicating that the Corkscrew Canyon sequence exposed in Corkscrew Canyon is upright, younging toward the east. Although thin laminar crossbeds are common, they are not photogenic because of poor exposure and lack of contrast. Foliation parallels relict bedding, making the distinction between the two difficult. Faint crossbedding and graded bedding are often poorly preserved in float and in poorly exposed outcrops south of Corkscrew Canyon.

A conformable, gradational contact may exist between the Upper and Lower Units, although the nature of the contact is doubtful because of poor exposures and east-west faults. If foliation parallels relict bedding throughout the entire sedimentary sequence, as in Corkscrew Canyon and elsewhere, than the Lower Unit is older than the Upper Unit.

DISTRIBUTION AND DESCRIPTION OF THE LOWER UNIT

The Lower Unit consists of 250 to 300 meters of arkose to subarkose and can be found in the southern half of sec. 18. The Lower Unit may be gradational with the Upper Unit of the Corkscrew Canyon sequence and the southern contact is intrusive with the gneissic granite (Map 1). Small gneissic dikes (2-15 cm. thick) intrude the Lower Unit along the sharp intrusive southern contact where foliation in the Lower Unit arkose is prominent. Also, small inclusions of the Lower Unit can be found within the gneissic granite.

The Lower Unit is locally foliated and consists of a dark gray, very fine-grained arkose to subarkose. Outcrops are poor and good exposures occur only along the intrusive contact with the granite. In thin section, poorly sorted, rounded to subrounded sand grains are preserved and often are graded. A fine-grained matrix (probably quartz and sericite, 35-40%) is present in the arkose along with sand- and silt-sized grains of quartz (20-25%), untwinned plagioclase (15-20%), green biotite (10%), muscovite (5-10%), and magnetite (<5%).

In contrast to the interbedded and foliated Upper Unit, the Lower Unit consists of a massive arkose with only local foliation and relict bedding preserved. Quartzite and subarkose interbeds, although common in the Upper Unit, are not present in the Lower Unit. In handspecimen, the arkose of the Lower Unit is similar in general appearance to the quartzites found in the overlying sediments of the Upper Unit. The units differ in thin section where the Lower Unit is not as well sorted and is composed of a larger quantity of fine-grained matrix than the arkoses in the Upper Unit.

DISTRIBUTION AND DESCRIPTION OF THE UPPER UNIT

Introduction

Approximately one thousand meters of interbedded arkoses and quartzites in the Upper Unit overlie the Lower Unit to the south. A muscovite-biotite granite is in fault or intrusive contact with the Upper Unit on the north forming a nearly vertical contact in sec. 7. Because of poor exposures the nature of this contact is uncertain. Chamberlin (1978) mapped this contact as the extension of a fault cutting the Kelley limestone; however, the lack of slickenslides and breccias is suggestive of an intrusive contact rather than a fault contact. The occurrence of inclusions of gray schist and arkose within the muscovite-biotite granite also favors an intrusive relationship. Mafic dikes, pegmatites, quartz veins, and carbonatite dikes also intrude the sediments.

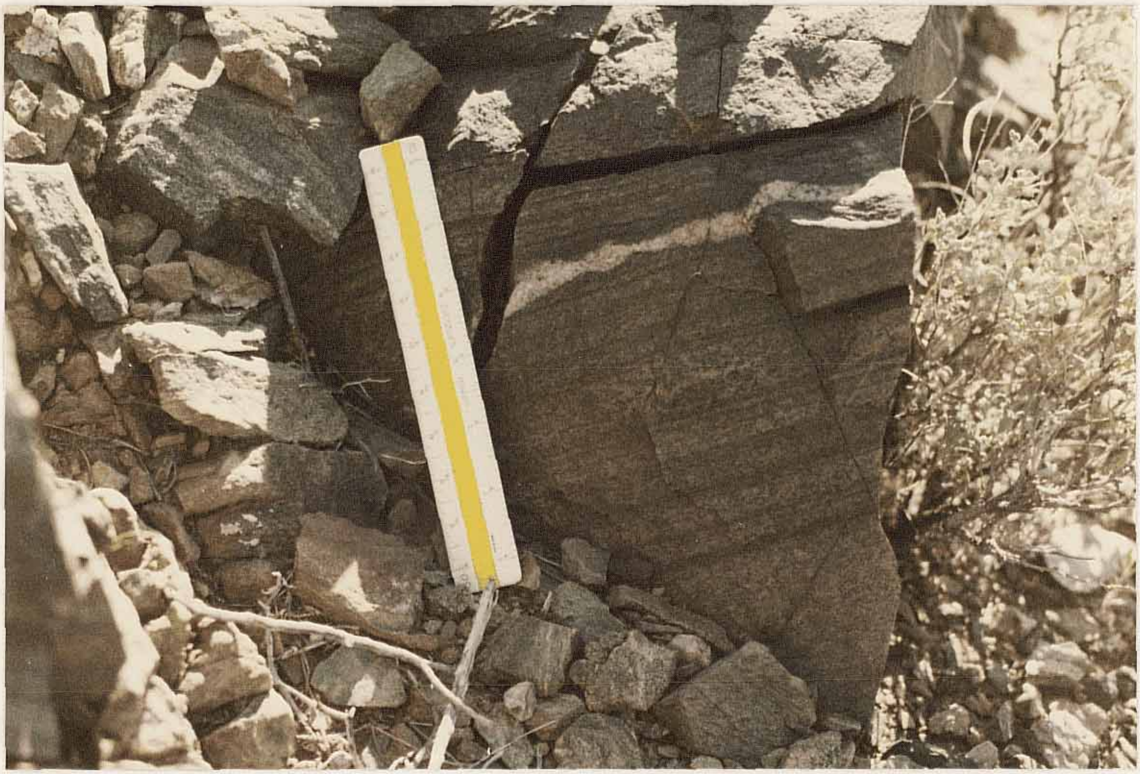
A fault block of sediments crops out in the southern portion of sec. 7. It is bounded by muscovite-biotite granite, the Lemitar diorite/gabbro, and Phanerozoic sediments. At this locality the sediments have been brecciated and recemented.

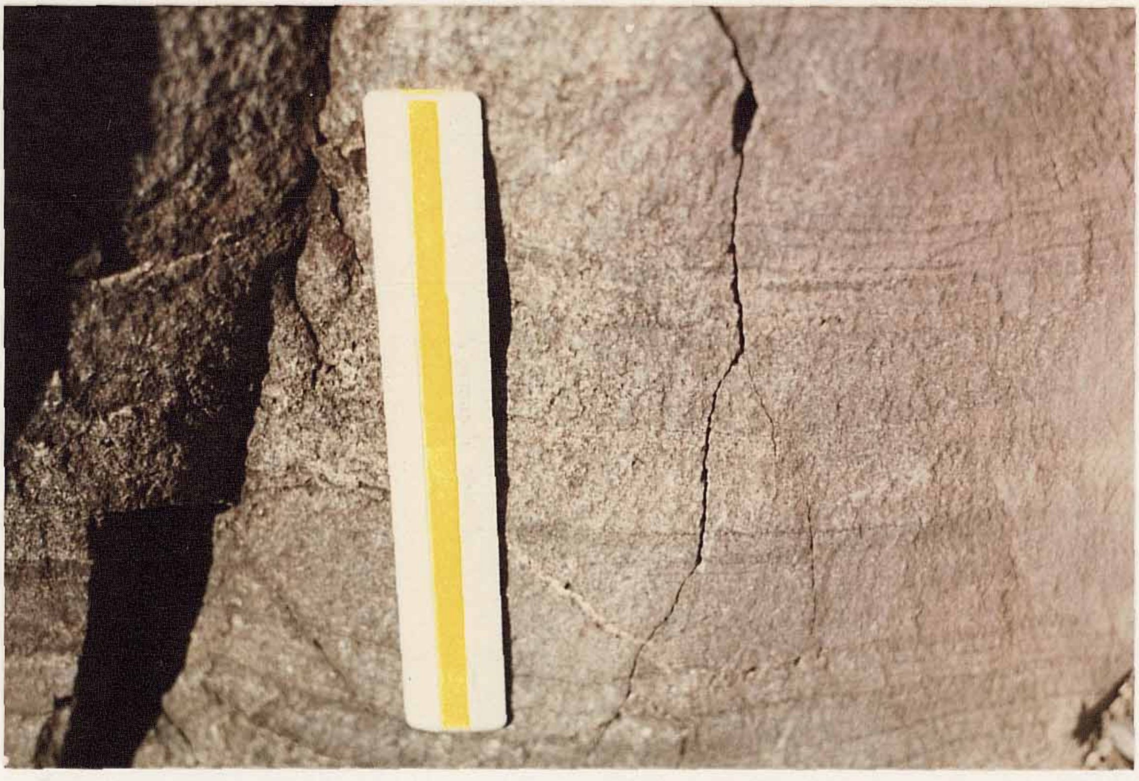
The best exposures of the Upper Unit are along Corkscrew Canyon, where several hundred meters of the sequence are exposed. Several Precambrian and Tertiary faults cut the rocks, so the exact thickness of the sequence is difficult to determine. In addition, strong deformation and shearing in the western quarter of the section along Corkscrew Canyon obliterates original textures and structures. Lenses and dikelets of granitic pegmatites and aplites are common in the sheared rocks, and small lens-shaped boudinage structures are preserved.

Bedding is distinguishable by color contrasts and textural variations (Pl. 1 and 2), but mineralogical compositions can be determined only microscopically. A ten-meter bed of homogeneous, massive quartzite can be distinguished from the other sediments but is seen only in Corkscrew Canyon (Map 1). Outcrops outside Corkscrew Canyon are poor and few in number. Relict crossbedding and graded

PL. 1: Thinly laminated interbedded arkose and quartzite cut by an aplite vein.

PL. 2: Relict crossbedding in arkose.





bedding can be detected in Corkscrew Canyon and elsewhere, indicating that the sequence is upright. Arkoses are the most abundant sediment, followed by (in order of abundance) subarkoses, mafic dikes, quartzites, and green and gray schist.

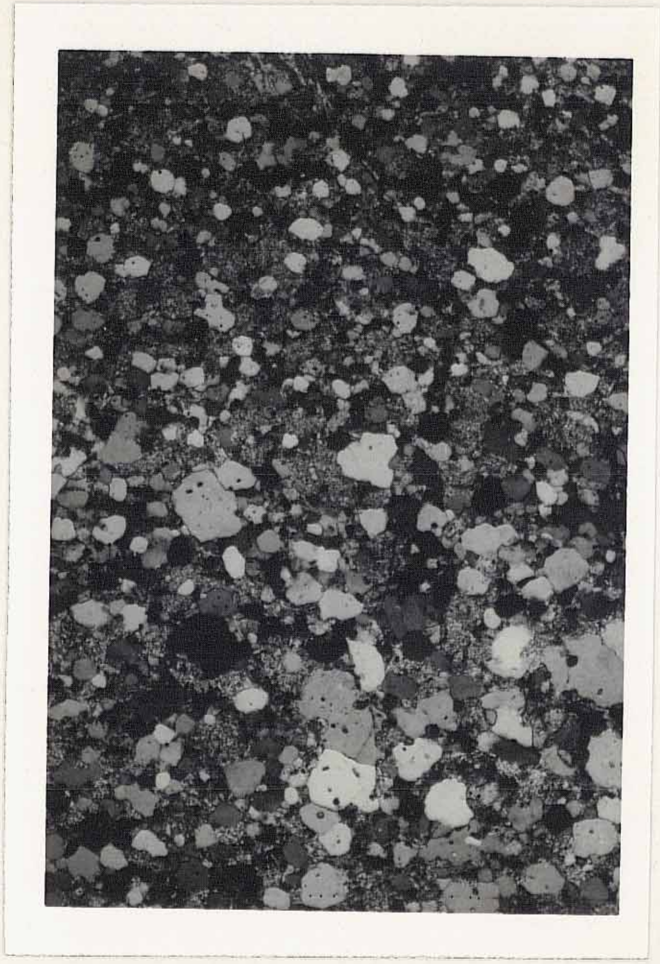
Arkose

The arkoses are common throughout the sequence and occur as fine- and medium-grained interbeds. Foliation of the fine-grained arkose is produced by dark-gray and grayish-pink layers consisting of poorly sorted sand- and silt-size grains of quartz (25-30%), feldspar (15-25%), biotite (10-20%), muscovite (5-15%), and a trace amount of hornblende and magnetite (fig. 4). Up to 15 - 20% matrix may be present in the fine-grained arkoses. Crossbedding and graded bedding are often preserved along with thin layers of coarse arkosic or subarkosic sand (pl. 3 and 4).

Medium-grained arkoses differ from the fine-grained arkoses by having little or no matrix and larger and more rounded sand grains. Foliation of the medium-grained arkose is similar to the fine-grained arkose. Medium-grained arkoses consist of sand-size grains of quartz (50-70%), K-feldspar (5-15%), plagioclase, An10-40 (15-30%), biotite (10-20%), muscovite (2-5%), and minor amounts of magnetite.

PL. 3: Photomicrograph (25x, cross-polars) showing graded bedding in arkose.

PL. 4: Fine-grained arkose, showing crossbedding.



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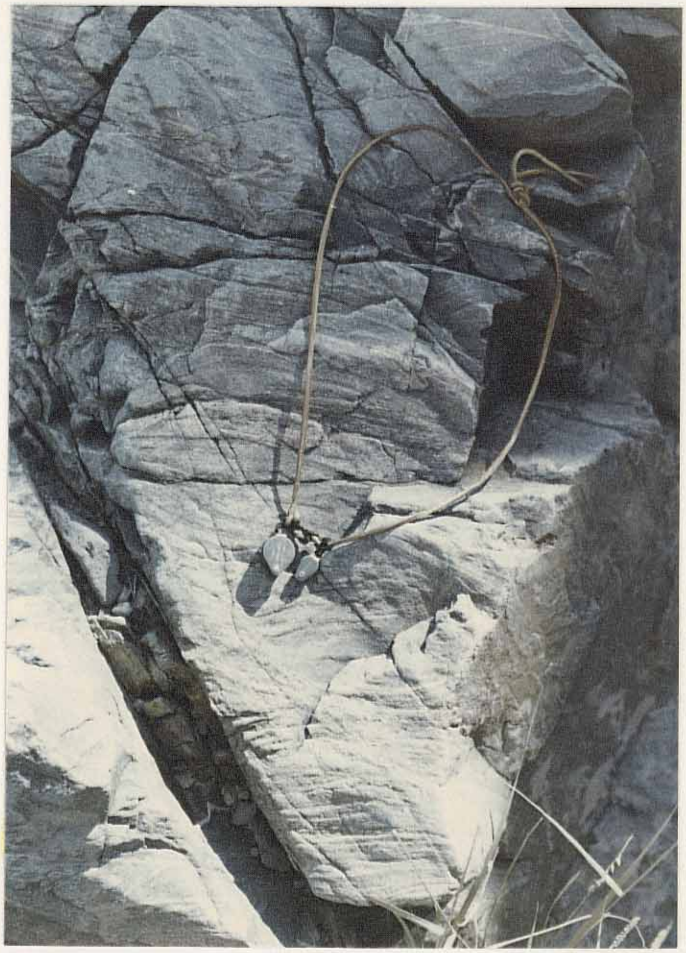


The interbedded and foliated arkoses of the Upper Unit differs from the massive arkose of the Lower Unit by having quartzite and subarkose interbeds and the presence of K-feldspar.

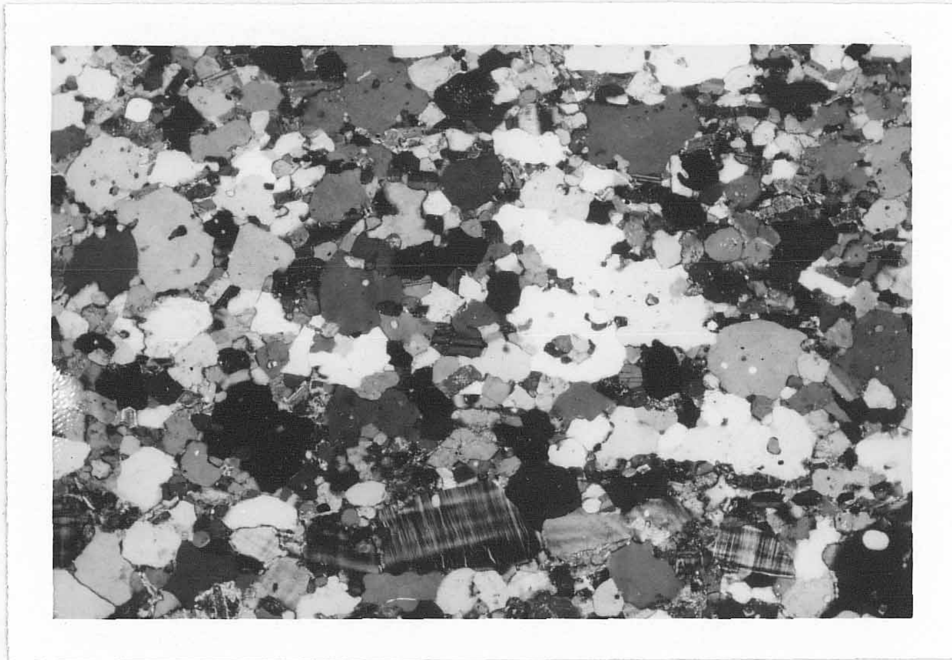
Subarkose

The subarkoses are distinguishable from the interbedded arkoses by their higher quartz content (75-90% quartz). The rocks are foliated with dark-gray and grayish-pink layers, similar to arkoses; they occur as thin interbeds (less than several meters thick) scattered throughout the sequence. In thin section, rounded and well-sorted fine- to medium-sand grains consist of quartz (70-80%), perthitic K-feldspar (probably microcline, 5-15%), biotite (10-15%), and minor amounts of plagioclase, muscovite, magnetite, and matrix (fig. 4 and pl. 5).

Quartzite

The quartzites are massive, pinkish gray to medium-gray, and very fined-grained. Thin laminar bedding is often preserved along with well rounded, well-sorted, and fine-sand grains, consisting of quartz (>90%) with minor amounts of perthitic K-feldspar (probably microcline), plagioclase, muscovite, magnetite, and matrix (see photomicrograph, fig. 8, p. 11, Woodward, 1973). The

PL. 5: Photomicrograph (25x, cross-polars) of a subarkose.



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quartzites occur as thin beds (several cm. thick) interbedded with arkoses and subarkoses.

Schist

Schist lenses occur scattered throughout the sediment sequence and as inclusions within various granitic rocks. The original rocks may have been mafic dikes or shale lenses. Most of these lenses are too small to be shown on the geologic map with the exception of some larger inclusions found within the granitic rocks (Map 1, sec. 7).

The schists are strongly foliated, grayish olive green, fine-grained, micaeous rocks and consist of chlorite and biotite (40-50%), plagioclase, An40-50 (30-35%), quartz (5-10%), and magnetite (5-10%). The chlorite and biotite content may range as high as 90%, with chlorite often more abundant than biotite.

Gray schist lenses occur as inclusions within the muscovite-biotite granite and within several isolated outcrops of Precambrian rocks in sec. 7 (Map 1); they are composed of thin (several cm. thick) alternating layers of massive quartz, plagioclase, biotite, and muscovite. The gray schist often grades into a thinly bedded arkose and often occurs as inclusions within the carbonatite dikes. These green chlorite and gray schist lenses are seldom more than a few meters long and are common along secondary arroyos in sec. 7 and 12.

GEOCHEMISTRY

A representative suite of samples from the Corkscrew Canyon sediments was analyzed for eight major and four trace elements (Appendix B). The sample locations are plotted on fig. 2. In comparison with the average feldspathic quartzite-arkose from the Precambrian of south-central New Mexico (Condie and Budding, 1979), the arkoses and subarkoses of the Upper Unit are lower in SiO_2, and higher in Al_2O_3, Fe_2O_3, MgO, Na_2O, Sr, Rb, and Ba (table 1). The arkose from the Lower Unit of the Corkscrew Canyon sequence (Lem 401) is higher in SiO_2, Fe_2O_3, MgO, CaO, Na_2O, Ba, Rb, and Sr and lower in K_2O, TiO_2, and Al_2O_3 than the average Precambrian feldspathic quartzite-arkose in New Mexico. These differences may represent the heterogeneity of source rocks for the New Mexico Precambrian feldspathic sediments.

The Lemitar sediments can be compared to an average graywacke and arkose (table 2 and fig. 5). The Lemitar sediments are higher in Na_2O and K_2O than the average graywacke and arkose. Generally, the Lemitar sediments fall in the arkose field (fig. 5).

TABLE 1

GEOCHEMISTRY OF SANDSTONES

	1	2	3	4	5	6	7
SiO2	77.5	77.1	66.1	66.7	77.8	65.6	75.2
TiO2	0.63	0.3	0.3	0.6	0.54	0.73	0.62
Al2O3	12.8	8.7	8.1	13.5	11.1	16.8	13.2
Fe2O3*	2.71	2.28	5.4	5.5	4.57	6.67	4.74
MgO	0.34	0.5	2.4	2.1	0.94	1.49	1.20
CaO	0.96	2.7	6.2	2.5	1.39	0.77	2.02
Na2O	1.71	1.5	0.9	2.9	2.45	2.37	2.70
K2O	3.14	2.8	1.3	2.0	2.91	4.71	3.00
TOTAL	99.79	95.88	90.7	95.8	101.70	99.14	102.68
K2O/Na2O	1.8	1.9	1.4	0.7	1.2	2.0	1.1
SiO2/Al2O3	6.0	8.9	8.2	4.9	7.0	3.9	5.7
Rb	113				139	223	202
Sr	52				78	156	162
Ba	530				1172	1189	1186

* - Total iron expressed as Fe_2O_3.
1 - average feldspathic quartzite-arkose from the Precambrian of New Mexico (Condie and Budding, 1979)
2 - average arkose (Pettijohn, 1963)
3 - average lithic arenite (Pettijohn, 1963)
4 - average graywacke (Pettijohn, 1963)
5 - arkose, Lower Unit, Lemitar Mountains (1 sample)
6 - average arkose, Upper Unit, Lemitar Mountains (average of 3 analyses)
7 - average subarkose, Upper Unit, Lemitar Mountains (average of 2 analyses)

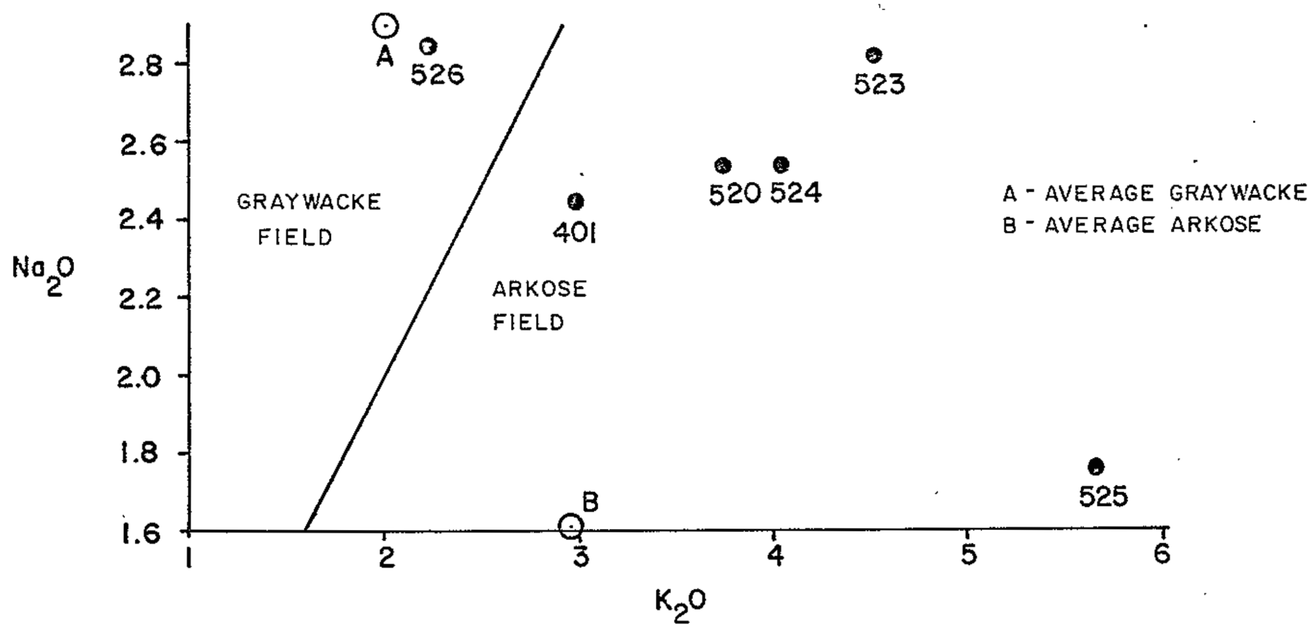


FIGURE 5 - Na_2O - K_2O PLOT OF SANDSTONES FROM THE CORKSCREW CANYON SEQUENCE (DIAGRAM AFTER PETTIJOHN, 1963)

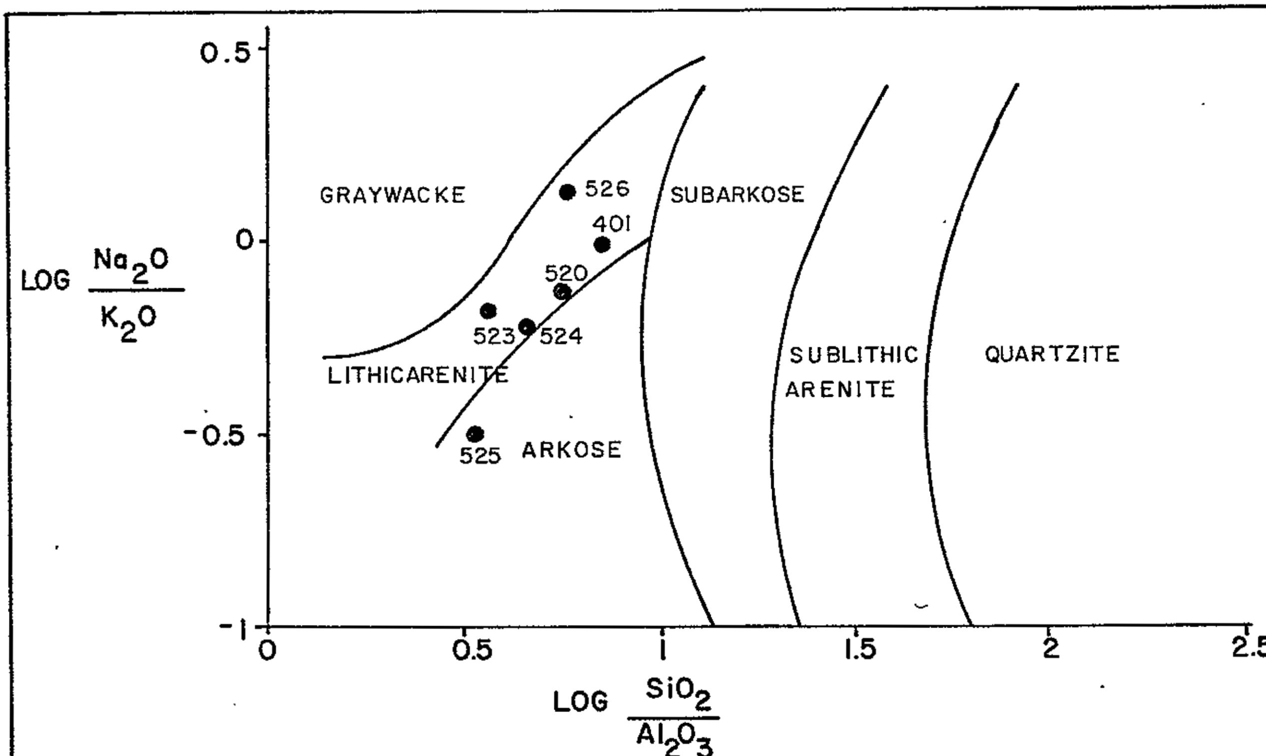


FIGURE 6 - GEOCHEMICAL CLASSIFICATION OF SANDSTONES FROM THE CORKSCREW CANYON SEQUENCE (AFTER PETTIJOHN, 1963)

TABLE 2

CHEMICAL CLASSIFICATION OF SANDSTONES

(modified from Pettijohn, Potter, and Siever, 1973)

HIGH SiO_2/Al_2O_3 RATIO - Quartz arenites (quartzites)

mature, little clay or detrital Al-silicate

(1) alkali rich (carbonate cement)

(2) alkali poor (silica cement)

LOW SiO_2/Al_2O_3 RATIO (<12)

immature, clay plus detrital Al-silicate

(1) alkali rich

(a) $Na_2O > K_2O$ - feldspathic graywackes

(b) $Na_2O < K_2O$ - arkoses, lithic graywackes

(2) alkali poor - lithic arenites

NOTE - graywacke is defined as a sandstone having >15% matrix.

A chemical classification, based on the compositional maturity of the sediment, has been proposed by Pettijohn (1963 and Pettijohn, Potter, and Siever, 1973; see table 2 and fig. 6). The Lemitar sediments fall in the low SiO_2/Al_2O_3 group and near the border between the high and low alkali subgroups. This grouping is characteristic of younger arkoses and lithic arenites.

One must use caution when using these diagrams because the affect of regional metamorphism on sediments is not clearly understood. Schwarcz (1966) studied an area of regional metamorphosed arkosic quartzites and found that no appreciable change in modal or major element composition occurred with increase in metamorphic grade. Shaw (1954, 1956), Barth (1936), and Mason (1962) also found almost no significant compositional changes in sediments metamorphosed up to the upper amphibolite facies. It is probable that metamorphism has not significantly changed the major element chemistry of the Lemitar sediments because their chemistries are not significantly different from chemistries of younger arkoses and subarkoses (Pettijohn, 1963), although metamorphic affects may account for some of the differences that exist between the Lemitar sediments and recent sediments.

PROVENANCE AND SEDIMENTATION

Some constraints on the original sedimentary environment and tectonic setting can be deduced from mineralogical, textural, and geochemical variations. Sandstone composition is controlled by a number of factors (Potter, 1978):

(1) composition and volume of the source

(2) relief

(3) weathering

(4) climate

(5) method and distance of transport.

The abundance of quartz and feldspar indicates a source area consisting of granite or gneiss. By applying Dickinson's criteria (1970, Dickinson and Suczek, 1979), a gneissic or granitic source is indicated for the Lemitar Mountains by the high quantities of quartz and feldspar (>25%) and the low quantities of lithic fragments (0%, fig. 7). Rounded to subrounded textures suggest intermediate transport distances, if these textures are not inherited from the reworking of a quartz sandstone in the source area.

The relative abundance of feldspar in the sediments is indicative of an environment in which intense weathering did not exist. Such sediments may have formed in a variable

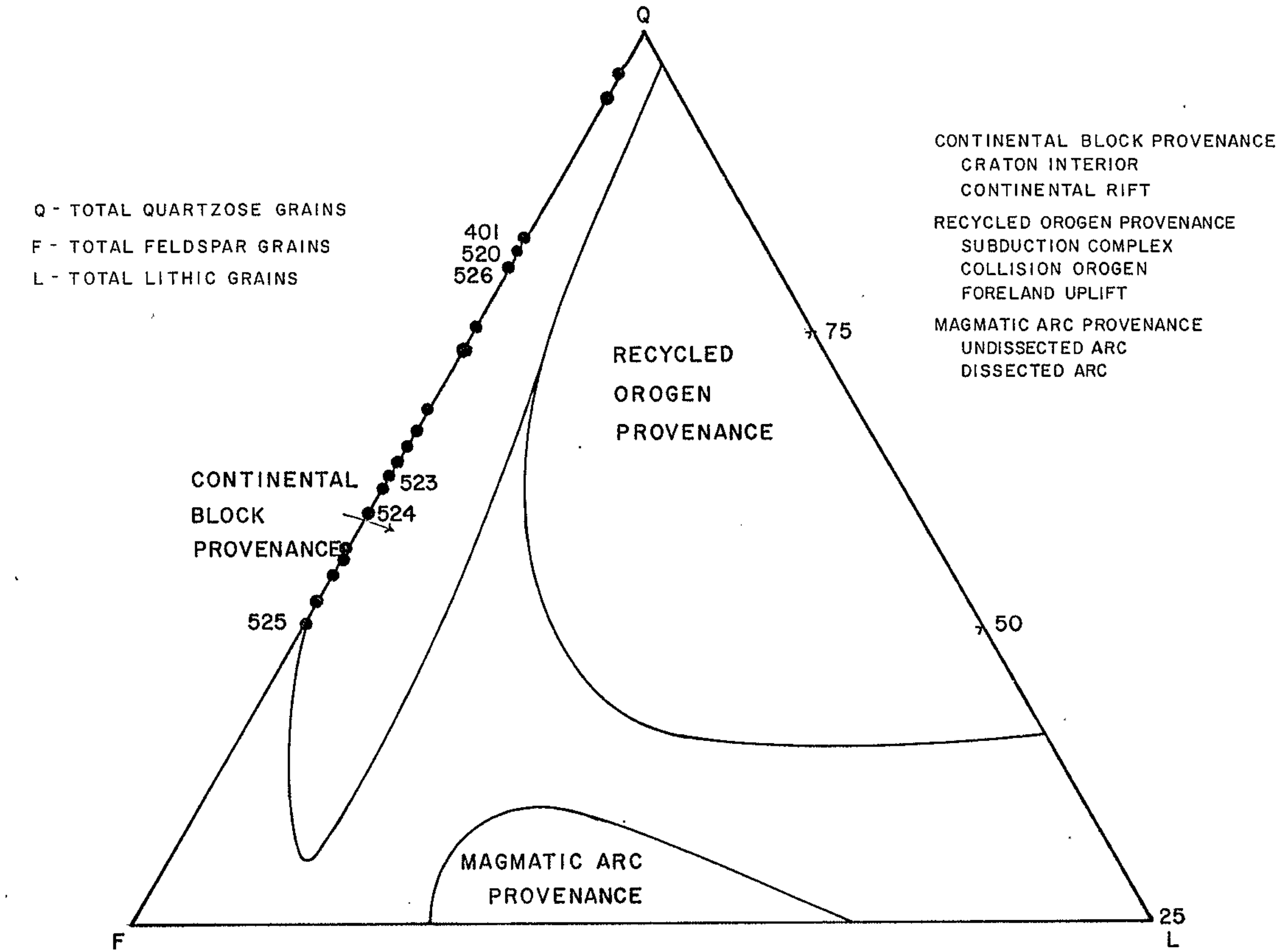


FIGURE 7 - TECTONIC PROVENANCE OF PROTEROZOIC SANDSTONES FROM THE LEMITAR MOUNTAINS (DIAGRAM PROPOSED BY DICKINSON AND SUCZEK, 1979)

climate in which erosion and burial were relatively rapid (Folk, 1974; Potter, 1978; Condie and Budding, 1979). The massive quartzite beds in the succession may reflect a local tectonically stable source or localized reworking of quartzo-feldspathic sediments in a high energy environment (such as an intertidal zone). The subrounded shapes and small size of the quartz grains favor reworking of quartzo-feldspathic sediments.

The mineralogical and textural evidence are consistent with deposition in a fluvial or deltaic environment (Reineck and Singh, 1973). However, the evidence is not sufficient to differentiate between a lacustrine or a marine setting.

The Rinconada Formation (Precambrian) in northern New Mexico consists of interbedded quartzites and pelitic schists similar to the Corkscrew Canyon Sequence (Barrett and Kirschner, 1979). These deposits have been interpreted to represent deltaic, fluvial, and shallow-marine deposits based on the presence of crossbedding, ripple marks, and graded bedding and on the similarity between the Rinconada sediments and Holocene sediments from the Donjeck River, Yukon (fluvial deposits), and Niger delta systems (Barrett and Kirschner, 1979). The Corkscrew Canyon sediments may represent a similar depositional environment because of the similarity in primary bedding structures and lithology.

Several attempts have been made to apply mineralogical composition to plate-tectonic settings (Dickinson, 1970; Dickinson and Suczek, 1979; Dickinson and Valloni, 1980). The dominance of feldspar and quartz (fig. 7) clearly indicates that the sediments found in the Lemitar Mountains were deposited in a continental block provenance, assuming Dickinson's theory is applicable to the Lemitar Mountain Precambrian sediments. Two specific tectonic settings are recognized by Dickinson and Suczek (1979) as occurring in a continental block provenance - the craton interior and the uplifted basement (rift zone).

Chemistry has been used to differentiate between ancient tectonic settings (Schwab, 1975). Quartz-rich sandstones (characteristic of rift valleys and rising, stable continental- margins) have a high SiO_2 content and a K_2O/Na_2O ratio equal to or greater than one. The Lemitar samples, with one exception, fit these criteria (table 3).

Block faulting associated with rifting could uplift a granitic basement; and rapid erosion along steep slopes could produce alluvial-fan deposits, resulting in the graded and crossbedded, poorly to moderately sorted feldspathic sediments such as those exposed in the Lemitar Mountains. Prolonged abrasion of any quartz-rich source could produce quartzites. Deltaic environments could develop further from

TABLE 3

GEOCHEMISTRY OF THE LEMITAR SEDIMENTS

	523	526	524	525	401	520
SiO_2	65.2	76.5	69.6	62.0	77.8	73.8
SiO_2/Al_2O_3	3.8	6.2	4.8	3.3	7.0	5.3
K_2O/Na_2O	1.6	0.8	1.6	3.2	1.2	1.5

the uplifted terrain.

A more tectonically stable environment could be envisioned as well, such as a rising continental-margin (Schwab, 1975) or a craton interior (Dickinson and Suczek, 1979). A granitic source could exist at relatively stable conditions for a long time; and, under dry or cold climatic conditions, the feldspars would not decompose. Over a length of time, the abrasive action produced by water or wind could produce arkosic sands (Folk, 1974). Quartzites may be derived from locally reworked sediment in an intertidal zone. Fluvial or deltaic environments would be consistent with such a setting.

IGNEOUS ROCKS

INTRODUCTION

The Precambrian igneous rocks in the Lemitar Mountains consist of a mafic intrusive body (Lemitar diorite/gabbro), a granitic complex, mafic dikes, and carbonatite dikes and are grouped according to a classification modified by Hyndman (1972) after Streckeisen (1967, fig. 8). The igneous rocks have been metamorphosed and should be prefixed with the term meta, but for the purposes of this report the original nomenclature is used, leaving off the term meta.

Precambrian granitic rocks in the Lemitar Mountains compose 75% of the total exposed Precambrian terrain, while the Lemitar diorite/gabbro compose 20% of the total exposed Precambrian terrain. In New Mexico, Precambrian granitic rocks compose approximately two thirds of the exposed Precambrian terrain (Condie and Budding, 1979) and the majority of the basement as well (Denison and Hetherington, 1969; Muehlberger, et al., 1966). Mafic rocks, although not as common, are present throughout the Precambrian in New Mexico. A 1.5-b.y. (White, 1978) gabbro crops out in the Magdalena Mountains (Loughlin and Koschman, 1942; Blakestad, 1976; Sumner, 1980) that may be related to the

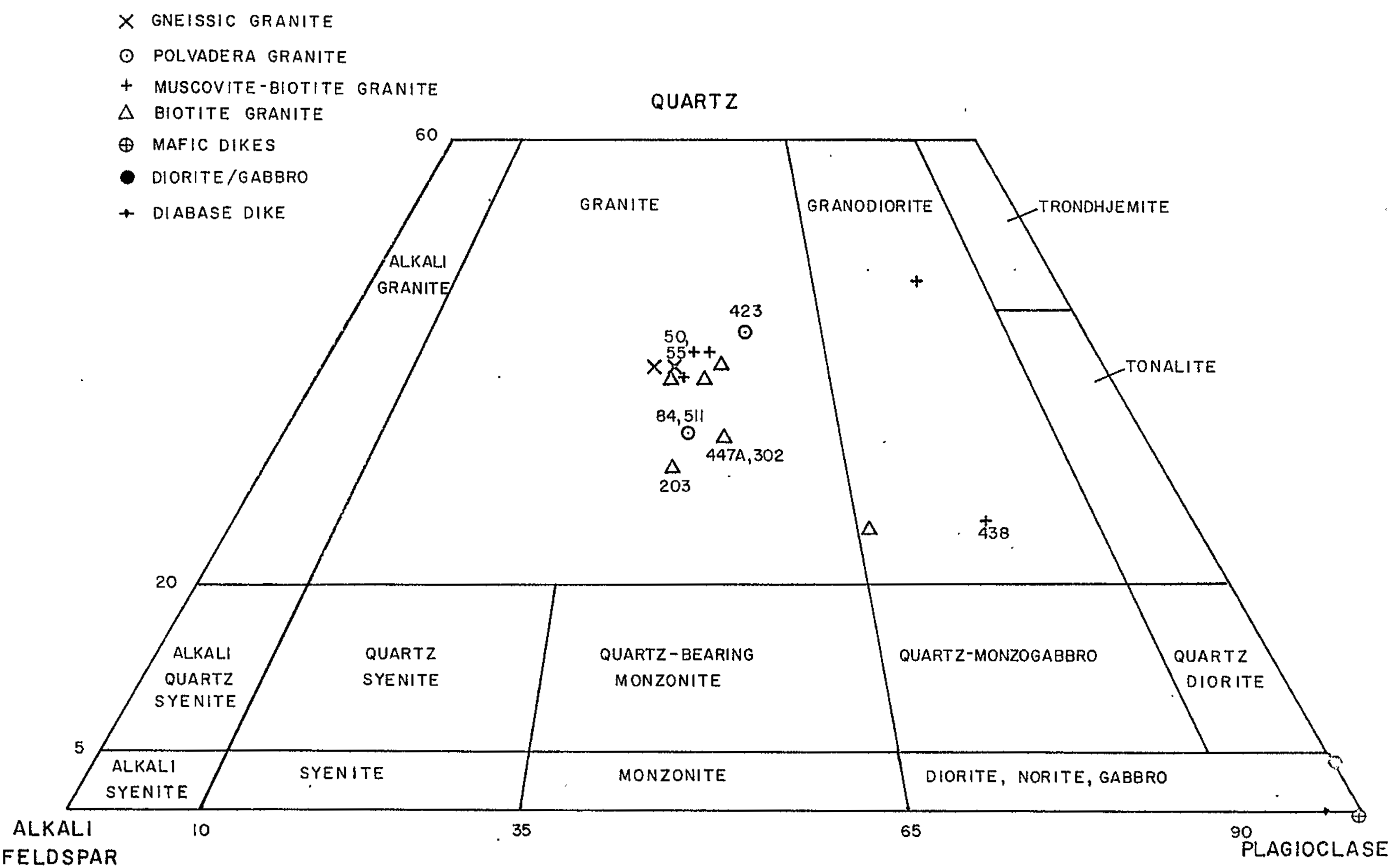


FIGURE 8 - CLASSIFICATION OF IGNEOUS ROCKS (AFTER STRECKEISEN, 1967 AND HYNDMAN, 1972) SHOWING SAMPLES FROM THE LEMITAR MOUNTAINS BASED ON ESTIMATED MODAL ANALYSIS

Lemitar diorite/gabbro.

Recent geochronologic studies (White, 1978; Brookins, et al., 1978; Condie and Budding, 1979) of the Precambrian rocks in central and southern New Mexico imply that most granitic plutonism occurred between 1.5 and 1.1 b.y. These studies suggest that perhaps the Precambrian granitic rocks in the Lemitar Mountains were emplaced during this period.

LEMITAR DIORITE/GABBRO

Introduction

The Lemitar diorite/gabbro crops out north of the Corkscrew Canyon sediments (fig. 2), forming many of the lower hills and ridges along the eastern portion of the mapped area. The diorite/gabbro continues as fault blocks and windows farther north of the mapped area.

The southern boundary of the body forms a nearly vertical, often migmitized, intrusive contact, where the diorite/gabbro is in contact with muscovite-biotite granite. The western boundary is formed by unconformably overlying beds of Phanerozoic sediments. The eastern contact is formed by a series of faults and unconformities with Phanerozoic sediments and volcanics.

The nature of the northwestern contact is in doubt because of the lack of good exposures. The Polvadera Granite is in fault or intrusive contact with the Lemitar diorite/gabbro on the north, forming a northeast-striking contact. Evidences of brecciation and slickenslides occur along part of the northeast- to east-trending contact between the diorite/gabbro and the Polvadera Granite and indicate a fault contact (sec. 32, Map 1). This fault could form the remainder of the contact between the two units as Chamberlin (1978) mapped it, but the lack of brecciation and slickenslides are more suggestive of an intrusive contact. Near the contact foliation in the diorite/gabbro and the Polvadera Granite parallels the contact suggesting an intrusive relationship.

The mafic body is intruded by biotite granite and leucogranite dikes and plugs, and portions of pegmatites and quartz veins are found scattered throughout. Mafic and carbonatite dikes also intrude the diorite/gabbro. Some mafic dikes may be a late stage of the diorite/gabbro; others intrude this granite and are post-granite.

Description

The diorite/gabbro maintains a speckled appearance produced by large (several mm. in diameter) white phenocrysts of plagioclase. It is a lithologically heterogeneous unit ranging from gabbro and diorite to quartz gabbro and quartz diorite (table 4). The diorite/gabbro varies in mineralogical composition, but primarily consists of plagioclase, An40-60 (30-40%), dark blue-green and brown hornblende (30-40%), biotite (partially altered to chlorite, 10-20%), and trace amounts of garnet, apatite, and magnetite. Augite, olivine, and/or pyroxene may have been originally present but have now been altered to hornblende. The plagioclase composition contributes to the lithologic differences between the diorite and gabbro. Quartz is often present in amounts up to 10%. Ophitic to subophitic textures, in which plagioclase is partially or completely enclosed by hornblende, are often preserved, suggesting the original rock may have been a gabbro (table 4). However hypidiomorphic-granular textures are often present and suggest that the rock may have been in part a diorite.

The diorite/gabbro has undergone deformation and shearing near the contact with the altered facies of the Polvadera Granite, where larger amounts of chlorite and

TABLE 4

Difference Between Gabbro and Diorite

(modified after Hyndman, 1972)

CRITERIA	GABBRO	DIORITE
plagioclase composition	An>50 (laboradiorite, bytownite)	An<50 (andesine, oligoclase)
Other Minerals	augite, olivine, hornblende, clinopyroxenes	hornblende, pyroxenes, biotite
Associated Rock Types	pyroxenites, anorthosites	granodiorites, quartz diorites
Color of the Plagioclase	gray to greenish gray	white
Texture	subophitic, cumulus, or ophitic	hypidiomorphic granular

NOTE: Metamorphism may change some of these variables.

biotite are found, forming schistose zones. This contact appears gradational and is poorly exposed. Quartz and K-feldspar (probably microcline) often increases in abundance near the contact with the Polvadera Granite and other granites.

Inclusions are found throughout the diorite/gabbro and especially in the southern portion of the outcrop area. The inclusions are generally fine grained, dark to light gray, exhibiting sharp contacts with the enclosing mafic rock (pl. 6). Light-colored leucosomes with mafic selvages occur in some parts of the diorite/gabbro suggestive of an origin by metamorphic differentiation (Pl. 7). Quartzite and foliated arkose occur as inclusions up to 50 cm. across (Pl. 8). Dark, fine-grained amphibolite inclusions occur and have an appearance and composition similar to the mafic dikes. Hornblende and biotite, possibly derived from the diorite/gabbro, often replaces original minerals within the inclusions.

Large blocks of sediments are scattered throughout the Lemitar diorite/gabbro (a few meters to 10 meters across). Some of these blocks are mappable (sec. 7, Map 1). Foliation and relict bedding are often preserved. Most, if not all, of these blocks are probably rotated xenoliths as opposed to roof pendants, because the attitude of foliation

PL. 6: Photomicrograph (10x, cross-polars) of diorite/gabbro with a fine-grained sediment inclusion.

PL. 7: Diorite/gabbro with a sediment inclusion.

0.35 mm

PL. 8: Amphibolite inclusion in the diorite/gabbro.

varies from that of the general attitude seen in Corkscrew Canyon.

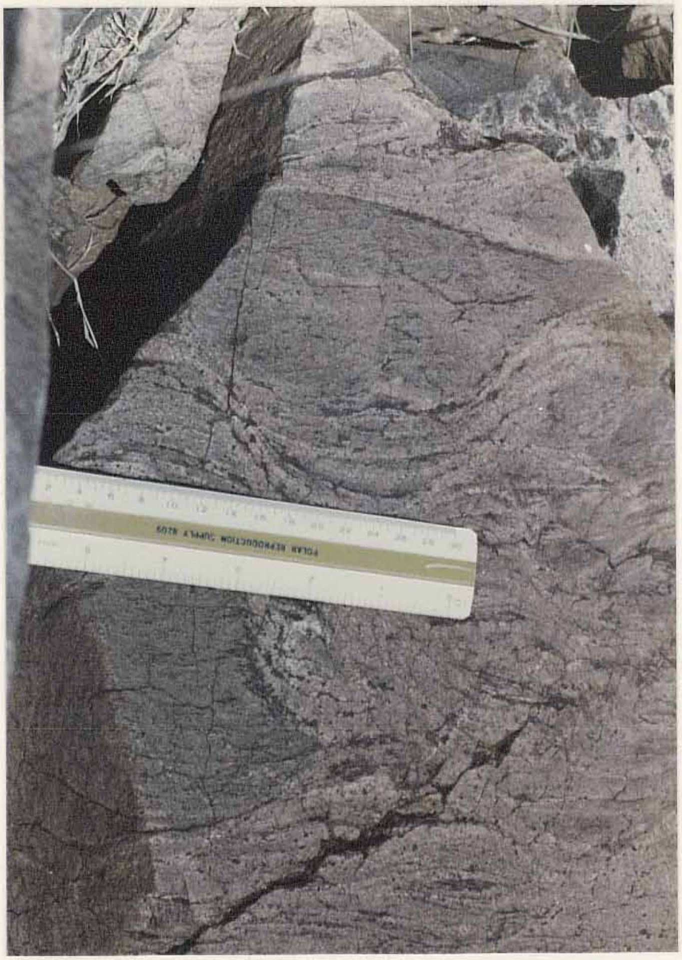
Migmitization

Migmitization of the Lemitar diorite/gabbro occurs along the southern intrusive contact with the muscovite-biotite granite. The granite is strongly foliated near the intrusive contact (Pl. 9), forming irregular, folded bands of quartz and feldspar. Folded veins of quartz and feldspar crosscut the melanocratic mafic rocks of the Lemitar diorite/gabbro (Pl. 10). Agmatitic structures (Pl. 11 and 12) and leucocratic ptygmatic folds occur locally. Boudinage structures (Pl. 13) are suggestive of the intense shearing and stretching.

Four possible mechanisms of migmitization have been proposed by Yardley (1978): igneous injection, anatexis, external metasomatism, and metamorphic segregation. Agmatization and rotation of individual xenoliths, as seen in the Lemitar migmitites, are likely wherever extensive melting has occurred, whether produced by igneous injection or anatectic melts. It is unlikely that external metasomatism or metamorphic segregation could produce enough fluid to cause rotations of large xenoliths (King, 1965).

PL. 9: Strongly foliated muscovite-biotite granite.

PL. 10: Migmititic layers in the diorite/gabbro of the Lemitar diorite/gabbro.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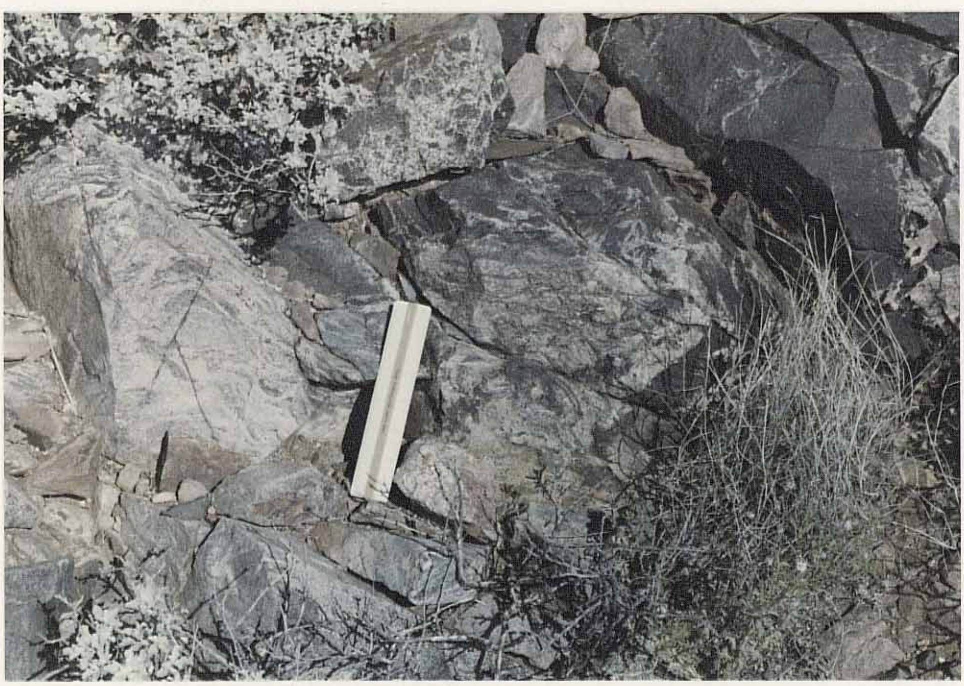


PL. 11: Agmatitic structures in diorite/gabbro.

PL. 12: Agmatitic structures in diorite/gabbro.

PL. 13: Boudinage structures in diorite/gabbro.

The appearance and composition of the leucosomes seen in the Lemitar migmitites resembles that of the adjacent muscovite-biotite granite. Leucosomes can be locally traced into the muscovite-biotite granite (Pl. 10), clearly indicating that igneous injection of the muscovite-biotite granite into the Lemitar diorite/gabbro produced the Lemitar migmitites.

Geochemistry

A representative sample of the diorite/gabbro was analyzed for eight major and four trace elements (Appendix C). The sample locations are plotted on fig. 2. CIPW Norms were calculated using a computer program (Appendix C). The diorite/gabbro from the Lemitar Mountains is higher in SiO_2, TiO_2, Fe_2O_3, and K_2O and lower in Al_2O_3, MgO, and CaO than other Precambrian mafic rocks from New Mexico and an average Archean basaltic andesite (table 5). In terms of SiO_2 content, the diorite/gabbro is higher than Nockolds' (1954) average diorite. All five samples of the diorite/gabbro contain normative quartz (Appendix C).

TABLE 5

Chemistry of the Mafic Rocks

	1	2	3	4	5	6	7	8	9
SiO2	52.5	48.2	49.2	51.9	48.4	53.1	47.5	53.4	46.4
TiO2	1.41	1.53	1.72	1.50	1.32	0.96	1.89	2.16	1.63
Al2O3	14.2	13.0	15.0	16.4	16.8	14.2	11.4	11.0	13.4
Fe2O3*	12.1	14.5	12.4	9.60	10.4	11.2	16.8	18.3	15.5
MgO	5.49	8.20	5.94	6.12	8.06	7.77	7.36	2.15	8.43
CaO	9.00	9.50	8.87	8.40	11.1	9.35	8.58	6.89	9.16
Na2O	2.05	2.57	2.28	3.36	2.26	2.47	1.94	2.39	3.14
K2O	0.56	0.53	0.54	1.33	0.56	0.36	1.58	1.72	0.35
TOTALS	97.31	98.03	95.95	98.61	98.90	99.41	97.05	98.01	98.01
Ba		25					356	366	108
Rb		205					55	47	11
Sr		108					109	150	191

1 - typical amphibolite of Las Tablas Quadrangle, Barker, 1958

2 - average of 6 areas of Precambrian mafic rocks in south-central New Mexico, Condie and Budding, 1979

3 - average of 10 analyses of metatholeiite and metabasaltic andesite from the Tusas Mts., Barker and Friedman, 1974

4 - average diorite, Nockolds, 1954

5 - average gabbro, Nockolds, 1954

6 - average Archean basaltic andesite, Pearce, et al, 1977

7 - average Lemitar mafic dike (average of 5 samples)

8 - average Lemitar diorite/gabbro (average of 5 samples)

9 - Magdalena gabbro, Condie and Budding, 1979

* - Total iron expressed as Fe2O3.

Gabbro of Garcia Canyon

The Lemitar diorite/gabbro and the gabbro of Garcia Canyon (Magdalena gabbro) have very similar textures and mineralogies, although they have different chemical compositions (Loughlin and Koschman, 1942; Sumner, 1980). Both mafic units intrude older sediments and are subsequently intruded by younger Proterozoic granites, implying that the two mafic units may have been emplaced at the same time. The gabbro of Garcia Canyon has been dated (1.5 b.y., White, 1978) and found to be of mantle derivation by Rb-Sr isotope studies, although the initial Sr86/Sr87 isotope ratio of 0.704 (White, 1978) is suggestive of some crustal contamination. The differences in chemical composition could be due to differences inherited from the source or to contamination of granitic magmas after emplacement. Differences in the degree of contamination and metamorphism could also account for the dissimilarity in chemical compositions between the two mafic units.

Origin

The lithologic heterogeneity of the Lemitar diorite/gabbro could be accounted for by a magma of original diorite to gabbro composition. However, if the Lemitar diorite/gabbro were derived from a diorite to gabbro magma from the upper mantle, other diorite/gabbros should be exposed in the Precambrian terrain of New Mexico. Instead, dominantly gabbros or basalts are seen.

Contamination by granitic magmas or crustal material of a gabbroic magma could account for the lithologic heterogeneity of the Lemitar diorite/gabbro. As a gabbroic magma ascends towards the earth's surface, it could become contaminated, altering parts of the gabbroic magma to a diorite. The quartz gabbro and quartz diorite may result from the contamination of the diorite/gabbro by granitic magma or as a late stage differentiate of fractional crystallization of the diorite/gabbro or both. The presence of quartz diorites near the intrusive contacts suggests that the mafic body probably was contaminated with granitic magma.

The Lemitar diorite/gabbro could also have been emplaced as a gabbro, and subsequent injection and mixing of granitic magmas would alter the gabbro to a diorite or even to a quartz diorite. Such features as migmitization, present in the Lemitar diorite/gabbro, would be consistent with such a model. Late differentiation of the gabbroic magma could crystallize as a diorite, and could also account for the Lemitar mafic body. A combination of both igneous injection and mixing of a granitic magma and late differentiation could also result in the Lemitar diorite/gabbro.

The presence of sediment and mafic dike inclusions indicates that the Lemitar diorite/gabbro is younger than the sediments and at least one early stage of mafic dikes. Because foliation is preserved in some of the arkose inclusions, a period of metamorphism occurred before the intrusion of the Lemitar diorite/gabbro.

MAFIC DIKES

Distribution

Mafic dikes intrude all of the exposed Precambrian rocks, except the carbonatites. Careful mapping of the mafic dikes indicates a complicated history of two or more periods of intrusion that can be recognized based on field relationships. The dikes strike dominantly in a northernly direction with almost vertical dips.

A series of unmetamorphosed diabase dikes also intrude the Precambrian section. Most of these dikes are probably Tertiary in age because of their lack of metamorphic character and similar dikes are found intruding the Phanerozoic sediments. One sample (Lem 56) is described (appendix B) and included with the analyses of the mafic dikes. Chemically, the diabase dike is similar to the mafic dikes.

Description

The mafic dikes are greenish-black and fine-grained and may include inclusions of sedimentary rocks. Thin granitic veins and carbonatite dikes often crosscut a few of these mafic dikes. In thin section, mafic dikes are slightly foliated and may exhibit subophitic textures. They consist of green hornblende (35-40%), altered plagioclase (30-35%), green and brown biotite (10-20%), magnetite (5-10%), and varying amounts of quartz, chlorite, hematite, garnet, fluorite, and carbonate. Mortar textures often accompany secondary carbonate, while carbonate fluids associated with the intrusion of the carbonatite dikes often followed and partially replaced these and earlier dikes.

A series of four thin sections along a mafic dike intruded by a carbonatite dike were studied. Adjacent to the carbonatite dike, the mafic dike exhibited extensive alteration where corroded magnetite, hornblende, and feldspar are replaced by carbonate (pl. 14). Apatite (1-3%) was introduced into the mafic dike. Subophitic textures were present in all four thin sections. Further from the carbonatite dike, less alteration is observed along with the disappearance of apatite. In the sample located farthest from the carbonatite dike, only slight alteration was observed. Magnetite cores, hornblende, and feldspar were only slightly replaced by carbonate.

The field evidence suggests three periods of intrusion by mafic dikes - Stage I, II, and III. The presence of mafic dike inclusions within the diorite/gabbro suggests that mafic dikes from Stage I were emplaced prior to the intrusion of the Lemitar diorite/gabbro. Mafic dikes from Stage II intruded the Lemitar diorite/gabbro and subsequently were crosscut by granitic and pegmatite dikes and veins, indicating intrusion after the emplacement of the diorite/gabbro but before emplacement of the granitic complex. Mafic dikes from the final stage, Stage III, intruded all of the older Precambrian rocks, including the granitic complex; but did not intrude the carbonatites.

PL. 14: Photomicrograph (25x, cross-polars) showing extensive carbonatization of a mafic dike, where carbonate has replaced feldspar crystals.

0.3 mm

Distinguishing between these three periods is difficult unless crosscutting relationships can be determined in the field.

Geochemistry

A representative suite of samples from the mafic dikes exposed in the Lemitar Mountains was analyzed for eight major and four trace elements (appendix C). The samples are plotted on fig. 2.

The mafic dike samples can be compared with other Precambrian mafic rocks from New Mexico and an average Archean básaltic andesite (table 5) and found to be higher in Fe_2O_3 and K_2O and lower in Al_2O_3, CaO, and Na_2O. In terms of the SiO_2 content the mafic dike samples have approximately the same amount of SiO_2 as Nockolds' (1954) average gabbro (table 5). Two samples of the mafic dikes contained normative quartz (appendix C).

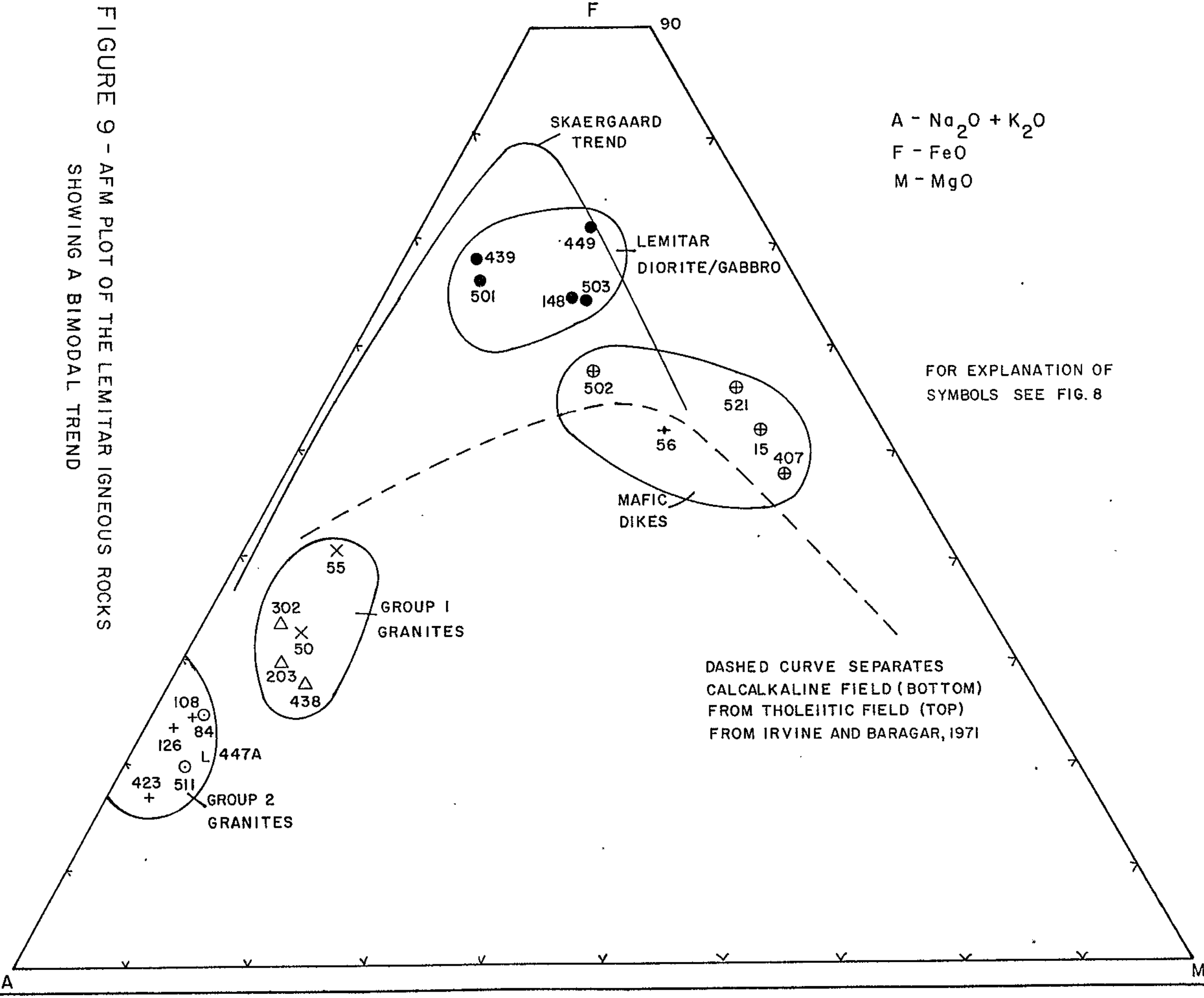
ORIGIN OF THE MAFIC ROCKS

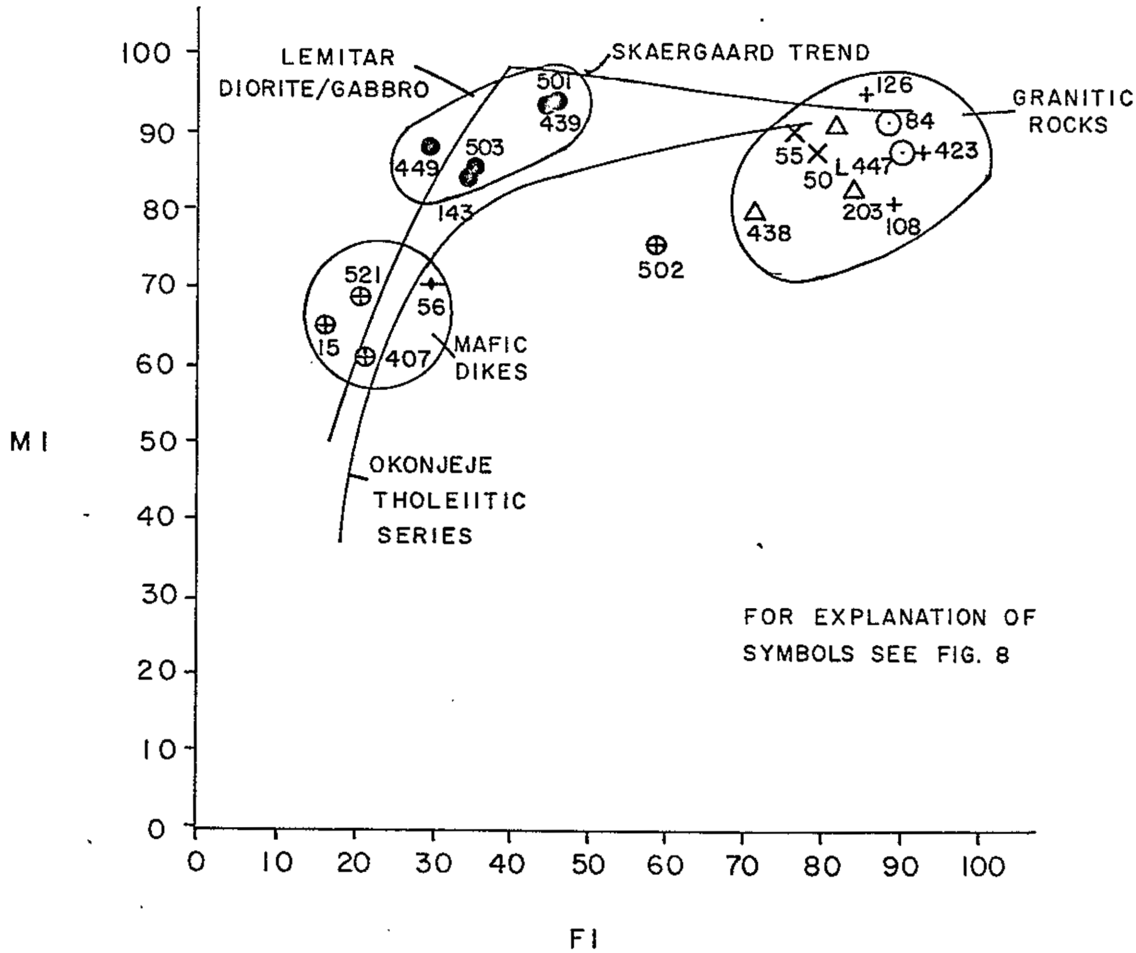
The mafic rocks of the Lemitar Mountains plot in the tholeiite field of an AFM diagram (fig. 9), with the mafic dikes falling close to the line between the tholeiitic and calc-alkaline fields, (using Irvine and Baragar definition, 1971). There is no obvious trend between the mafic and felsic rocks, although a bimodal population exists. Two chemical indices have been proposed as a measure of magmatic fractionation of minerals; the mafic and the felsic indices (Simpson, 1954). The Lemitar samples plot on a trend similar to the Skaergaard trend (fig. 10), suggesting that the mafic rocks may be derived from a similar source. Metamorphism may be responsible for the scatter of data points seen in fig. 10.

Two mafic bodies are exposed in the Lemitar Mountains - three stages of mafic dikes and the Lemitar diorite/gabbro. Most mafic magmas originate in the upper mantle (Condie and Budding, 1979), and it is conceivable that the mafic magmas producing the mafic rocks seen in the Lemitar Mountains could have emerged from the upper mantle as well.

Although no definite chemical trends between the mafic dikes and the Lemitar diorite/gabbro exist, it is conceivable that both are derived from a similar source.

FIGURE 9 - AFM PLOT OF THE LEMITAR IGNEOUS ROCKS SHOWING A BIMODAL TREND





$$MI = \frac{(FeO + Fe_2O_3) \times 100}{MgO + FeO + Fe_2O_3} \qquad \text{MAFIC INDEX}$$

$$FI = \frac{(Na_2O + K_2O) \times 100}{CaO + Na_2O + K_2O} \qquad \text{FELSIC INDEX}$$

FIGURE 10: MAFIC-FELSIC INDEX PLOT OF THE LEMITAR IGNEOUS ROCKS (FROM SIMPSON, 1954)

The differences between the two mafic units are exhibited by the dissimilarity in quartz (SiO_2) contents - the mafic dikes having little or no quartz and the diorite/gabbro containing quartz in amounts up to 10%. If the diorite/gabbro were contaminated by granitic magma at some point in its early history, it is within the bounds of possibility that the mafic dikes and the diorite/gabbro originated from the same upper mantle source. Three stages of mafic dike intrusion would be consistent with a unique source. Similar chemistries between the three stages of mafic dikes and the diorite/gabbro support such a model. However, separate sources for the mafic dikes and the diorite/gabbro could exist.

GRANITIC COMPLEX

Introduction

Granitic rocks make up about three fourths of the entire exposure of Precambrian rocks in the Lemitar Mountains (fig. 2). Six variations of one or more plutons have been distinguished on Map 1, although the relationship between them is uncertain because of the lack of any field relationships. These map units are:

(1) gneissic granite

(2) muscovite-biotite granite

(3) biotite granite

(4) leucogranite

(5) Polvadera Granite

(6) pegmatites and quartz veins

The gneissic granite intrudes the base of the sediments and is not in contact with the other granites nor with the Lemitar diorite/gabbro. A few pegmatites do cut the gneissic granite (Map 1). The gneissic granite could be older than the other granites exposed in the Lemitar Mountains; strong foliation is present in the gneissic granite and absent from from the other granites. If the gneissic granite is older, then the foliation of the gneissic granite is possibly related to the foliation of the sediments. It is difficult to foliate one granite (gneissic granite) without affecting the other granites in the Lemitar Mountains, unless the other granites were emplaced after the foliation occurred. Pegmatites and quartz veins are common throughout the sediments, the Lemitar diorite/gabbro, and the Polvadera granite. The granitic rocks may be derived from a similar source because of the similarity in composition and texture.

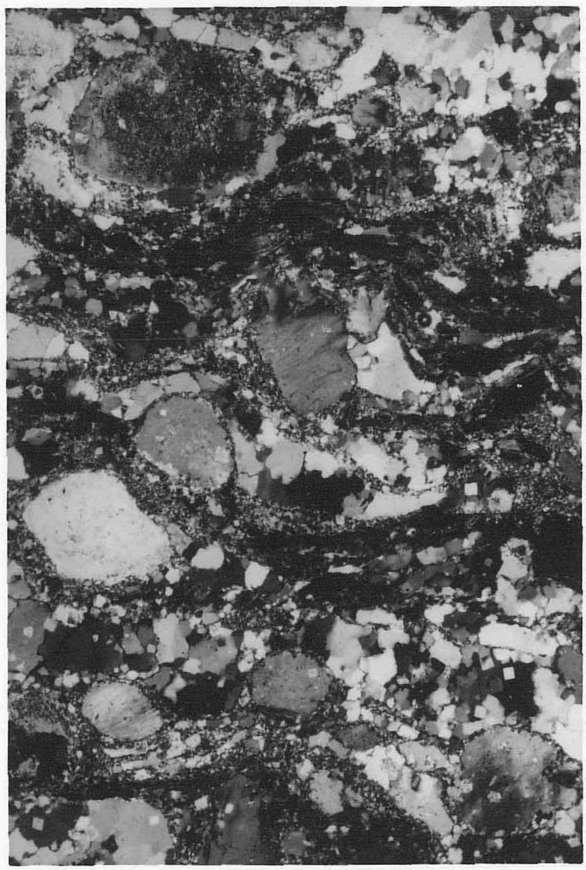
Gneissic Granite

The gneissic granite crops out in the extreme southern portion of the mapped area (Map 1) and is bounded on the south by a brecciated fault zone (forming an arroyo) and on the east and west by unconformities with the Phanerozoic sediments. The northern limit of exposure is formed by an intrusive contact with the sediments, and thin dikes of gneissic granite intrude the sediments along the intrusive contact.

Several Precambrian mafic dikes and several greenish-black diabase dikes of uncertain age intrude the gneissic granite. Phanerozoic limestone caps the granite on a few of the higher hills. Pegmatite dikes and veins are rare.

The gneissic granite is a strongly foliated (see Pl. 15), pinkish-gray to medium-gray, coarse- to medium-grained quartz-monzonite, weathering to a reddish-orange arkosic sand. The granite consists of quartz (30-35%), K-feldspar (25-30%), plagioclase (20-25%), biotite (10-15%), and trace amounts of hematite and magnetite (fig. 8). Mortar textures are often developed. This granite differs from other Precambrian granites in the Lemitar Mountains by strong foliation produced by strongly aligned biotite crystals and by the lack of mafic and abundant sediment

PL. 15: Photomicrograph (25x, cross-polars) of gneissic granite.



0.3 mm

inclusions. Inclusions of the arkose are found along the intrusive contact (Pl. 16), but mafic inclusions are absent.

Muscovite-biotite Granite

The muscovite-biotite granite crops out north of Corkscrew Canyon, where it is in intrusive or fault contact (as previously discussed, see Sedimentary Rocks) with the sediments on the south and the Lemitar diorite/gabbro on the north, it occupies less than a fourth of a square kilometer.

Mafic dikes and several Tertiary dikes intrude the muscovite-biotite granite. Small lenses of dark green chlorite schist and sediments occur as xenoliths, suggesting an intrusive relationship with the sediments. Migmitization occurs along the intrusive contact with the Lemitar diorite/gabbro as discussed earlier (see Lemitar diorite/gabbro).

The muscovite-biotite granite is a slightly foliated, pinkish-gray to grayish-pink, fine-grained quartz monzonite or granite. It differs from the other granites in the Lemitar Mountains by the presence of large (often megascopic) flakes of primary muscovite (pl. 18). Porphyritic, white and black varieties are found along the crest of the westernmost ridge. The rock consists of quartz

PL. 16: Arkose inclusion within the gneissic granite.


"ARCO"

(30-40%), K-feldspar (10-30%), plagioclase, An40-50 (20-35%), biotite (5-10%), muscovite (3-10%), and trace amounts of magnetite, hematite, and calcite (fig. 8). Mosaic textures dominate.

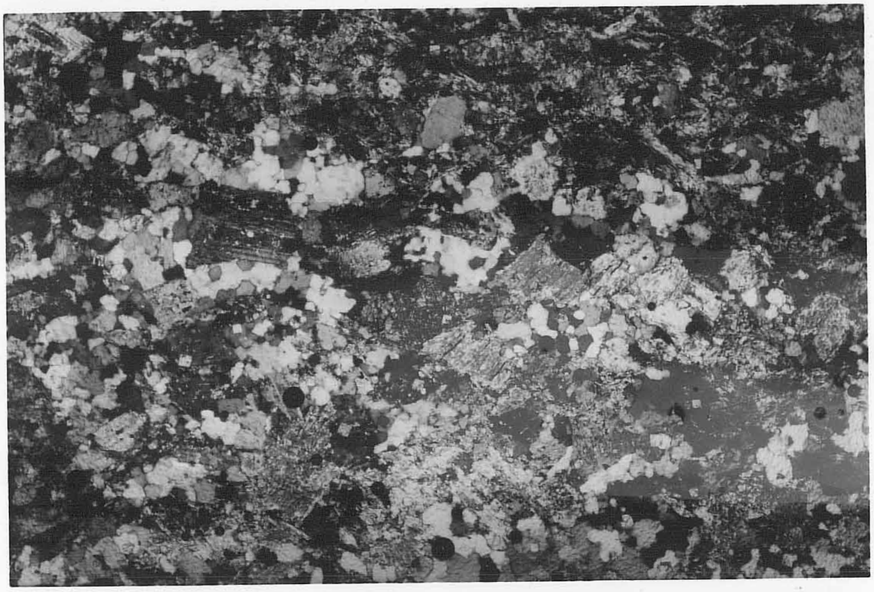
Biotite Granite

The biotite granite intrudes the central and northern portions of the Lemitar diorite/gabbro. It is often gradational with the leucogranite and forms the crests of the ridges and appear as pods and small islands surrounded by mafic rocks. The granite may represent dikes and/or plugs.

The biotite granite is a grayish-pink to gray, fine- to medium-grained, quartz monzonite and differs from the other Lemitar Mountain Precambrian granites by its fine-grained nature and granophyric texture (pl. 17). It is composed of quartz (30-40%), K-feldspar (30-40%), plagioclase, An40-50 (20-30%),biotite (5-10%), and trace amounts of hematite, magnetite, and hornblende (fig. 8). Distinctive granophyric texture is well developed in thin sections of the biotite granite, distinguishing it from the other granites in the Lemitar Mountains. Granophyric texture may indicate crystallization at a eutectic (Hyndman, 1972). Mosaic and porphyritic textures are also common.

PL. 17: Photomicrograph (25x, cross-polars) of a muscovite-biotite granite.

PL. 18: Photomicrograph (25x, cross-polars) of biotite granite showing granophyric texture.



0.3 mm

Leucogranite

The leucogranite intrudes the central and northern portions of the Lemitar diorite/gabbro and differs from other granites in the Lemitar Mountains by its coarser grain size and whitish color. It is often gradational with the biotite granite and forms the crests of ridges and occurs as small islands surrounded by mafic rocks along the arroyos (Map 1). The leucogranite probably represents dikes and/or plugs.

The leucogranite is a white and black, coarse-grained rock. The granite consists of equal amounts of quartz, perthitic K-feldspar, and plagioclase, with trace amounts of biotite (<5%) and magnetite (<1%, fig. 8).

Polvadera Granite

The Polvadera Granite (Woodward, 1971) crops out in the northern third of the mapped area and extends northward for about three km. This granite comprises about three fourths of the Precambrian rocks exposed in the Lemitar Mountains (see fig. 2).

A medium- to coarse-grained facies and an altered facies are distinguished on Map 1, with the medium- to coarse-grained facies being the most extensive. The southern limit of exposure of the medium- to coarse-grained facies is formed by a northeast-trending intrusive or fault contact (as previously discussed) with the Lemitar diorite/gabbro. The western and eastern limits of exposure are formed by faults and unconformities with Phanerozoic sediments and volcanics.

The altered facies is located southwest of the medium- to coarse-grained facies. It is bounded on the south, west, and north by faults and unconformities with Phanerozoic sediments. The eastern limit of exposure is formed by a gradational intrusive contact with the Lemitar diorite/gabbro.

Both facies of the Polvadera Granite are intruded by mafic and carbonatite dikes. The medium- to coarse-grained facies often contains inclusions of mafic rocks and of gray and green chlorite schist.

The medium- to coarse-grained facies of the Polvadera Granite is a pale red, medium- to coarse-grained, slightly foliated rock that weathers to a moderate orange arkosic sand. This granite consists of equal amounts of quartz, plagioclase, and K-feldspar, with varying trace amounts of biotite, hornblende, and magnetite (fig. 8). Mortar and porphyritic textures are often present in thin section. Green and gray schist, often several meters long, occur as inclusions within the granite.

The altered facies of the Polvadera Granite is poorly exposed and badly weathered. Pegmatites, mafic dikes, and Phanerozoic mineralization occur within the granite. Mineralization consists of quartz, feldspar, and barite. Some galena, calcite, and copper minerals are also present.

Fresh samples of the altered facies are similar in composition and texture to the medium- to coarse-grained facies. The rocks are black and dusky red, medium- to coarse-grained granites. The granite consists of quartz (25-30%), plagioclase, An40-45 (20-25%), perthitic K-feldspar (30-35%), biotite (15-20%), and trace amounts of hornblende, magnetite, and hematite. Submortar texture is present and granophyric texture is often preserved.

Inclusions of strongly foliated quartz and feldspar, sediments, gray and green schist, and mafic inclusions are scattered throughout. Dioritic to gabbroic inclusions are found along the intrusive contact. Inclusions are more common than in the medium- to coarse-grained facies.

The alteration of this facies of the Polvadera Granite results from some combination of the following:

(1) partial assimilation of sediments and diorite/gabbro rocks

(2) shearing and tensional stress

(3) regional metamorphism

(4) fenitization associated with the intrusion of the carbonatites

(5) hydrothermal alteration produced by Phanerozoic mineral solutions.

Small blocks of sediment and diorite/gabbro occur within the altered facies of the Polvadera granite and partial assimilation of these sediments and diorite/gabbro blocks along the southern intrusive contact could result in the brick-red, badly eroded altered facies seen in the Lemitar Mountains. Shearing and tensional stress has often occurred as evidenced by northeast-trending layers of foliated quartz and feldspar in some outcrops (Map 1). Fenitization associated with the intrusion of a carbonatite body at depth could also result in the alteration of the granite, assuming that a carbonatite body is at depth beneath this altered facies of the Polvadera granite. Hydrothermal alteration is superimposed on older metamorphism and alteration, complicating any interpretation which might have been possible.

Pegmatites and Quartz Veins

Grayish-pink and white pegmatite and white quartz dikes and veins intrude the Polvadera Granite, the gneissic granite, the Lemitar diorite/gabbro, and the sediments.

Some of the pegmatite veins have been folded. The pegmatites are of the simple type, consisting of unzoned feldspar, quartz, mica, and a trace amount of epidote. These dikes and veins are discontinuous, with a northerly strike and often form pod-like bodies surrounded by the host rock. In the granite, numerous pegmatite dikes range in thickness from a few cm. to several meters. It is possible that they represent a final stage of the Polvadera Granite.

Geochemistry

The granitic rocks are either quartz monzonites or granites, however one sample (Lem 126) is a granodiorite (fig. 8). Generally, the granites fall into two groups - Group I and Group II (table 6 and fig. 9, 11, and 12); both groups fall within the calc alkaline field (fig. 9). These groupings broadly correspond to Condie's high Ca (Group I) and high Si or high K (Group II) groups (table 6 and 7). More trace element data are required to further differentiate between Condie's high Si and high K groups. Metamorphism and other alteration may have affected the Lemitar granites, shown by the scatter of points away from the general trend of New Mexico Precambrian granites on a Rb-Sr diagram (fig. 12). Despite alteration and

TABLE 6

Summary of the Chemistry of the Lemitar Mountain Granites

	1	2	3	4
SiO2	66-70%	73-76%	66-73%	70-77%
CaO	1.5-3%	<1.5%	1.7-4%	0.9-2%
MgO	0.8-1.5%	<0.8%	0.6-2.5%	<1.4%
K2O	<4%	3-6%	2.5-4%	4-5%
Mn	550-900 ppm	200-450 ppm		

1 - Group I granites, Lemitar Mountains
Gneissic Granite and Biotite Granite

2 - Group II granites, Lemitar Mountains
Polvadera Granite and Muscovite-biotite granite

3 - High Ca granite, Condie, 1978

4 - High K and High Si granite, Condie, 1978

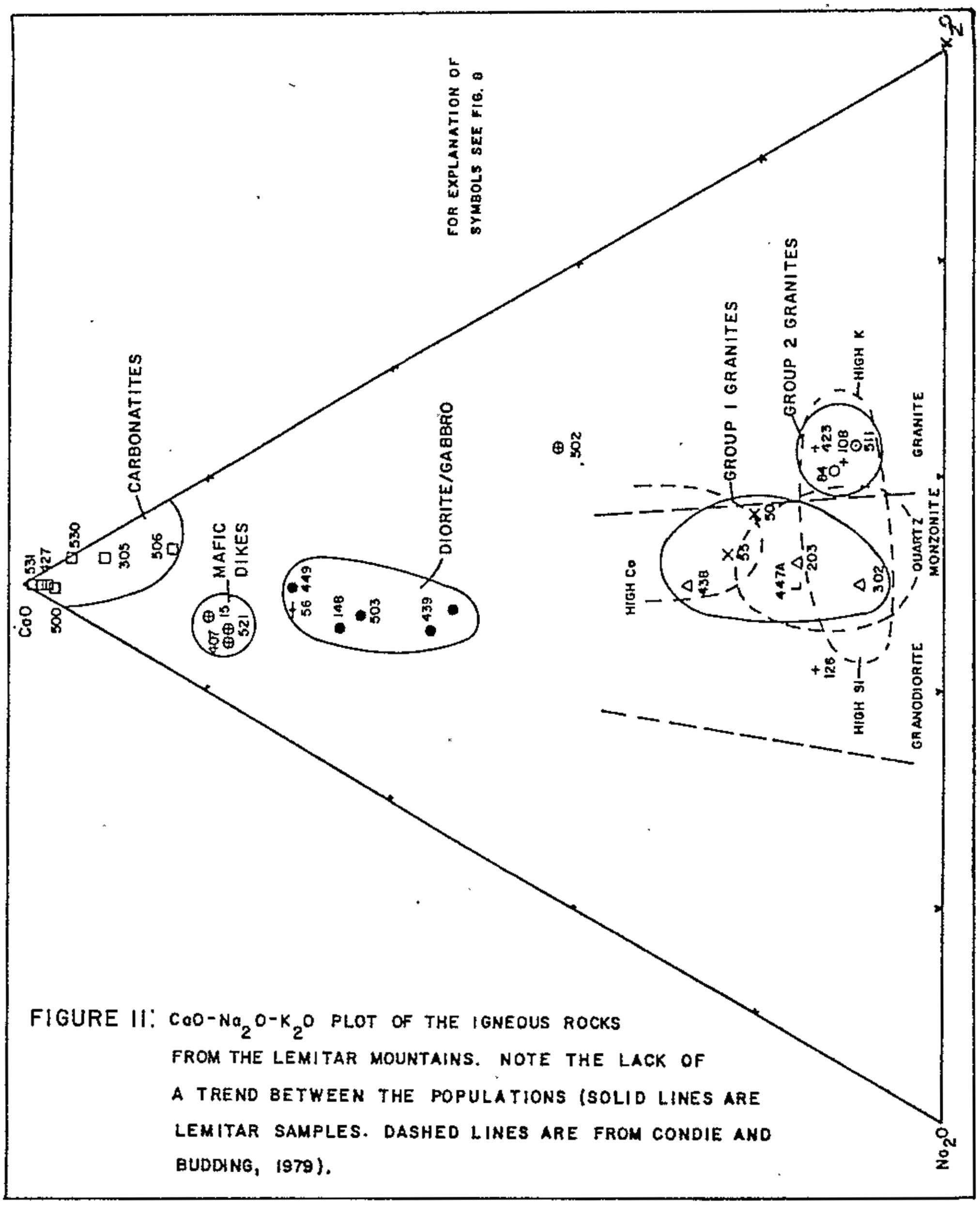


FIGURE 11: $CaO-Na_2O-K_2O$ PLOT OF THE IGNEOUS ROCKS FROM THE LEMITAR MOUNTAINS. NOTE THE LACK OF A TREND BETWEEN THE POPULATIONS (SOLID LINES ARE LEMITAR SAMPLES. DASHED LINES ARE FROM CONDIE AND BUDDING, 1979).

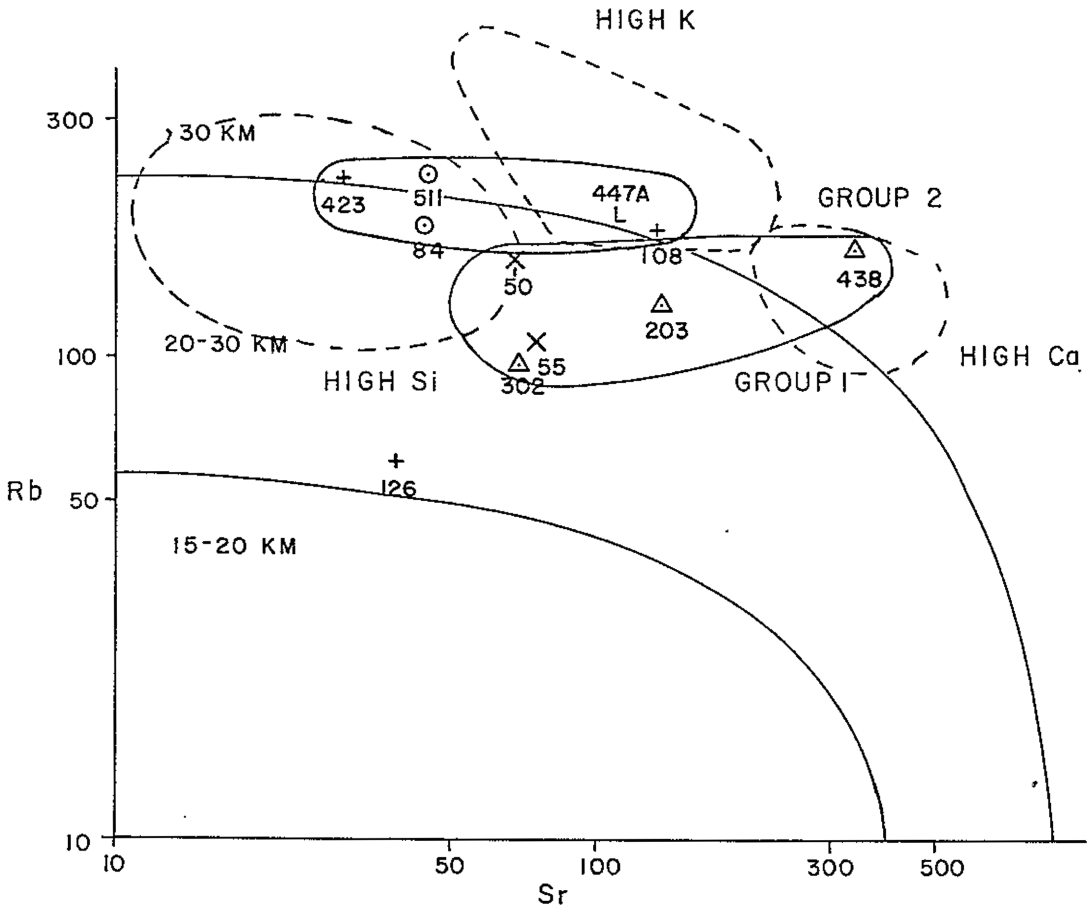


FIGURE 12: Rb-Sr PLOT OF THE LEMITAR GRANITES. FIELDS SHOWING CRUSTAL THICKNESS ARE FROM CONDIE, 1973. FIELDS OF HIGH Ca, HIGH Si, AND HIGH K GRANITES (DASHED LINES) ARE FROM CONDIE, 1978. SOLID LINES REPRESENT FIELDS OF GROUP I AND 2 FROM THE LEMITAR MOUNTAINS.

TABLE 7

CHEMISTRY OF THE GRANITES

	1	2	3	4	5	6	7	8
SiO2	76.4	74.2	73.5	68.0	69.8	69.1	76.1	72.3
TiO2	0.07	0.46	0.45	0.78	0.79	0.63	0.19	0.40
Al2O3	12.5	13.6	13.2	14.3	12.2	14.4	12.6	14.3
Fe2O3*	0.95	3.66	4.43	6.46	8.05	4.48	1.72	2.76
MgO	0.05	0.47	0.44	1.05	0.93	1.41	0.11	0.51
CaO	0.95	1.07	1.04	2.03	1.98	2.69	0.70	1.35
Na2O	3.67	3.45	3.03	3.69	3.03	3.22	3.48	3.08
K2O	4.81	4.40	5.20	3.94	3.85	3.53	4.63	4.79
TOTAL	99.4	101.31	101.29	100.25	100.63	99.46	99.53	99.49
Ba	100	1279	1155	820	816	780	517	779
Sr		71	77	226	110	274	37	255
Rb		168	218	140	147	150	350	242

1 - Two mica granite, St. Francois, Missouri, Kisvarsanyi, 1980 (1 sample)
2 - Average muscovite-biotite granite, Lemitar Mountains (3 samples)
3 - Average Polvadera granite, Lemitar Mountains (2 samples)
4 - Average biotite granite, Lemitar Mountains (3 samples)
5 - Average gneissic granite, Lemitar Mountains (2 samples)
6 - Average High-Ca granite, N.M., Condie, 1978 (9 samples)
7 - Average High-Si granite, N.M., Condie, 1978 (12 samples)
8 - Average High-K granite, N.M., Condie, 1978 (15 samples)

NOTE: 2 and 3 comprise Group II granites and 4 and 5 comprise Group I granites.

metamorphic effects, it is apparent that the granitic rocks were emplaced in a continental crust which was >25 km. thick (fig. 12; Condie and Budding, 1979). This is assuming that the crustal thickness grid proposed by Condie (1973) can be applied to such granites.

Origin

Experimental, chemical, and isotopic evidence indicate that granitic magmas, such as those found in the Lemitar Mountains, may form by fractional crystallization of mafic magmas or by partial melting of the lower crust. Contamination of a granitic magma of either origin by crustal material could produce heterogeneous granites as found in the Lemitar Mountains.

Geochemical model studies on New Mexico Precambrian granites indicate that 30 - 50% partial melting of siliceous granulites in the lower crust could produce granitic melts similar in composition to granites of Condie's high Ca group (Condie, 1978), which broadly correspond to the Group I granites in the Lemitar Mountains. Granites from Condie's high Si and high K, which broadly correspond to Group II granites in the Lemitar Mountains, could be produced by fractional crystallization of granodiorite magmas. This may imply that the Lemitar granites may be derived from similar mechanisms that may have produced other Precambrian granites in New Mexico.

Differences in depths of emplacement of the granitic rocks exposed in the Lemitar Mountains may account for the heterogeneity seen. The biotite granite is thought to be emplaced at a relatively shallow depth due to its fine-grained and porphyritic nature and its similarity to the Puntigudo granite porphyry in the Dixon-Pennasco area, also thought to be emplaced at 2 - 4 km. (Long, 1974). The fine-grained, porphyritic muscovite-biotite granite is also thought to be emplaced at shallow depths because of its discordant relationship with the Corkscrew Canyon sequence (Buddington, 1959). However, the migmitization along the intrusive contact with the Lemitar diorite/gabbro is suggestive of deeper depths of emplacement than the biotite granite (2 -6 km.). The abundance of pegmatites throughout the Polvadera granite suggest deeper depths of emplacement (>6 km.). Pegmatites are rare in the epizone (depths of 2 - 6 km.) and those few pegmatites known to have formed at shallow depths are characterized by bi-pyramidal quartz and sanidine, and are absent in the Lemitar pegmatites. The gneissic granite is thought to be emplaced at relatively deep depths, 6 - 13 km., due to its concordant relationship with the Corkscrew Canyon sequence, evidence of forceful injection (thin dikes intruding the sediments), coarse-grained size, and similarity with the Pennasco quartz monzonite (also emplaced at 8 - 13 km., Long, 1974). Barker and others (1975) proposed a model for the origin of the Pikes Peak granite, which is similar in composition to the Lemitar granites, suggesting that the Pikes Peak granite was emplaced at depths of 3 - 7 km. This range in depth of emplacement correlates well with the 2 - 8 km. range determined for the Precambrian granites exposed in northern New Mexico (Long, 1974) and in the Lemitar Mountains.

CARBONATITE DIKES

Introduction

Carbonatites are igneous rocks consisting of >50% carbonate (Heinrich, 1966). Sovite (>80% calcite), rauhaugite (>80% dolomite and/or ankerite), and silicocarbonatite (50-80% carbonate species) dikes and veins occur throughout the mapped area and in the Precambrian rocks to the north in the Lemitar Mountains.

The carbonate-bearing dikes intruding the Precambrian terrain in the Lemitar Mountains are distinct texturally, mineralogically, and chemically from the Precambrian rocks. Mineralogical and chemical studies were undertaken to determine if these carbonate-bearing dikes were carbonatites. These dikes contain mineralogies and chemistries similar to mineralogies and chemistries of other occurrences of carbonatites (table 8, 9, and 10). Other features such as occurrence, rock associations, structures and textures, alteration, and fenitization are also similar to other occurrences of carbonatites throughout the world (table 11). Bastnaesite occurs in some of the carbonatite dikes as determined by x-ray diffraction studies on heavy mineral separates (table 12) further supporting the conclusion that the carbonate-bearing dikes in the Lemitar Mountains are carbonatites.

Distribution

The carbonatite dikes strike dominantly north-south or east-west and dip steeply (Pl. 19 and 20) and crosscut the entire Precambrian sequence. The dikes range in thickness from a few cm. to a few meters. Most dikes are discontinuous due to erosion, however a few dikes can be

TABLE 8

MINERALS OF CARBONATITE COMPLEXES

LOCALITY	MINERALS
Mountain Pass, California	calcite, dolomite, ankerite, siderite, bastnaesite, quartz, phlogopite, biotite, allanite, magnetite, hematite, galena, pyrite, fluorite, and other minerals including several sulphides
Iron Hill, Colorado	dolomite, calcite, apatite, limonite, aegirine, soda amphibole, phlogopite, microcline, quartz, fluorite, sulphides, pyrite, and other minerals
Magnet Cove, Arkansas	calcite, dolomite, ankerite, microcline, apatite, magnetite, phlogopite, and others
Alno Island, Sweden	calcite, dolomite, ankerite, biotite, pyroxene, quartz, pyrite, albite, garnet, chlorite, barite, apatite, fluorite, and others
Fen, Norway	sovite - calcite, biotite, apatite, manganophyllite, microlite rauhaugite - carbonates, apatite, biotite,
Wet Mountains, Colorado	calcite, dolomite, barite, bastnaesite, biotite, phlogopite, apatite, garnet, galena, sphalerite, quartz, zircon, and other minerals
Lemitar Mountains, New Mexico	calcite, dolomite, ankerite, barite, bastnaesite, biotite, phlogopite, fluorite, micas, apatite, garnet, zircon, quartz, magnetite, and microcline

TABLE 9

CHEMISTRY OF CARBONATITES

	1	2	3	4	5	6	7
SiO2	13.87	24.16	3.40	10.30	14.96	20.65	5.19
TiO2	0.48	1.78	0.28	0.73	1.10	0.47	0.06
Al2O3	2.88	4.95	0.50	3.29	1.32	4.32	0.81
Fe2O3	3.39	7.68	3.04	3.46	6.53	1.91	0.54
FeO	4.80	6.87	11.75	3.60	3.13	8.92	-
MgO	9.56	6.80	7.05	5.79	7.04	9.47	7.89
CaO	29.9	17.2	28.7	36.1	30.4	20.33	42.57
Na2O	0.37	0.75	0.01	0.42	2.28	0.24	0.05
K2O	0.63	1.51	0.10	1.36	1.44	2.08	0.33
MnO	0.64	0.35	0.48	0.68	0.36	1.30	-
P2O5	3.44	1.32	0.06	2.09	2.33	1.97	0.04
CO2	26.77	17.77	35.80	28.52	26.81	26.25	41.54
TOTAL	96.73	91.14	95.56	91.17	97.70	97.91	99.02

1 - average primary magmatic carbonatite, Lemitar Mountains
2 - average replacement-type carbonatite, Lemitar Mountains
3 - average ankeritic carbonatite, Lemitar Mountains
4 - average carbonatite, Heinrich, 1966
5 - rauhaugite, Iron Hill, Colorado, Nash, 1971
6 - biotite, ankeritic-dolomitic carbonatite breccia, Castigon Lake, Canada, Currie, 1976
7 - average limestone, Pettijohn, 1957

TABLE 10

TRACE ELEMENT CHEMISTRY OF CARBONATITES

	1	2	3	4	5	6	7	8
Ba	1294	2490	2155	450-1120	830	1000	5300	15000
Sr	297	355	130		3200	3000	880	3200
Ni	44	286	59	8	85		200	51
Cu	13	63	13	2.5	51		39	43
Co	36	64	54	17	nil		470	110
Cr	16	231	15	48	nil-13		470	110
Li	36	40	7		8			
Zn	133	275	527		109			
U	8.7	8.4	4.7			40	5	26

1 - average primary magmatic carbonatite, Lemitar Mountains
2 - average replacement-type carbonatite, Lemitar Mountains
3 - average ankeritic carbonatite, Lemitar Mountains
4 - average carbonatite, Heinrich, 1966
5 - average of 4 sovites, Sokli, Finland, Vartiainen and Woolley, 1976
6 - carbonatite, Magnet Cove, Arkansas, Erickson and Blade, 1963
7 - primary magmatic, Wet Mountains, Colorado, Armbrustmacher, 1979
8 - replacement, Wet Mountains, Colorado, Armbrustmacher, 1979

TABLE 11

SIMILARITIES AND DIFFERENCES BETWEEN THE LEMITAR CARBONATITE AND OTHER CARBONATITES

SIMILARITIES

A. Occurrence

(1) Nonalkalic igneous complex, examples: Ravalli County, Montana; Verity, British Columbia, Canada; Salmon Bay, Alaska; Turi Peninsula, U.S.S.R.; (Heinrich, 1966).

(2) Mafic association, examples: Magnet Heights, Transvaal (gabbro, magnetite, albitite, Verwoerd, 1966), Stjernoy, Norway (gabbro, Verwoerd, 1966); Sokli, Finland, (amphibolite, Vartiainen and Woolley, 1976), Messum, South West Africa (basalt, dolerite, gabbro, Verwoerd, 1966).

Structure and Texture

(3) Replacement carbonatites common, example: Wet Mountains, Colorado (Armbrustmacher, 1979); Siilinjarvi, eastern Finland (Puustinen, 1969).

(4) Porphyritic textures common, example: Wet Mountains, Colorado (Armbrustmacher, 1979).

(5) Occurrence of xenoliths within the carbonatite dikes, examples: Mountain Pass, California; Matopon Hill, Nyasaland; Panda Hill, Tanganyika (Heinrich, 1966).

(6) Slight foliation parallel to the walls of the dikes, examples: Mountain Pass, California (Olson, et al. 1954); Wet Mountains, Colorado (Heinrich, 1966).

(7) Presence of zoning within the carbonatite dike, example: Mountain Pass, California (Heinrich, 1966).

C. Mineralogy

(8) Common mineralogy (table 8).

(9) Lack of feldspathoids and soda amphiboles, example: Mountain Pass, California (Olson, et al., 1954).

TABLE 11 - continued

D. Alteration

(10) Fenitization, if present, is poorly developed, examples: Magnet Heights, Transvaal (Verwoerd, 1966); Sokli, Finland (Vartiainen and Woolley, 1976).

DIFFERENCES

A. Occurrence

(1) Absence of related alkalic rocks, examples: Fen, Norway (Heinrich, 1966); Alno, Sweden (von Eckermann, 1948).

(2) Lack of associated large mass or plug of carbonatite, examples: Mountain Pass, California (Olson, et.al., 1954); Alno, Sweden (von Eckermann, 1948).

(3) No associated kimberlites which are often, but not always, associated with carbonatite complexes, examples: Fen, Norway; southwest Tanganyika; Gibeon province, South-West Africa (Heinrich, 1966).

B. Mineralogy

(4) Apparent lack of sulphide minerals common to other complexes (table 2).

(5) Lack of feldspathoids and soda amphiboles, examples: Fen, Norway (Heinrich, 1966); Alno, Sweden (von Eckermann, 1948).

C. Alteration

(6) Absence of large halo of fenitization, examples: Alno, Sweden (von Eckermann, 1948); Fen, Norway (Heinrich, 1966).

TABLE 12

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

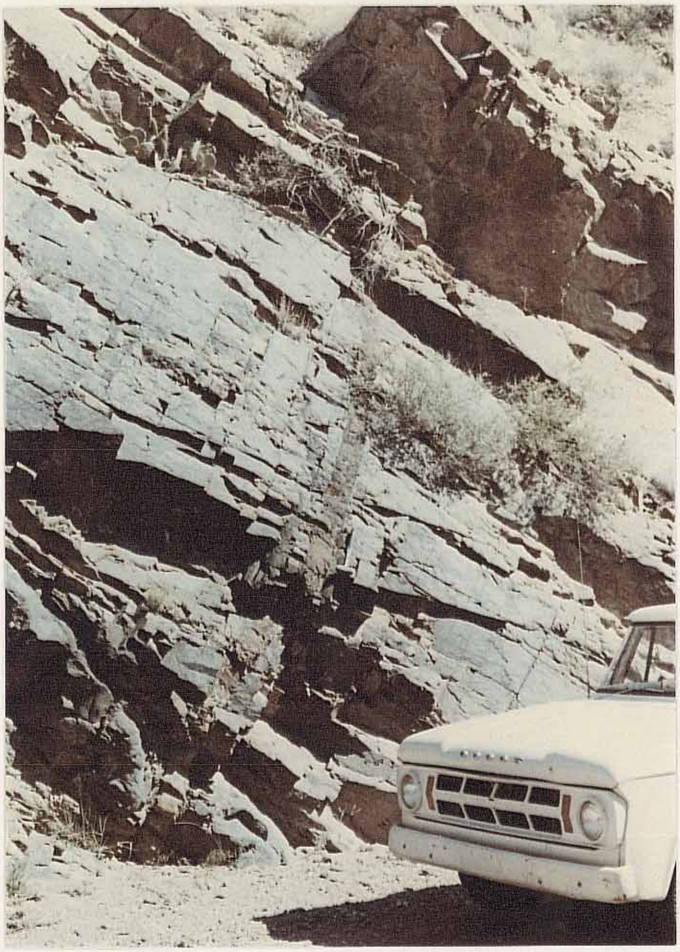
Lem 500 - heavy mineral separate from the Lemitar Mountains (see fig. 2 for sample location)

PDF - Powder Diffraction File (1972), card 11-340

Chemical formula of bastnaesite is CeCO3F

PL. 19: Breccia silicocarbonatite dike crosscutting sediments in Corkscrew Canyon (looking north).

PL. 20: Steeply dipping carbonatite dike intruding the Lemitar diorite/gabbro (looking north, in sec. 7).



traced for several hundred meters along strike. Flow structures or banding often parallels the contacts of the dikes (Pl. 21). Some dikes follow pre-existing fracture zones. Feeder systems often fill fractures adjacent to the main dike. The random orientation of the dikes (Map 1) suggests that the carbonatite fluids followed pre-existing fracture zones in the diorite/gabbro, the sediments, and the Polvadera Granite. Often the carbonatite fluids followed earlier mafic dikes, partially or completely replacing them, as discussed earlier (see Mafic Dikes).

Apparently, fractures were rare in the granitic rocks, because thick carbonatite dikes are not as abundant within the granite as they are within the diorite/gabbro. Carbonatite dikes are not often found within the biotite, muscovite-biotite, or gneissic granites, except occasionally along the intrusive contacts. The carbonatite fluids generally shattered the Polvadera Granite, forming a stockwork pattern.

Carbonatite dikes are rare in the southern third of the area. This may suggest that the source may be centered in the area north of Corkscrew Canyon (northern portion of sec. 7), where the frequency of carbonatite dikes is greater.

PL. 21: Banded silicocarbonatite dike.

Description

One of the characteristics of carbonatites in the Lemitar Mountains is the petrologic variations they exhibit. The dikes vary in mineralogy (fig. 13, table 13), grain size, texture, and chemistry (Appendix C). In thin section, the carbonatites exposed in the Lemitar Mountains can be differentiated as to primary magmatic and replacement carbonatites (Armbrustmacher, 1979). Texture and mineralogy (table 13) are the primary criteria for this differentiation. Primary carbonatites exhibit igneous textures, either primary porphyritic or hypidiomorphic-granular (pl. 22). Primary porphyritic carbonatites are characterized by large phenocrysts of apatite, magnetite, feldspar, and biotite/phlogopite. Replacement carbonatites are characterized by fine- or coarse-grained carbonate partially or completely replacing relict phenocrysts of feldspar and/or hornblende, preserving the original textures of the rock (pl. 23 and 24). The original rocks were mafic dikes, granites, or diorite/gabbro, as indicated by relict textures. Apatite is more abundant in the primary magmatic carbonatites, while magnetite is more abundant in the replacement carbonatites, although both apatite and magnetite may be present in

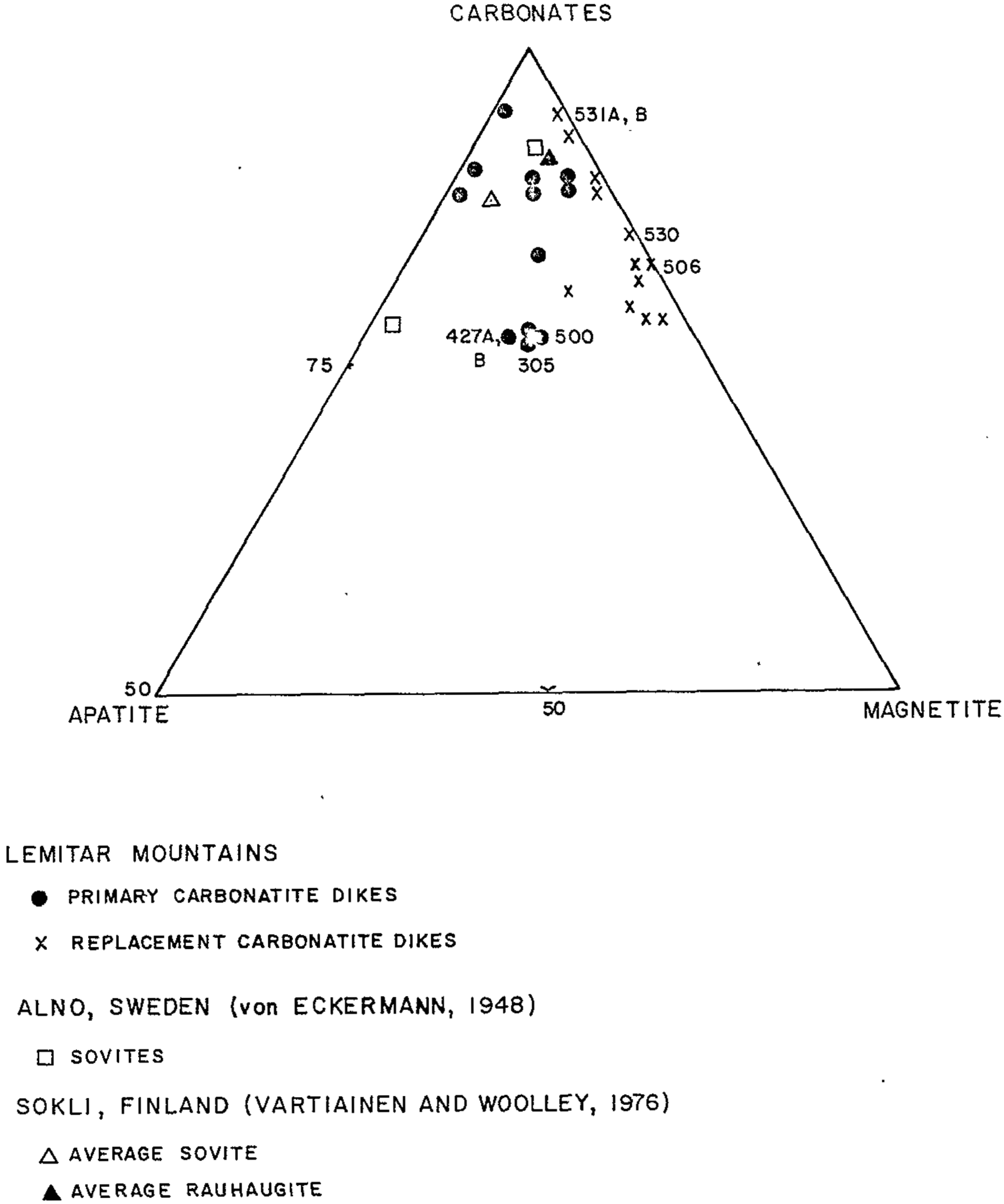


FIGURE 13: CARBONATE-APATITE-MAGNETITE PLOT OF THE LEMITAR CARBONATITES

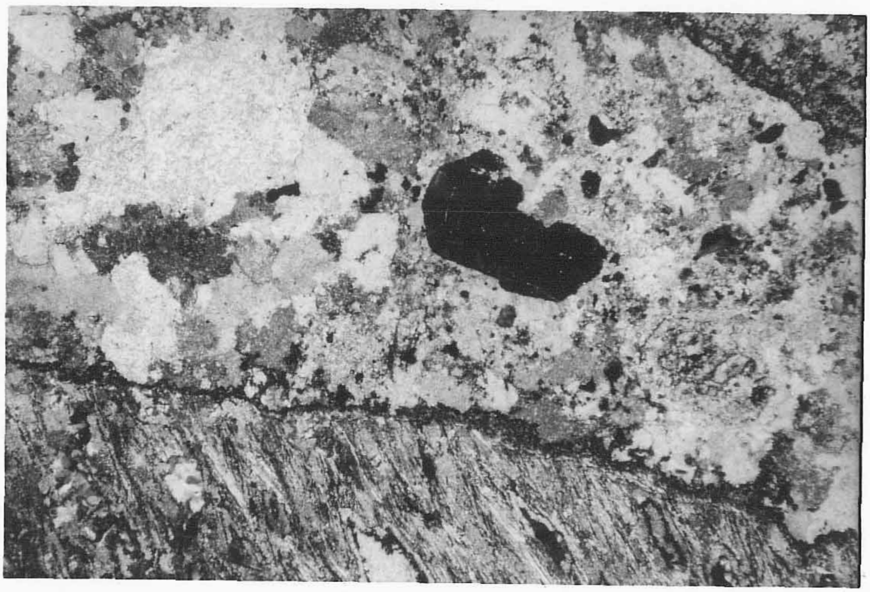
TABLE 13

MINERALOGY OF CARBONATITES OF THE LEMITAR MOUNTAINS

MINERAL	ABUNDANCE PRIMARY MAGMATIC	REPLACEMENT
Ankerite	C,E	R
Apatite	E	R
Barite	R	C
Bastnaesite	R	-
Biotite/phlogopite	C	C
Calcite	E	E
Chlorite	R	C,E
Dolomite	E	E
Fluorite	R	-
Garnet	R	-
Hematite/goethite	C	C
Hornblende	R	R
Ilmenite	R	R
K-feldspar	C	C
Magnetite	C	E
Muscovite/sericite	R	C
Plagioclase	C	C
Pyrite	R	-
Pyrochlore	R	-
Sphene/leucoxene	C	R
Quartz	C	C
Zircon	R	R

E - essential to all samples, C - present in most samples,
R - present in a few samples, - - not present

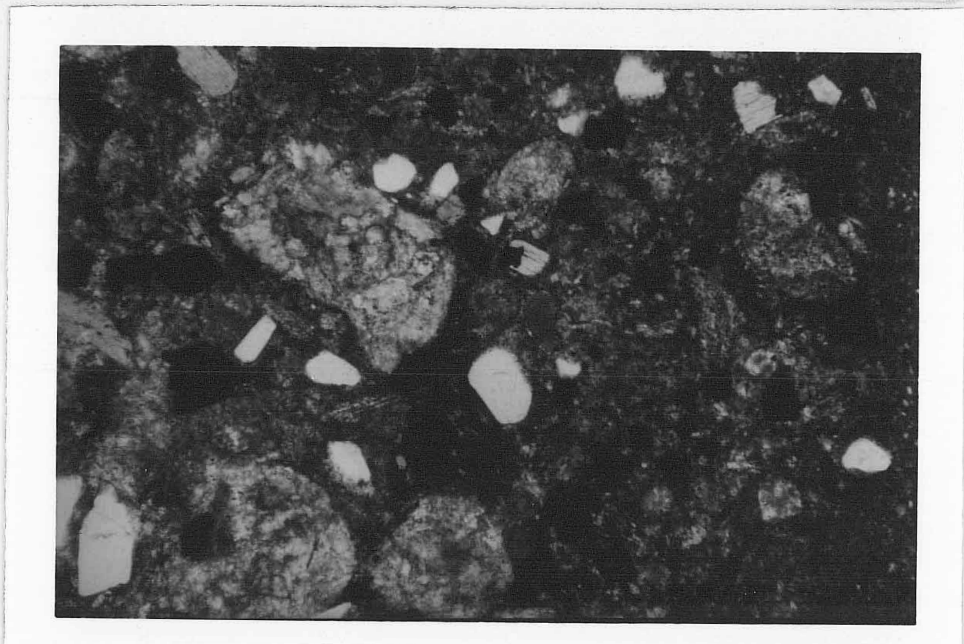
PL. 22: Photomicrograph (25x, cross-polars) of a porphyritic carbonatite. At the bottom of the photograph is part of a rock fragment.



0.3 mm

PL. 23: Photomicrograph (25x, plane light) of a replacement carbonatite, preserving the original porphyritic texture.

PL. 24: Photomicrograph (25x, plane light) of a replacement carbonatite preserving the original ophitic texture.



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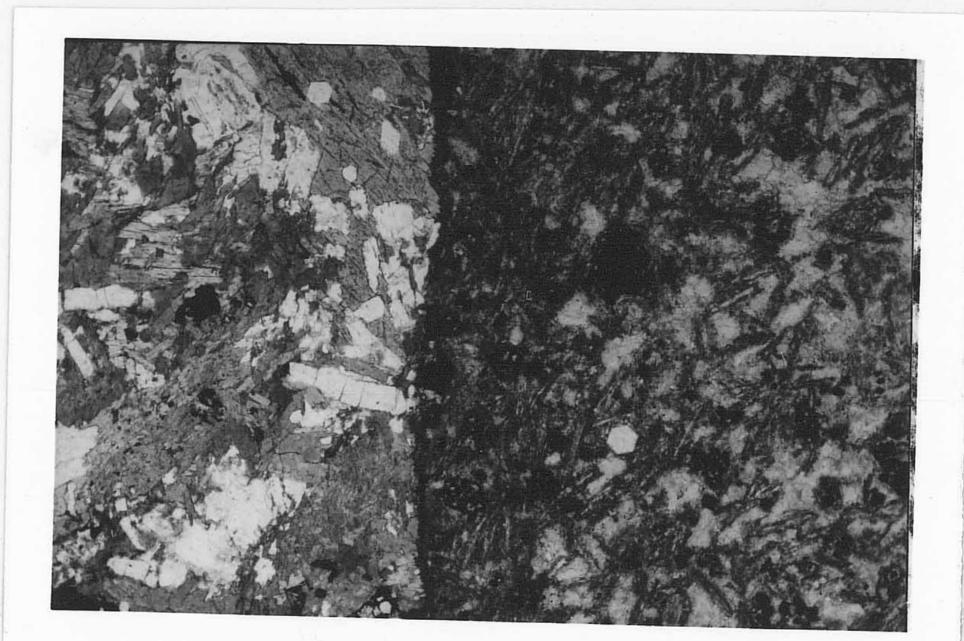


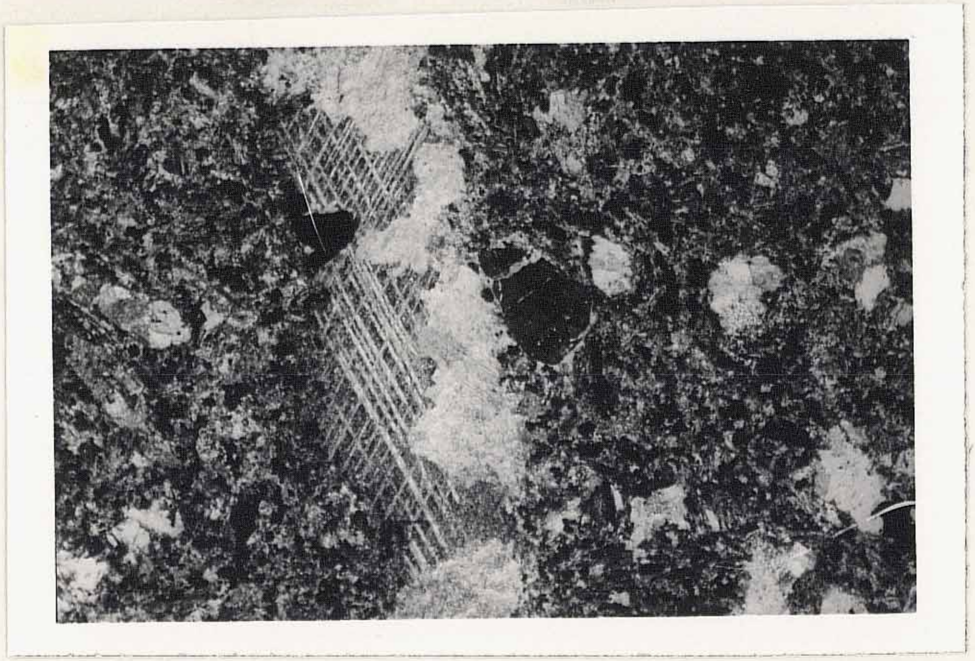
either. This classification is inadequate in the field and further groupings according to mineralogy and texture are necessary.

The carbonatite dikes in the Lemitar Mountains can be broadly characterized as dikes containing xenoliths (breccia and microbreccia silicocarbonatite dikes) and those without xenoliths. The breccia and microbreccia silicocarbonatite dikes are light to medium-gray, weathering to a dirty brown, and generally primary magmatic. The dikes consist of 10 - 40% xenoliths (rock fragments) and >60% carbonatite matrix (pl. 25 and 26). Large phenocrysts, often megascopic (up to several mm. across), of magnetite (5-10%), apatite (5-10%), biotite/phlogopite (5-15%), and feldspar (<2%) are found scattered throughout, forming a porphyritic texture. Other minerals occur throughout the fine-grained carbonate matrix (table 13). Often these minerals are corroded or cracked and replaced by carbonate. Resorption of phenocrysts is common. On a weathered surface these phenocrysts often stand out where the carbonate matrix has dissolved away. Sovite and rauhaugite veins often crosscut the dike (pl. 26). The carbonatite dikes often crosscut earlier mafic dikes (pl. 27).

PL. 25: Breccia silicocarbonatite dike (sample Lem 500).
Pencil is approximately 20 cm. long.

PL. 26: Photomicrograph (25x, cross-polars) of a sovite or rauhaugite vein crosscutting a replacement carbonatite. The vein is 0.7mm thick.

PL. 27: Breccia silicocarbonatite dike (brown) crosscutting diorite/gabbro (lighter gray) and a mafic dike (darker gray, fine-grained).



0.3 mm

Xenoliths vary in size from a few mm. to a meter across Xenoliths include fragments of the host rock, foliated granites, foliated arkoses, quartzites, gray and green schist, phyllites, and red granitic fenites. Some granitic xenoliths have similar appearance, composition, and texture as the Polvadera Granite, while others have been completely or partially altered to a fenite composed of K-feldspar and biotite with little or no quartz and plagioclase. The xenoliths are often rounded, possibly as a result of chemical reactions with the carbonatite fluids and/or as a result of collusions with each other and the surrounding wall rock.

Carbonatite dikes without xenoliths can be further grouped according to mineralogical composition:

(1) fine-grained dolomitic to calcitic silicocarbonatite dikes

(2) ankeritic rauhaugite dikes

(3) sovite and rauhaugite veins (<5 cm. thick)

Both primary magmatic and replacement types are found within thin sections of the various groupings.

Fine-grained dolomitic to calcitic silicocarbonatite dikes are light to medium-gray, weathering to a brownish gray. Both primary magmatic and replacement varieties occur in both types. Often fine-grained silicocarbonatite dikes grade into mafic dikes. One occurrence of dolomitic to calcitic silicocarbonatite dikes (sec. 7) contained small veins of megascopic purple fluorite and sulfide minerals.

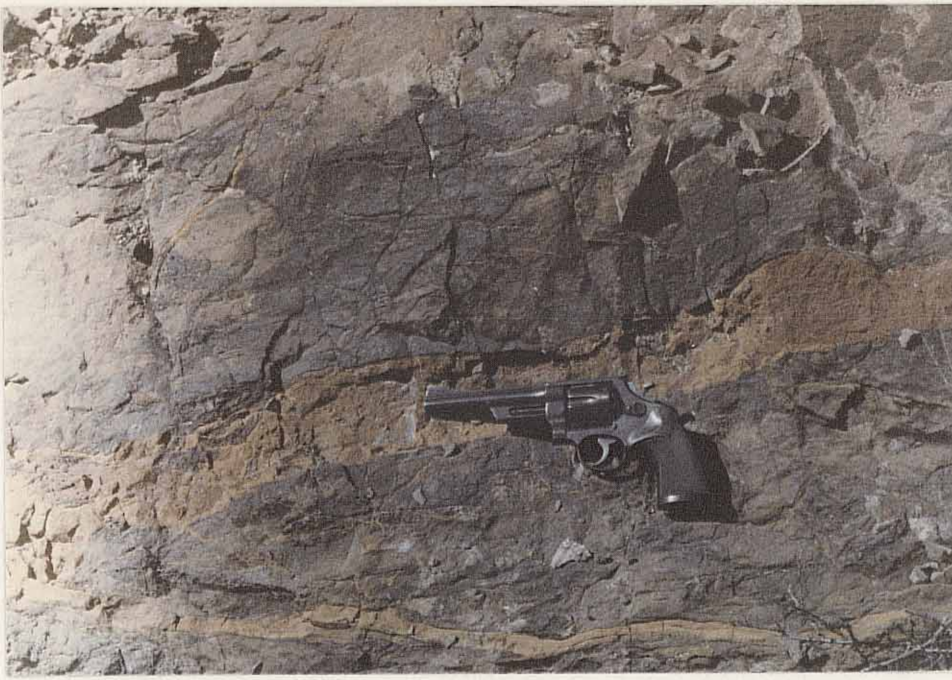
Ankeritic rauhaugite dikes crosscut fine-grained silicocarbonatite dikes (pl. 28 and 29). These dikes are light brown and consist of ankerite, calcite, barite, dolomite, hematite, and magnetite. These dikes commonly occur in and north of sec. 6.

Thin sovite and rauhaugite veins crosscut other carbonatite dikes. Larger sovite veins (up to several mm. thick) often follow pre-existing fractures or earlier mafic dikes and some are highly radioactive (up to 100 times background). Microscopically, sovite and rauhaugite veinlets crosscut the carbonatite matrix, xenoliths, and phenocrysts. Clearly these veinlets represent a later stage of carbonatite intrusion.

Thin, light brown dikelets or veins fill the fracture systems in the Polvadera Granite, forming a stockwork pattern (Map 1). Carbonatite fluids apparently intruded the granite and followed pre-existing fracture or shatter zones. These veins consist of barite, calcite, dolomite, ankerite, and hematite. Original granitic textures and minerals are often preserved. Feldspars have been partially or completely replaced by carbonate. These micas have been

PL. 28: Fine-grained dolomitic silicocarbonatite dike (sample Lem 530) cut by ankeritic rauhaugite dikes (sample Lem 531A and B). Pistol is approximately thirty cm. long.

PL. 29: Fine-grained dolomitic silicocarbonatite dike cut by ankeritic rauhaugite dikes. Pencil is approximately 20 cm. long.



left intact, suggesting low temperatures at the time of replacement.

The age of the Lemitar carbonatites is difficult to determine. Tertiary faults truncate the carbonatite dikes in sec. 6 (Map 1) indicating that the carbonatites were emplaced prior to Tertiary faulting. Furthermore, carbonatites have not been found in any rocks younger than the Precambrian (personal reconnaissance and R.M. Chamberlin, personal communication). The carbonatites may have been faulted by a Pennsylvanian fault (sec. 7, Map 1), suggesting a pre-Pennslyvanian age.

Geochemistry

A representative suite of samples from the various carbonatite dikes was analyzed for major and minor elements (Appendix C). A scintillation counter was not available during the sampling period; therefore, the samples were collected without any knowledge of the radioactivity content. A few of the carbonatites have major element oxide sums less than 100%. The difference can be accounted for by numerous other elements that were not determined.

The carbonatite dikes fall into two populations based on iron content (table 9). The higher iron content is due to the presence of ankerite and hematite. The high iron carbonatite dikes are not in contact with the low iron carbonatite dikes, so the exact age relationship is unknown. However, evidence from other localities indicates that ankerite is one of the last carbonates to form (examples: Eastern Sayan Mountains, U.S.S.R.; Iron Hill, Colorado; Mountain Pass, California; Heinrich, 1966). The high calcium content of the carbonatites relative to other Lemitar Precambrian rocks is quite obvious in fig. 13. The carbonatites have a high volatile content as well (table 9).

In any particular occurrence, the carbonatites are quite heterogeneous mineralogically and chemically. Due to this heterogeneity, normal variation diagrams commonly used in the study of igneous rocks are not very useful. 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 throughout the world (misc. data compiled by the author), defines a carbonatite field, which overlies the area between and within the kimberlite and mafic carbonatite fields. The Lemitar samples fall nicely within this field (fig. 14).

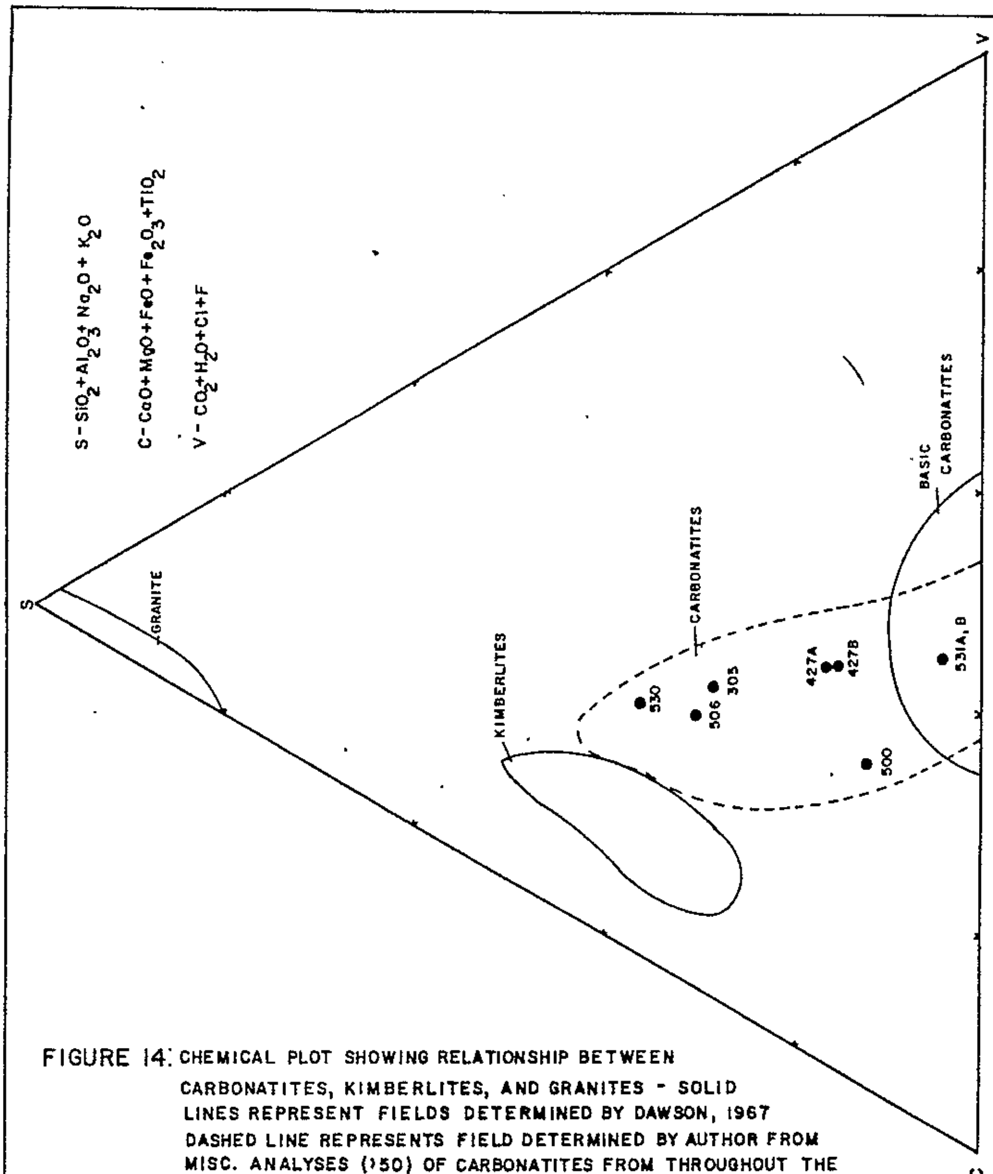


FIGURE 14: CHEMICAL PLOT SHOWING RELATIONSHIP BETWEEN CARBONATITES, KIMBERLITES, AND GRANITES - SOLID LINES REPRESENT FIELDS DETERMINED BY DAWSON, 1967 DASHED LINE REPRESENTS FIELD DETERMINED BY AUTHOR FROM MISC. ANALYSES (150) OF CARBONATITES FROM THROUGHOUT THE WORLD

The Lemitar carbonatites can be compared with Heinrich's average carbonatite (table 9 and 10). The Lemitar carbonatites are grossly similar to this average. The average carbonatite represents an average of analyses without any regard as to location, mineralogy, or heterogeneity of the carbonatites. The average carbonatite does not reflect the extreme heterogeneity found in carbonatites in general and even within a particular locality.

The distribution of major and minor elements in carbonatites have been examined by several authors (table 14, Olson, et. al, 1954; Russel, et al., 1954; Erickson and Blade, 1963; Heinrich, 1966; Barber, 1974). The differences in CaO, MgO, and total iron among the Lemitar Mountain carbonatites probably reflect differences in the amounts of calcite, dolomite, ankerite, and magnetite (table 15). K2O exceeds Na2O in all but one sample, reflecting the dominance of mica and K-feldspar over plagioclase. The presence of apatite is reflected by the amount of P2O5 and H2O (includes F and Cl). Ba and Sr are found in early carbonate minerals (Heinrich, 1966). Ba is also a major constituent of barite (table 15, samples Lem 427a and b, 506, 530, and 531a). Differences in mineralogy would account for the differences in chemical composition between

TABLE 14

DISTRIBUTION OF ELEMENTS IN CARBONATITES

OXIDE/ELEMENT	DISTRIBUTION
SiO_2	quartz, feldspar
TiO_2	magnetite, sphene, garnet, pyrochlore, micas
Al_2O_3	feldspar
Fe_2O_3, FeO	magnetite, ankerite, hematite
MgO, CaO	carbonates, magnetite (MgO)
Na_2O, K_2O	micas, feldspar
MnO	carbonates, apatite
Sr	carbonates, apatite
Ba	carbonates, apatite, barite
U	apatite, zircon, pyrochlore, sphene, fluorite
P_2O_5	apatite
H_2O, F, Cl	mica, apatite, fluorite, bastnaesite
Cr, Ni, Co	pyrite, magnetite, apatite
Cu	pyrite, calcite, magnetite
Zn	magnetite, calcite
Li	phlogopite

References: Olson, et al., 1954; Russell, et al., 1954; Erickson and Blade, 1963; Heinrich, 1966

TABLE 15

MINERALOGY OF THE LEMITAR CARBONATITES BY X-ray DIFFRACTION

Mineral	305	427a	427b	500	506	530	531a	531b
Biotite	x	x	x	x	x	x		
Chlorite	x	x	x		x	x		
quartz	x	x	x	x	x	x	x	x
fluorite	x	x		x	x	x	x	
calcite	x	x	x	x	x	x	x	x
dolomite	x	x	x	x	x	x		
ankerite						x	x	x
apatite	x	x	x	x	x	x		
magnetite	x	x	x	x	x	x		
barite			x		x	x	x	
bastnaesite				x				

x - present

the Lemitar Mountain carbonatites and other carbonatites throughout the world.

Fenitization

Fenitization is the alkali metasomatic replacement of country rocks generally associated with the intrusion of carbonatites or alkalic complexes. Rocks which have undergone complete metasomatic replacement and are associated with alkali intrusions have been termed fenites (Heinrich, 1966). Two processes of fenitization are recognized (table 16). One involves the addition of sodium and potassium (normal or sodic fenitization), and the other involves the addition of potassium only (potassic fenitization).

Normal or sodic fenitization is the most common alteration process associated with the carbonatite intrusives in the Lemitar Mountains, as will be discussed later. Some potassium has been added to the diorite/gabbro in the form of K-feldspar, but this addition is minor. Some red granitic fenites, consisting of microcline and biotite with little or no quartz, occur as xenoliths within breccia and microbreccia silicocarbonatite dikes and exhibit potassic fenitization.

TABLE 16

CLASSIFICATION OF FENITES

(after Vartiain and Woolley, 1976)

FENITE TYPE	FEATURES	EXAMPLE
NORMAL or SODIC FENITIZATION	Na and K added, alkali pyroxenes and amphiboles	
Sodic Type	strongly sodic	Sokli, Finland
Intermediate Type	major Na and K	Alno, Sweden
Potassic type	major K, minor Na	Amba Dongar, India
POTASSIC FENITIZATION	K added, no alkali pyroxenes or amphiboles, often phlogopite	
Potassic type	K only	Bakusu, Uganda
Late Stage Fenitization	K fenitization superimposed on normal fenitization	Chilwa Island, Nyasaland (Africa) Sokli, Finland

A thin zone of sodic fenitization is developed along some carbonatite dikes in the diorite/gabbro. This zone is not seen everywhere, but appears to be restricted to the western sides of the thicker (<1 meter) carbonatite dikes. The zone is two to ten cm. thick and is characterized by large (up to 60 mm. in diameter), orange-pink albite crystals. The reddish color is common to other fenite occurrences and is thought to have been produced by the oxidation and exsolution of iron molecules originally within the feldspar lattice (von Eckermann, 1948, p. 29). The oxidation is believed to be a result of the degassing of carbon dioxide from the carbonatite intrusive.

The plagioclase composition reflects an increase in sodium by the change from An40 - An50 to An5 - An15. The fenitized diorite/gabbro appears also to increase slightly in quartz and perthitic K-feldspar content. A similar type of fenitization is reported from the Messum carbonatite vein in South West Africa. Four stages of fenitization can be distinguished at this locality (in order of increasing fenitization, Verwoerd, 1966):

(1) increase in albite content

(2) introduction of perthitic K-feldspar

(3) introduction of nepheline replacing plagioclase with accessory sodalite and analcite

(4) increase of orthoclase, nepheline, and ferrohastingsite

Fenitization of the Lemitar diorite/gabbro appears to have progressed as far as stage 2 of this sequence.

Two samples of the fenitized diorite/gabbro (samples Lem 532 and 533, Appendix B) were analyzed for eight major elements and two minor elements (Appendix C). These preliminary studies show a significant increase in Na2O and a significant decrease in CaO compared to unfenitized samples (fig. 15). Other chemical changes are summarized in table 17. These chemical changes are consistent with normal sodic fenitization as seen at Sokli, Finland (Vartiain and Woolley, 1976).

The increase in Na2O is reflected by the conversion of andesine and laboradiorite to albite and may be directly related to loss of sodium by the adjacent carbonatite. The increase in Na2O is also reflected by an increase in normative albite (Appendix C). The loss of CaO may be due to the formation of thin calcite veins crosscutting the diorite/gabbro in the vicinity of the carbonatite dikes. Some CaO may migrate to the carbonatite dike. TiO2 and Fe2O3 may be loss to the crosscutting hematite veins. Similar chemical trends are reported from carbonatites throughout the world (table 18).

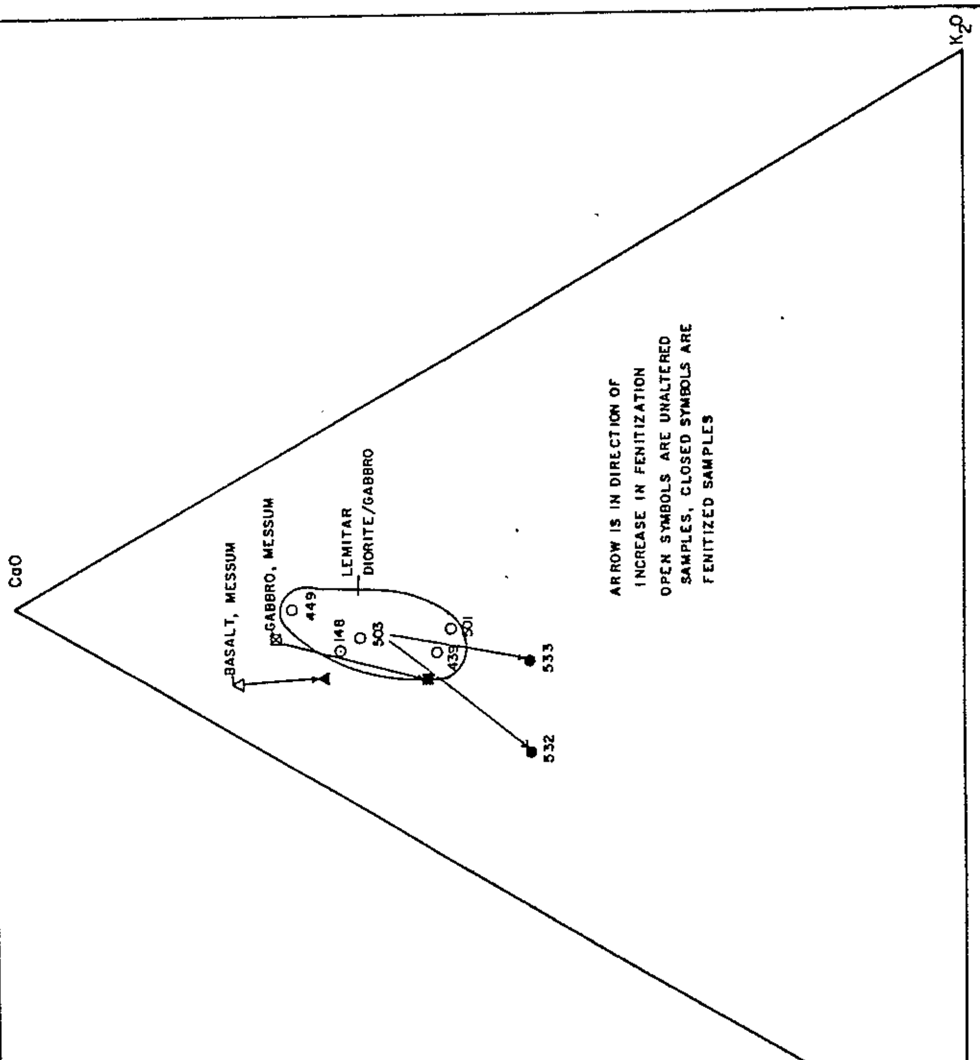


FIGURE 15: $CaO-Na_2O-K_2O$ PLOT OF THE EFFECT OF FENITIZATION ON THE LEMITAR DIORITE/GABBRO, TRENDS REPORTED BY VERWOERD, 1966 FROM BASALT AND GABBRO NEAR THE MESSUM CARBONATITE, SOUTH WEST AFRICA

TABLE 17

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
No significant trend	SiO_2, K_2O, Rb, Sr

TABLE 18

CHEMICAL TRENDS OF FENITIZED MAFIC ROCKS

COMPLEX	FENITIZED ROCKS	GAINS	LOSSES	REF.
Messum, S.W. Africa	basalt, dolerite, gabbro	Na, Al, K	Si, Ca, Fe	1
Breivikbotn, Norway	metagabbro	Fe, Mn	Al	2
Khibina, Kola Soviet Union	diabase	K, Na, Mg, Fe, Al, Ti followed by K, Na, Al, Si	Ca, Si Ca, Mg, Fe Ti	2
Mbozi, S.W. Tanzania	gabbro	K, Na, Al, Si	Ca, Mg, Fe, Ti	2
Blue Mountain, Ontario	amphibolite	K, Na, Al	Ca, Mg, Fe	2
Callander Bay, Ontario	garnet amphibolite	Si, Al, Na, K	Ti, Mg, Ca	3
Lemitar, New Mexico	diorite/gabbro	Na, Al, Mg	Ca, Ti, Fe	4

1 - Verwoerd, 1966
2 - Robins and Tysseland, 1979
3 - Currie and Ferguson, 1972
4 - This report

Fenites are not always produced in the Lemitar diorite/gabbro when adjacent to carbonatite dikes. At Magnet Heights, Transvaal, a sovite dike intrudes gabbro, magnetite, and albitite with no apparent fenitization (Verwoerd, 1966). At Stjernoy, Norway, a gabbro has been altered to an hornblendite by gaseous H2O and CO2 erupting from the carbonatite (Verwoerd, 1966). Fenitization is also absent within the amphibolite at Sokli, Finland (Vartiainen and Woolley, 1976). Fenitization is poorly developed in country rocks surrounding the Siilinjarvi carbonatite complex, Finland, and is characterized by light green alkali-amphiboles and bluish quartz (Puustinen, 1969).

The apparent lack of evidence for fenitization of the Lemitar diorite/gabbro is probably a result of some combination of these factors:

(1) stability of hornblende (resists fenitization)

(2) lack of conduits for fenitizing fluids

(3) insufficient volatile content (H2O, CO2) of the carbonatite to initiate fenitization

(4) insufficient pressures and temperatures of the carbonatites to initiate fenitization

(5) composition of the Lemitar diorite/gabbro is incompatible with fenitization

(6) quick cooling and crystallization of the

carbonatite dikes, allowing insufficient time for fenitization to occur

(7) distance from the source of the carbonatite dikes is great.

Vartiainen and Woolley (1976) suggest that the lack of fenites at Sokli, Finland may be a result of the stability of hornblende which resists alteration and the lack of fractures and veinlets, which act as a path for the fenitizing fluids. This may partially explain the lack of fenites in the Lemitar Mountains. Fenitization of the country rock is dependent on volatile content, pressure, and temperature of the carbonatite; if these factors are not great enough, fenitization may not occur, as in the Lemitar Mountains. Unfortunately, experimental evidence is lacking to substantiate this theory. The composition of the country rock affects the fenitization process. The lack of alkalis would partially explain the absence of fenitization effects (Verwoerd, 1966), and it has already been mentioned that the stability of hornblende is such as to resist fenitization. If the carbonatite dikes cool and crystallize quickly, the temperature and pressure would drop off, not allowing enough time for fenitization to take place. Furthermore, as the distance from the carbonatite source becomes larger, fenitization becomes less pronounced. This was observed at

Alno, Sweden (von Eckermann, 1948), and may be a primary reason for the lack of fenites in the Lemitar Mountains.

The effects of fenitization have been minor in the Polvadera Granite and the sediments. Some hematite and carbonate veins are present and may be related to the early stages of fenitization. Often an increase in plagioclase and K-feldspar can be detected in the rocks adjacent to the carbonatite dikes. The Polvadera Granite often becomes brecciated and fractured, forming only veinlets of the carbonatite and creates a stockwork pattern. A similar type of fenitization occurs at Callander Bay, Canada, where fenitization of granitic rocks progresses as follows (Currie and Ferguson, 1971):

(1) hematite veins (first stage)

(2) increase in the ordering of K-feldspar

(3) plagioclase converted to albite plus calcite

(4) K-feldspar converted to maximum microcline, pyroxenes become abundant (final stage).

The presence of hematite-carbonate veins and the increase in plagioclase and K-feldspar contents in the Lemitar granites and sediments indicates that fenitization has occurred, but has progressed only to first stage.

Thin (several millimeters) hematite veins occur within the Precambrian rocks and as coatings along fracture and joint surfaces. The veins are often discontinuous with a lateral extent of about a meter. In thin section, hematite often occurs around corroded magnetite and biotite crystals. The majority of this type of alteration is a result of the weathering of iron-rich minerals, although some may be related to oxidation produced by the degassing of the carbonatite intrusive.

Origin

The carbonatite dikes were probably emplaced at a great distance (laterally or vertically) from the source, as evidenced by:

(1) the lack of any radial or conical patterns in the dike outcrop

(2) the lack of fenitized haloes about the dikes

(3) the common occurrence of replacement-type carbonatite dikes

(4) the lack of carbonatite dikes in the southern portion of the area.

Only one other occurrence of carbonatites is reported from New Mexico, located in the Monte Largo area (Lambert, 1961). This carbonatite is a massive dolomitic carbonatite dike with apatite, magnetite, and mica. Other occurrences of carbonatites are found associated with the alkalic complexes in southern Colorado (Heinrich, 1966). The age of the carbonatites in Colorado is 520 m.y. (Olson, et al., 1977).

Carbonatites are generally associated with alkalic intrusives (Heinrich, 1966). Alkalic intrusives of Precambrian age in New Mexico include the Pajarito Mountain syenite (1170 m.y., Kelley, 1968) and the Florida Mountain syenite (420 - 700 m.y., Brookins, 1974). This evidence may be suggestive of an alkalic igneous province occurring in Colorado and New Mexico between 1100 and 420 m.y. The Lemitar Mountain carbonatites would be part of this postulated province.

Carbon and oxygen isotope studies in the Wet Mountain carbonatite complex, Colorado, clearly indicate that those carbonatites are from a deep-seated source (Armbrustmacher, 1979). Other carbon, oxygen, sulfur, and strontium isotope studies also indicate a deep-seated or upper mantle source for carbonatites (Hayatsu, et.al., 1965; Powell, et.al., 1966; Heinrich, 1966; Taylor, et.al, 1967; Suwa, et.al., 1975; Mitchell and Krouse, 1975). With this abundance of isotope evidence, it is probable that the carbonatites in the Lemitar Mountains also are derived from a deep-seated or upper mantle source. It is conceivable that the carbonatites of the Lemitar Mountains may be derived from a mafic source which gave rise to the mafic dikes and the diorite/gabbro, although preliminary chemical studies appear not to exhibit any chemical trends. An extensive geochemical and isotopic study of the Lemitar Mountains carbonatites would have to be conducted before constraints on the composition of the source could be achieved.

Experimental evidence confirms that melts with a variety of compositions can produce the wide variance in mineralogy and chemistry seen in carbonatites similar to those found in the Lemitar Mountains (Heinrich, 1966; Wyllie, 1966; Watkin and Wyllie, 1971). The evidence suggests that carbonatites, similar in composition to those in the Lemitar Mountains, may have been emplaced at temperatures of 450 - 600 degrees C. and pressures ranging from 1 - 1000 bars (Heinrich, 1966).

STRUCTURE AND METAMORPHISM

INTRODUCTION

The Lemitar Mountains lie on the western edge of the Rio Grande graben, where normal faults have uplifted and exposed the Precambrian rocks. The metamorphosed Precambrian rocks are structurally complex. Foliation, faults, shearing, and brecciation, most of which are Laramide and Tertiary structures, affected the Precambrian rocks. The difficulty in interpreting the Precambrian structure is in differentiating younger complex faulting and shearing from that of the Precambrian.

The Precambrian rocks have undergone successive periods of metamorphism, making the identification of mineral associations difficult. The rocks are also affected by retrograde metamorphism, such as the chloritization of biotite and the sericitization of feldspars. The effects of metasomatism, such as carbonatization and hematization, are superimposed over the metamorphic fabric indicating that metamorphism occurred prior to alteration. The complicated structural trends in the Lemitar Mountains may suggest several periods of burial and uplift during the Laramide and Tertiary orogenies. Contact metamorphic effects are rare.

METAMORPHISM

Generally, the mineral assemblages of the Precambrian rocks in the Lemitar Mountains can be summarized as follows:

quartz-muscovite

quartz-muscovite-biotite-plagioclase-(garnet)

quartz-biotite-potassium feldspar-plagioclase-(garnet)

blue-green hornblende-biotite-plagioclase-(garnet)

quartz-biotite-muscovite-potassium feldspar-plagioclase

These mineral assemblages represent the transition between the greenschist facies (low grade metamorphism) and the amphibolite facies (medium grade metamorphism, Winkler, 1976; Condie and Budding, 1979).

Regional metamorphism completely recrystallized the sediments. The mineral assemblages and gneissic foliation are consistent with the upper greenschist and lower amphibolite facies of metamorphism; undulatory extinction of crystals may possibly be related to regional metamorphism. The presence of trace amounts of garnet in some of the thin sections is suggestive of metamorphism to the transitional zone between the greenschist and lower amphibolite facies. Well-preserved foliated arkose inclusions are found scattered throughout the diorite/gabbro suggesting that this period of metamorphism occurred prior to the emplacement of the Lemitar diorite/gabbro. The foliation within the arkose inclusions is randomly oriented.

At least one other period of metamorphism that affected the Corkscrew Canyon sequence also affected the Lemitar diorite/gabbro and the mafic dikes. The presence of garnet and the transformation of pyroxenes to hornblende, found in the Lemitar diorite/gabbro, are indicative of the transition between the greenschist and amphibolite grades of metamorphism, occurring after the emplacement of the diorite/gabbro.

It is difficult to determine whether the granitic rocks have undergone metamorphism. Foliation within the granitic rocks is randomly oriented and localized and may be partially related to the emplacement of the granites. Mortar textures are often present, but these too may be related to the emplacement of the granites. Crosscutting mafic dikes have been metamorphosed, as indicated by the transformation of pyroxenes to hornblende, clearly indicating that low grade metamorphism occurred after the emplacement of the mafic dikes and the granites.

The carbonatites probably have been unaffected by metamorphism due to the lack of a metamorphic fabric. Mortar textures and undulatory extinctions of feldspar crystals are probably related to the intrusion of the carbonatite dike.

FOLIATION

Foliation in the Corkscrew Canyon sediments approximately parallels relict bedding. Relict bedding is distinguished from foliation by color and textural contrasts. The trend of foliation along Corkscrew Canyon ranges from N40W to N40E, with easterly dips of 40 - 70 degrees. Relict crossbedding and graded bedding indicates that the sequence is presently upright, younging towards the east.

Very few outcrops are found between the sediments exposed in Corkscrew Canyon and the arkose from the lowest exposed unit in the southern portion of the map area (Map 1). The foliation of the arkose parallels the east-west trend of foliation in the gneissic granite. If the sediments are still in an upright position in the southern portion of the study area, then the arkose is the oldest sediment exposed. This age relationship is uncertain, because primary textures are not well preserved in this arkose and faulting may have offset the arkose from the sediments exposed in Corkscrew Canyon. The foliation of the arkose may also be due to the intrusion of the gneissic granite.

A Tertiary fault cuts the gneissic granite south of the intrusive contact with the arkose (Map 1). North of this fault, foliation trends east-west and dips to the north. South of this fault, foliation is still in an east-west direction, but dips to the south, while further south the dip direction changes to the north. This foliation may be partially inherited from the emplacement of the granite.

Foliation is absent to poorly developed in the northern granitic rocks, the Lemitar diorite/gabbro, and the mafic dikes. Some foliation, parallel to the edges of the dikes, occurs in the carbonatite dikes and is probably related to the emplacement of the dikes. Foliation in the Lemitar diorite/gabbro is restricted to shear zones and near the western and northern contacts with the altered facies of the Polvadera Granite. Foliation in the biotite and Polvadera Granite is poorly developed to absent, and may represent primary flow structures, while foliation in the muscovite-biotite granite is related to migmitization occurring along the intrusive contact with the Lemitar diorite/gabbro.

FAULTS

Faulting has occurred on a large scale making the determination of thickness and orientation of the sediments difficult to determine. The Laramide orogeny and Tertiary Basin-and-Range-type faulting (rifting) overprinted the Precambrian fabric, reinforcing the northerly structural trends of the Precambrian terrain. Laramide structures consist of broad folds and reverse faults (Woodward, 1973) and rotational effects during the Laramide are minor (about 15 degrees west, Woodward, 1973), while Tertiary faults, related to rifting, tilted the Precambrian rocks even more (approximately 40 degrees west, Woodward, 1973).

North-trending faults with silicified carbonated gouge zones cut the rocks along Corkscrew Canyon and also cut the Polvadera Granite along the main arroyo in sec. 31 (Map 1). Not all of these faults can be mapped. Widths of the fault breccia zones range in thickness from a few cm. to a meter. Several east-west faults cut the sequence south of Corkscrew Canyon, forming arroyos such as Corkscrew Canyon. East-west faults also cut the Polvadera Granite and the Lemitar diorite/gabbro. Tertiary and Precambrian faults are difficult to distinguish outside of Corkscrew Canyon due to the lack of good exposures. A few shear zones within the sediments and altered facies of the Polvadera Granite may be indicative of pre-Laramide faults, for these zones only affect the Precambrian rocks. For the purposes of this report, breccia and shear zones have been described separately.

A northwest-trending Tertiary fault (Chamberlin, 1978) cuts the Precambrian rocks in sec. 6 and 7 (Map 1). Local brecciation along the northern part of the fault and the discontinuity of several mafic dikes in in the central part of sec. 7 occurs and is suggestive of a fault. Generally, the exposures in the Precambrian rocks are too poor to extend Laramide and Tertiary faults that cut the adjacent Phanerozoic rocks.

SHEAR ZONES

A northeast-trending shear zone cuts across the western quarter of the section along Corkscrew Canyon. Bedding has been obliterated and in thin section, cataclastic textures, undulatory extinction of the grains, and sutured grain boundaries are present. Boudinage structures (several cm. across) subparallel the trend of the original bedding

Boudinage indicates the stretching and shearing of layered competent and incompetent rocks. Foliation is formed by small-scale (wavelength of several cm.) highly folded quartz and feldspar bands and by tight, ptygmatic folds which are often sheared in places (see fig. 18-A and B, p. 54, Woodward, 1973). The 120 - 150 meter wide shear zone is not seen south of Corkscrew Canyon and ends at the intrusive contact with the muscovite-biotite granite. This shear zone is Precambrian in age and probably occurred before or during the intrusion of the muscovite-biotite granite, as the shear zone affects only the sediments. It may even be related to the intrusion of the muscovite-biotite granite.

Shearing has also affected the altered facies of the Polvadera Granite where zones of foliated quartz and feldspar layers occur, indicative of intense shearing. The trend of this foliation is northeast with a western dip of about 62 degrees. This shearing may also be related to Precambrian faulting, because faulting and shearing does not appear to have affected the Paleozoic sediments.

Shearing occurs within the Lemitar diorite/gabbro near the contact with the Polvadera Granite. This shearing could be due to a Pennsylvanian reverse fault (Chamberlin, 1978) or to the intrusion of the Polvadera granite. Foliated chlorite- and biotite-rich zones, several meters across, are locally present along the intrusive contact. The foliation subparallels the intrusive contact and is absent within the Polvadera Granite, suggesting a relationship to the emplacement of the Polvadera Granite.

BRECCIATION

Several small (several meters across) heterolithologic breccia zones occur within the sediments (Map 1) and are generally cemented by white carbonate. Angular rock fragments are composed of Precambrian gneissic and granitic rocks and are often surrounded with a light-colored reaction rim. Brecciation had occurred after metamorphism as indicated by the randomly oriented foliated rock fragments.

In contrast, several monolithologic breccia zones occur within the muscovite-biotite granite (Map 1) where the rock fragments consist entirely of muscovite-biotite granite. The matrix is black and very fine-grained and carbonate is absent from the matrix. The rock fragments are angular and unsupported (surrounded by matrix) and randomly arranged, similar to rock fragments found in the brecciated sediments. This breccia zone represents part of the low angle fault forming the eastern contact between the Precambrian and Phanerozoic sediments and volcanics (Chamberlin, 1978).

A brecciated and sheared zone occurs in the central portion of the Lemitar diorite/gabbro (Map 1, sec. 6 and 7), where fragments of diorite/gabbro have been cemented and forms an angular breccia. The diorite/gabbro has been slightly foliated and altered to a chlorite- and biotite-rich gouge. Foliation within this shear zone dips to to the northwest about 44 degrees. Original textures have been obliterated and sheared. Some of these zones may represent lenses of sedimentary inclusions. This sheared breccia zone may have resulted from faulting; Chamberlin (1978) shows the area to be transected by two faults - an early Oligocene transverse fault and a Pennsylvanian reverse fault.

MINERALIZATION

Five periods of mineralization affected the Precambrian rocks in the Lemitar Mountains (in order of decreasing age):

(1) Precambrian pegmatite and quartz veins

(2) Carbonatite dikes (late Precambrian)

(3) Phanerozoic barite-galena-copper veins

(4) Phanerozoic barite-galena-sphalerite veins

(5) Barite veins

Mining claims cover much of the eastern portions of the map area (sec. 5, 6, and 7, Socorro County Courthouse Records).

Precambrian pegmatites are of the simple type, consisting of unzoned feldspar, quartz, and mica as previously discussed (see Granitic Rocks). Quartz veins appear to be barren of any other mineralization. Both are discontinuous, forming poorly exposed outcrops.

The carbonatite dikes are composed of rare-earth bearing minerals, radioactive minerals, and fluorite. High areas of radioactivity (100 times background) occur in sec. 6 and 7. Two samples of high radioactivity were analyzed and found to contain 0.08 (190 ppm U) and 0.06% (143 ppm U) U308 (Christopher Rautman, personal communication). The eight samples analyzed by the author ranged from 0.0011 to 0.0045% U308 (Appendix B). Megascopic fluorite is found along the walls of several prospect pits in sec. 7. The concentration of rare-earth elements may be relatively high because bastnaesite is present.

Phanerozoic barite-galena-copper veins occur along the western contact with the Phanerozoic sediments. Prospect pits and a shaft (sec. 18) expose this mineralization. Copper minerals coat the fracture and joint surfaces of the Precambrian rocks in the vicinity of the mineralization. At one locality within the altered facies of the Polvadera Granite, a vein of galena, sphalerite, chacolcite, quartz, fluorite, barite, and secondary copper minerals crosscuts a pegmatite dike. Some silver and zinc have been reported from these veins (Lasky,1932).

Phanerozoic barite-galena-sphalerite veins occur within Phanerozoic limestone along the eastern contact (sec. 5). This mineralization is localized and restricted to some small outcrops of limestone. The study of three thin sections of veins within the limestone reveals coarse-grained limestone crosscut by thin veinlets of barite and calcite containing galena and sphalerite. The lack of apatite, magnetite, and biotite clearly distinguishes these veins from carbonatite dikes. Small quantities of barite were shipped from one of the larger zones within the limestone (sec. 5, Map 1).

Barite veins, also Phanerozoic, occur along the eastern contact, generally striking east-west. Barite veins often intrude the carbonatite dikes. This mineralization may be related to other barite mineralization in the area.

The Phanerozoic mineralization is not associated with the carbonatite dikes. The mineralogies and textures differ. The carbonatite dikes do not contain sphalerite or galena, and barite is rare in the carbonatites. The barite mineralization does not include apatite, magnetite, or biotite. Field relationships suggest that the carbonatites are older than the limestone that hosts the barite mineralization.

GEOLOGIC HISTORY, TECTONIC SETTING, AND CONCLUSIONS

A summary of the Precambrian geologic history of the Lemitar Mountains is presented in table 19. The first event recorded in the Lemitar Mountains is the deposition of the Corkscrew Canyon sequence consisting of two units - Unit I characterized by massive arkose and Unit II characterized by interbedded, foliated arkoses, subarkoses, and quartzites. This sequence of sediments is similar to the feldspathic quartzite-arkose association exposed throughout central New Mexico (Condie and Budding, 1979), although correlation to a particular basin is uncertain. The gneissic granite may have been emplaced after the deposition of the sediments, although it is possible that this foliated granite may have been emplaced at the same time as the younger granites. The intrusion of Stage I mafic dikes followed. Metamorphism, faulting, and shearing of of the sediments occurred before or during emplacement of the Stage I mafic dikes. The emplacement of the Lemitar diorite/gabbro followed by the intrusion of Stage II mafic dikes occurred next. The similarity in mineralogy and texture between the Lemitar diorite/gabbro and the gabbro of Garcia Canyon (Magdalena gabbro) suggests that the two mafic units may be related to a similar source that crystallized about 1.5 b.y. according

TABLE 19

SUMMARY OF THE GEOLOGIC HISTORY OF THE PRECAMBRIAN ROCKS

(1) Deposition of the Corkscrew Canyon sediments derived from a granitic or gneissic source.

(2) Possible emplacement of the gneissic granite, although this foliated granite may have been emplaced along with the other granitic rocks later on.

(3) Intrusion of Stage I mafic dikes and metamorphism, folding, faulting, and shearing of the sediments.

(4) Emplacement of the Lemitar diorite/gabbro.

(5) Intrusion of Stage II mafic dikes.

(6) Emplacement of the granitic rocks, often associated with migmitization and/or shearing of the Lemitar diorite/gabbro.

(7) Intrusion of pegmatites and quartz veins and dikes and intrusion of Stage III mafic dikes, followed by a final period of metamorphism.

(8) Intrusion of carbonatites and associated fenitization of the Lemitar diorite/gabbro and granitic rocks. May include brecciation, carbonatization, and hematization of the country rocks.

to Rb/Sr isochron dating of the gabbro of Garcia Canyon (White, 1978). The granitic rocks intrude the Lemitar diorite/gabbro and often are associated with migmitization and shearing of the diorite/gabbro. Most granitic plutonism in central New Mexico occurred between 1.2 - 1.4 b.y. (Condie and Budding, 1979) and perhaps the Lemitar granites were emplaced during this period due to the similarity in mineralogy, texture, and chemistry between these granites. Simple, unzoned pegmatites and quartz veins represent a final stage of granitic magmatism in the Lemitar Mountains. Stage III mafic dikes intruded the granitic rocks, followed by a period of metamorphism. The intrusion of carbonatite dikes and veins along pre-existing faults and fractures followed and was often associated with normal sodic fenitization of the Lemitar diorite/gabbro and the granitic rocks. Brecciation, carbonatization, and hematization of the country rocks may also be associated with the intrusion of the carbonatites. Laramide and Tertiary structures are superimposed over the Precambrian fabric.

The mafic rocks are probably mantle-derived from a similar source. The lithologically heterogeneous Lemitar diorite/gabbro may have been derived from either late differentiation of a gabbroic magma or injection and mixing of granitic magmas with a gabbroic body. The mafic dikes, some of which intrude the granite, may represent a fraction of the same gabbroic source.

The granites can be divided into two groups based on similar compositions - Group I (gneissic granite, biotite granite) and Group II granites (muscovite-biotite granite, Polvadera granite). Group I granites are lower in SiO_2 and K_2O and higher in CaO and MgO than Group II granites. Geochemical model studies on granites similar in composition to Group I granites (Condie, 1978) suggest that partial melting of siliceous granulites in the lower crust could produce melts similar in composition to Group I granites. Group II granites are similar in composition to melts produced by fractional crystallization of granodiorite magmas (Condie, 1978). The granitic rocks are thought to be emplaced at depths of 2 - 13 km. as evidenced by field and experimental studies.

A carbonatite magma intruded the older Precambrian rocks as dikes and veins and was probably derived from the upper mantle as evidenced by experimental data from other carbonatites similar in composition to the Lemitar carbonatites. The random orientation of the carbonatite dikes suggest that a carbonatite magma penetrated the crust beneath the present erosion surface and the carbonatite magma followed pre-existing fractures and zones of weakness in the Precambrian rocks. Preliminary geochemical studies do not exhibit any chemical trends between the carbonatites and the mafic dikes (fig. 11).

The textures, mineralogy, and geochemistry of the Corkscrew Canyon sediments are consistent with deposition in a fluvial or deltaic environment in either a continental-rift or a rapidly rising continental-margin setting. Bimodal (fig. 9) and alkali magmatism followed the deposition of the sediments and is consistent with a continental-rift setting. These conclusions suggest that the the Proterozoic terrain of the Lemitar Mountains is consistent with a continental-rift setting such as the multiple-rift system proposed by Condie and Budding (1979).

The carbonatites in the Lemitar Mountains may be of a late Proterozoic-Cambrian age and if so may be related to other alkali rocks found in Colorado (Wet Mountains, Iron Mountains) and New Mexico (Monte Largo, Florida Mountains, Pajarito Mountain). The Wet Mountains and Iron Mountain complexes in Colorado consist of syenites, mafic nepheline-bearing rocks, and carbonatites and are of a similar age - about 520 m.y. (Olson, et al., 1977). The Monte Largo carbonatite (New Mexico) has been identified on the basis of carbonatite float in a narrow zone in the Monte Largo area and is thought to be Precambrian in age on the basis of field relationships (Lambert, 1961). It is similar in appearance and mineralogy to the carbonatites of the Lemitar Mountains. Radiometric determinations of the syenites of Florida Mountains range from 420 to 700 m.y. and are very uncertain due to either a thermal (magmatic or metasomatic) event or mixing of younger syenitic material with older granitic rocks (Brookins, 1974). The alkaline rocks at Pajarito Mountain, New Mexico, consist of syenites and gneisses; radiometric dating shows the rocks to be near 1.17 b.y. (Kelley, 1968). The occurrence of these alkalic rocks and the carbonatites in the Lemitar Mountains may be suggestive of an alkali province in Colorado and New Mexico ranging in age from 1.2 and 0.4 b.y. An alkali province would be consistent with a continental-rift setting in the Lemitar Mountains and a multiple-rift setting throughout the southwestern U.S. as proposed by Condie and Budding (1979), because carbonatites are known to be associated with areas of crustal weakness such as a continental-rift setting (Bailey, 1961).

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APPENDIX A

ANALYTICAL PROCEDURES

Sample Preparation

Samples were first crushed in a rock crusher to silt-size fragments. Ten grams of each sample were ground in an automatic mortar and pestle with acetone for thirty minutes. Duplicate briquettes were made of each sample and standard for subsequent X-ray fluorescence.

Eight samples of the carbonatite dike were prepared as above, except that thirty grams of each sample were used. A single briquette was made of each sample for future X-ray diffraction. The remainder of each sample was dried at 110 degrees C. for one hour and then used for wet chemical analyses.

X-ray Fluorescence

X-ray fluorescence data were obtained on a Norelco 8-position spectrograph (table 1). Ten thousand counts were collected for each briquette. A standard 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 instrumental drift. A computer program was employed for determining the ratio for each briquette (J.R. Renault, personal communication). The counting statistics are better than 2% for all elements except Na2O 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 (table 2). The errors are summarized in table 3.

Chemical Procedure

Major and minor elements were determined on eight carbonatite samples using atomic absorption, titration, colorimetric, and gravimetric methods (table 4). A standard HF (hydrofluoric) dissolution process was used to decompose the samples for subsequent atomic absorption analysis (L. Brandvold, personal communication). Two dissolutions were made; one contained one half to one gram of sample for the detection 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 a Varian 1250 spectrometer (table 5). Standards were prepared from analytical grade reagents. Calibration curves were determined for each element analyzed. The relative error is within 5% for most of the elements. Some elements analyzed (such as Na, K, and ect.) are within 3%; while other elements (such as Cu and Ba) are within 10% (L. Brandvold, personal communication).

Modified titration procedures were employed to determine FeO and CO2 (table 4), using one gram of each sample to determine FeO and one half gram to determine CO2. Duplicate samples were analyzed for each sample and resulted in a reproducibility of 0.3% for FeO and 1.5% for CO2. The relative error for FeO is approximately 1%. Two standards (limestone and dolomite) were analyzed for CO2 and were within 3% of the known CO2 concentration. Fe2O3 was found by subtracting Fe2O3 from total Fe determined by atomic absorption.

Various colorimetric procedures were employed to determine TiO2, P2O5, and U3O8 for each sample (table 4). Silica was determined by the classical gravimetric method (table 4) and the filtrate from the silica determination was used to determine TiO2. P2O5 was determined using 1 - 5 ml. of the 0.5 gram HF dissolution sample. One to five grams of each sample was decomposed using nitric and perchloric acids for the analysis of U3O8 (table 4). Absorbance was measured using a Bausch and Lomb Spec 20. The relative error for TiO2 and P2O5 was within 1%, while the relative error for U3O8 is within 5% (L. Brandvold, personal communication).

TABLE 1

INSTRUMENTAL PARAMETERS FOR X-RAY FLUORESCENCE

ELE	TUBE	CRYSTAL	DETECTOR	PATH	PEAK	PEAK 2θ	BKGRD 2θ
Si	Cr	GYP	FPC	VAC	KA1	26.00	-
Ti	Cr	QTZ	FPC	VAC	KA	48.70	-
Al	Cr	GYP	FPC	VAC	KA1	66.65	65.00
Fe	Cr	QTZ	FPC	VAC	KA	33.79	-
Mg	Cr	GYP	FPC	VAC	KA	81.32	80.00
Ca	Cr	QTZ	FPC	VAC	KA	60.42	-
K	Cr	QTZ	FPC	VAC	KA	68.24	-
Na	Cr	GYP	FPC	VAC	KA1	103.35	102,105
Mn	W	LiF	SCIN	AIR	KA	62.82	62.2,63.5
Ba	W	LiF	SCIN	AIR	LB	78.92	78,79.5
Rb	Mo	LiF	SCIN	AIR	KA	26.34	25.5,26.8
Sr	Mo	LiF	SCIN	AIR	KA	24.85	24,25.5

FPC - Flow proportion counter
SCIN - Scintillation counter
VAC - Vacuum
GYP - Gypsum
QTZ - Quartz
LiF - Lithium Fluoride

TABLE 2

ROCK STANDARDS USED FOR X-RAY FLUORESCENCE

STD	SiO2	TiO2	Al2O3	Fe2O3*	MgO	CaO	K2O	Na2O
BCR-1	54.5	2.20	13.6	13.4	3.46	6.92	1.70	3.27
LOSP	75.9	0.20	12.3	1.81	0.07	0.93	4.83	3.49
BLCR	55.7	0.84	16.9	7.51	5.97	8.11	1.52	3.51
JB-1	52.1	1.34	14.5	9.04	7.70	9.21	1.42	2.79
GSP-1	67.4	0.66	15.3	4.33	0.96	2.02	5.53	2.80
AGV-1	59.0	1.04	17.3	6.76	1.53	4.90	2.89	4.26
F-3	64.8	0.84	20.7	6.36	-	0.22	2.63	-
G-2	69.1	0.50	15.4	2.65	0.76	1.94	4.51	4.07
JG-1	72.2	0.26	14.2	2.21	0.73	2.18	3.96	3.39
HI-31	58.8	0.88	16.7	6.47	4.21	6.50	2.88	3.11
W-1	52.6	1.07	15.0	11.1	6.62	11.0	0.64	2.15
BR	38.2	2.60	10.2	12.9	13.3	13.8	1.40	3.05

STD	Mn	Ba	Rb	Sr
BCR-1	-	-	47	330
LOSP	-	-	179	41
BLCR	1080	370	37	234
JB-1	-	400	41	438
GSP-1	331	1300	254	233
AGV-1	763	-	67	657
F-3	-	-	-	-
G-2	260	1870	168	479
JG-1	-	-	186	184
HI-31	-	772	59	684
W-1	1280	160	21	190
BR	-	-	-	-

* - Total iron calculated as Fe2O3.

TABLE 3

ERRORS

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
Ba	25.49	2.04	11.8
Rb	0.82	1.15	7.4
Sr	0.58	0.85	7.25
Mn	17.19	7.39	4.45

S - standard deviation
C - coefficient of variation = S/mean composition x 100
RMS% ERROR - relative error =

TABLE 4

SUMMARY OF CHEMICAL PROCEDURES FOR ANALYSIS OF CARBONATITES

ELEMENT	METHOD	REFERENCE
SiO2	gravimetric	Maxwell, 1968, p. 323 - 332; Jeffery, 1975, p. 35 - 39, 470 - 471
TiO2	colorimetric	Maxwell, 1968, p. 379 - 381; Jeffery, 1975, p. 470 - 471
FeO	titration	Jeffery, 1975, p. 281; Pratt, 1894
CO2	titration	Jeffery,, 1975, p. 64 - 66; Shapiro, 1975; Grimaldi, Shapiro, and Schnepfe, 1966
P205	colorimetric	Jeffery, 1975, p. 382 - 385
LOI	gravimetric	Jeffery, 1972, p. 270
NOTE:	LOI = loss on ignition - CO2	
U308	colorimetric	modified from Yoe, Fritz, and Black, 1953

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

TABLE 5

ATOMIC ABSORPTION INSTRUMENTAL PARAMETERS

ELEMENT	WAVELENGTH	STANDARDS, ppm	FLAME	INSTRUMENT
Al	3100	10 - 200	a-N20	Varian 1250
Fe	2494	2 - 15	a-a	Perkin Elmer 303
Mg	2862	.1 - 2.0	a-a	Perkin Elmer 303
Ca	2122	0.5 - 5	a-a	Perkin Elmer 303
Na	2950	0.5 - 5	a-a	Perkin Elmer 303
K	3838	0.5 - 5	a-a	Perkin Elmer 303
Mn	2805	0.5 - 10	a-a	Perkin Elmer 303
Cr	3584	1 - 10	a-a	Varian 1250
Co	2412	0.5 - 15	a-a	Perkin Elmer 303
Ni	2369	1 - 15	a-a	Perkin Elmer 303
Sr	2350	0.5 - 10	a-a	Perkin Elmer 303
Ba	5542	10 - 50	a-N20	Varian 1250
Li	3394	0.5 - 10	a-a	Perkin Elmer 303
Zn	2152	0.5 - 2.0	a-a	Perkin Elmer 303
Cu	3254	0.5 - 5	a-a	Varian 1250

* - a-N20: acetylene-nitrous oxide flame,
a-a: air-acetylene flame

APPENDIX B

BRIEF PETROLOGIC DESCRIPTIONS OF THE ANALYZED ROCK SAMPLES

SEDIMENTS

Lem 401, Arkose, Lower Unit: a dark-gray, very fine-grained rock with minor foliation (relict bedding). Relict sand grains are very poorly sorted, very fine sand-sized with average roundness and spherecity. Possible graded bedding may exist locally. The rock consists of a fine-grained matrix (probably sericite and quartz, 35-40%), quartz (30-35%), untwinned feldspar (10-15%), green biotite (5-10%), magnetite (<5%), and muscovite (5-10%).

Lem 524, Medium-grained Arkose, Upper Unit: a pinkish-gray to dark-gray, medium-grained rock with strong foliation. Relict sand grains are poorly sorted, fine- to medium-sand size with moderate roundness and variable spherecity. The rock consists of quartz (30-35%), altered plagioclase, An50 (20-25%), a fine-grained matrix (probably sericite, 10-15%), muscovite (10-20%), dark green to brown biotite (partially altered to chlorites, 5-10%), magnetite (5%) and a trace amount of garnet.

Lem 525, Fine-grained Arkose, Upper Unit: a dark-gray, fine-grained rock with strong foliation. Relict sand grains are poorly sorted, fine-sand sized with variable roundness and spherecity. The rock consists of quartz (25-30%), untwinned feldspar (25-30%), fine-grained matrix (probably sericite, 20-25%), biotite (partially altered to chlorite, 15-20%), muscovite (5%), and magnetite (<1%).

Lem 523, Medium-grained Arkose, Upper Unit: a pinkish-gray to dark-gray, fine-grained slightly foliated rock. Relict sand grains are poorly sorted, fine- to medium-sand sized with fair roundness and spherecity. Graded bedding can be detected in thin section. The rock consists of quartz (50-60%), plagioclase, An70 (20-25%), green biotite (10-15%), perthitic K-feldspar (5-10%), magnetite (<5%), and muscovite (<5%).

Lem 526, Subarkose, Upper Unit: a medium-gray, fine-grained, massive rock. Relict sand grains are well-sorted, medium-sand size with good roundness and spherecity. The rock consists of quartz (70-80%), perthitic K-feldspar (5-10%), plagioclase, An20-40 (5-10%), biotite (5-10%), muscovite (5-10%), and magnetite (<5%).

Lem 520, Subarkose, Upper Unit: a pinkish-gray to medium-gray, fine-grained, foliated rock. Relict sand grains are fairly sorted, fine- to medium-sand sized with fair roundness and spherecity. Thin laminations of arkosic to subarkosic lenses can be detected in thin sections. The rock consists of quartz (70-80%), green biotite (5-10%), perthitic K-feldspar (10%), untwinned plagioclase (<5%), muscovite (<5%), and fine-grained matrix (probably sericite, <%5).

MAFIC DIKES

Lem 56, Diabase dike: a porphyritic, greenish-gray, fine-grained unmetamorphosed rock consisting of plagioclase (altered to calcite, (40-45%), hornblende (35-40), biotite (<5%), chlorite (<5%), magnetite (5-10%), and a trace amount of quartz. Ophitic texture is well preserved.

Lem 15 and 521, Mafic dike: a dark-gray to black, very fine-grained, massive rock consisting of green hornblende (35-40%), feldspar, An50 (30-35%), green and brown biotite (partially altered to chlorite, 10-20%), magnetite (5-10%), and a trace amount of quartz. Slight foliation can be detected in thin section.

Lem 407 and 502, Mafic dike: a black, aphanitic rock consisting of green hornblende (40-45%), plagioclase, An50 (40-45%), magnetite (5-10%), brown biotite (partially altered to chlorite, <4%), and a trace amount of quartz. Ophitic texture is preserved. Some of the plagioclase is slightly replaced by carbonate and sericite.

LEMITAR DIORITE/GABBRO

Lem 148, 439, 501, and 503, Diorite/gabbro: a white and black, speckled, coarse-grained rock consisting of dark blue-green hornblende (30-40%), altered plagioclase, An40-55 (30-40%), brown and green biotite (15-20%), magnetite (5%), quartz (<5%), and trace amounts of apatite, sphene, and garnet. Subophitic to ophitic texture is preserved. Fine- and coarse-grained inclusions can be found within the central part of the pluton.

Lem 449, Quartz diorite: a black and white, speckled, medium-grained rock consisting of green hornblende (25-30%), brown and green biotite (25-30%), altered plagioclase, An50 (20-25%), crushed quartz (7-10%), perthitic K-feldspar (5-7%), corroded magnetite (5-7%), and trace amounts of apatite and garnet. The quartz and garnet often form inclusions in the biotite. The K-feldspar is often zoned and altered to sericite. Subophitic texture is preserved.

Lem 532, Fenitized diorite/gabbro: a pink and black, speckled, coarse-grained rock consisting of dark green and brown hornblende (35-40%), altered plagioclase, An5-15 (40-45%), magnetite (2-3%), hematite (1-2%), and quartz (5-10%).

Lem 533, Fenitized diorite/gabbro: a pink and black, speckled, coarse-grained rock consisting of green and brown hornblende (40-45%), plagioclase, An15 (40-45%), perthitic K-feldspar (5-10%), quartz (5-10%), and a trace amount of magnetite and zircon.

GRANITIC ROCKS

Lem 50, Gneissic granite: a pinkish-gray to medium-gray, medium- to coarse-grained, foliated rock. Mortar texture is developed. The rock consists of quartz (30-35%), K-feldspar (25-30%), plagioclase (20-25%), green biotite (10-15%), and hematite (<5%).

Lem 55, Gneissic granite: a pinkish-gray to medium-gray, medium-grained, foliated rock. The rock consists of quartz (30-35%), K-feldspar (25-30%), plagioclase, An60-70 (25-30%), green and brown biotite (partially altered to chlorite, 10-15%), and a trace amount of hematite, magnetite, and disseminated fluorite.

Lem 84, Polvadera Granite: a pale-red and black, medium- to coarse-grained rock consisting of quartz (30-35%), perthitic K-feldspar (30-35%), plagioclase (25-30%), brown biotite (5-10%), and trace amounts of hornblende, garnet, and magnetite. A mortar texture is often preserved.

Lem 511, Polvadera Granite: a moderate orange and black, coarse-grained rock consisting of quartz (30-35%), perthitic K-feldspar (30-35%), plagioclase (25-30%), biotite (partially altered to chlorite, 5-10%), and trace amounts of magnetite and garnet. A submortar texture is preserved.

Lem 447A, Leucogranite: a white and black, coarse-grained rock ~~consisting of equal amounts of quartz, perthitic K-feldspar, and~~ plagioclase, An40, and trace amounts of biotite (<5%) and magnetite (<1%).

Lem 108, Muscovite-biotite granite: a grayish-pink to medium-gray, fine-grained, slightly foliated rock, consisting of quartz (30-35%), perthitic K-feldspar (25-30%), plagioclase, An40 (20-25%), green biotite (10%), muscovite (5%), and magnetite (<3%).

Lem 126, Muscovite-biotite granite: a grayish-pink to light gray, fine-grained, porphyritic rock consisting of plagioclase (30-35%), quartz (25-30%), K-feldspar (20-25%), magnetite (altered to leucoxene, 3-5%), brown biotite (2-3%), muscovite (2-3%), and a trace amount of zircon. Granophyric texture is preserved.

Lem 423, Porphyritic muscovite-biotite granite: a yellowish- to brownish-gray, porphyritic medium-grained rock, consisting of quartz (35-40%), perthitic K-feldspar (25-30%), plagioclase, An40-60 (20-25%), biotite (5-10%), muscovite (5%), and trace amounts of magnetite, hematite, and green hornblende. Granophyric texture is preserved.

Lem 203, Biotite granite: a light-gray, medium-grained, slightly foliated rock, consisting of quartz (25-30%), plagioclase, An50 (30-35%), K-feldspar (25-30%), brown biotite (10%), and magnetite (<5%).

Lem 302, Biotite granite: a grayish-red, medium-grained rock, consisting of perthitic K-feldspar (25-30%), quartz (25-30%), plagioclase, An40 (25-30%), brown biotite (5-10%), and magnetite (5%). Granophyric texture is preserved.

Lem 438, Biotite granite: a medium-gray, medium-grained, biotite-rich rock. This rock consists of plagioclase, An40-50 (45-50%), quartz (20-25%), brown biotite (10-15%), K-feldspar (10-15%), and magnetite and hematite (<2%). This rock was taken near the boundary between the Lemitar diorite/gabbro and the altered facies of the Polvadera Granite.

CARBONATITES

Lem 305, 427a, 427b, and 500, Primary silicocarbonates: medium-grained, gray to brown, porphyritic rock consisting of carbonate matrix (dolomite, calcite 60-80%), apatite (5-10%), opaques (magnetite 5-10%), rock fragments (0-15%), disseminated fluorite (<5%), brown biotite and phlogopite (5-15%), and trace amounts of quartz, feldspar, hematite, and hornblende. Often large rock fragments (1-2 inches in diameter) are trapped in these dikes. These rocks are very heterogeneous, often layered, showing relict crystals replaced by carbonate fluids. Individual crystals are corroded and cracked with carbonate replacement.

Igneous textures, such as absorption, are prevelant. Sovite veins often crosscut phenocrysts and xenoliths. (Samples 427a and 427b come from the same dike, about 5-6 feet apart along strike.)

Lem 506, Replacement silicocarbonatite: layered, medium-grained, gray to brown, porphyritic rock consisting of carbonate matrix (70-75%), magnetite (10-15%), sericite (10-15%), and a trace amount of biotite. Subophitic texture is preserved. Sovite and hematite veinlets crosscut the rock.

Lem 530, Replacement silicocarbonatite: fine-grained, gray, porphyritic rock consisting of carbonate matrix (50-60%), green and brown biotite and chlorite (20-25%), magnetite (10-15%), hematite (5%), quartz (1-2%), and a trace amount of feldspar. Relict subophitic and porphyritic textures are preserved.

Lem 531a and 531b, Ankeritic rauhaugite: a fine-grained, brown rock consisting of coarse carbonate (80-90%), magnetite (2-10%), hematite (5-10%), and a trace amount of biotite and chlorite. (Both samples are from the same dike, about six feet apart along strike.)

DESCRIPTION OF ROCK SAMPLES NOT ANALYSED FOR CHEMISTRY

Lem 3, Quartzite: a pinkish-gray to medium-gray, very fine-grained rock. Relict sand grains are well-sorted, very fine-sand sized with good roundness and spherecity. The rock consists of quartz (>90%), K-feldspar (<5%), plagioclase (<5%), and trace amounts of biotite, magnetite, muscovite, and a fine-grained matrix.

Lem 522, Green chlorite schist: a foliated, grayish olive green, fine-grained, micaeous rock. The rock consists of chlorite and biotite (40-50%), plagioclase, An40-50 (25-30%), quartz (5-10%), and magnetite (5-10%).

APPENDIX C

CHEMICAL ANALYSES*

SEDIMENTS

	Lem 401	Lem 524	Lem 525	Lem 523	Lem 526	Lem 520
SiO2	77.8	69.6	62.0	65.2	76.5	73.8
TiO2	0.54	0.72	0.72	0.75	0.59	0.65
Al2O3	11.1	14.6	18.6	17.3	12.4	13.9
Fe2O3*	4.57	6.09	7.52	6.66	4.42	5.05
MgO	0.94	1.54	1.54	1.38	1.03	1.37
CaO	1.39	1.05	0.20	1.06	2.65	1.39
Na2O	2.45	2.53	1.76	2.83	2.86	2.54
K2O	2.91	4.03	5.63	4.48	2.22	3.79
MnO	0.07	0.08	0.06	0.07	0.08	0.07
TOTAL	101.77	100.24	98.03	99.73	102.75	102.56
Mn	512	600	490	577	592	548
Ba	1172	1140	892	995	1534	1376
Rb	139	203	303	244	164	161
Sr	78	144	87	163	237	162

* - Total iron expressed as Fe2O3.

Oxides expressed in weight %, elements expressed in ppm.

MAFIC DIKES

	Lem 56	Lem 15	Lem 407	Lem 502	Lem 521
SiO2	49.8	47.8	46.9	45.0	48.0
TiO2	1.58	1.77	1.85	1.85	2.38
Al2O3	11.7	12.0	12.1	10.2	11.2
Fe2O3*	14.7	15.9	15.7	20.9	16.9
MgO	5.78	8.00	9.37	6.32	7.31
CaO	9.27	10.0	9.44	4.52	9.69
Na2O	2.28	1.68	2.05	1.75	1.92
K2O	1.58	0.71	0.60	4.37	0.67
MnO	0.26	0.25	0.19	0.35	0.22
TOTAL	96.95	98.11	98.20	95.26	98.29
Mn	2011	1936	1549	2677	1698
Ba	333	334	375	397	341
Rb	45	35	24	119	56
Sr	120	99	122	98	108

CIPW Norms

or	9.3	4.2	3.5	25.8	4.0
ab	19.3	14.2	17.3	14.8	16.2
an	17.1	23.1	22.0	7.1	19.8
di	24.0	21.9	20.4	12.8	23.3
hy	19.7	25.5	14.2	0.1	24.4
ol	-	0.9	13.3	24.2	-
mt	4.9	5.3	5.3	7.0	5.6
il	3.0	3.4	3.5	3.5	4.5
Q	0.3	-	-	-	0.6

or - orthoclase
ab - albite
an - anorthite
c - corundum
di - diopside

il - ilmenite
mt - magnetite
ol - olivine
Q - quartz
hy - hypersthene

LEMITAR DIORITE/GABBRO

	Lem 148	Lem 439	Lem 449	Lem 501	Lem 503
SiO2	51.2	54.5	51.0	59.1	51.0
TiO2	2.88	1.46	2.29	1.17	2.99
Al2O3	11.1	12.1	9.26	11.8	10.6
Fe2O3*	18.2	17.7	21.1	15.9	18.6
MgO	3.08	1.01	2.58	0.98	3.12
CaO	7.63	6.10	7.97	5.34	7.43
Na2O	2.43	2.83	1.73	2.53	2.43
K2O	1.50	1.90	1.50	2.03	1.65
MnO	0.19	0.31	0.33	0.32	0.27
TOTAL	98.21	97.91	97.76	99.17	98.09
Mn	1502	2395	2538	2448	2063
Ba	386	346	404	329	366
Rb	35	55	44	52	49
Sr	176	214	86	185	89

CIPW Norms

Q	6.4	9.7	9.1	17.3	6.2
or	8.9	11.2	8.9	12.0	9.8
ab	20.6	23.9	14.6	21.4	20.6
an	15.0	14.7	13.1	14.7	13.2
di	19.5	13.7	22.8	10.3	20.2
hy	17.4	17.0	18.5	16.7	17.0
mt	6.1	5.9	7.0	5.3	6.2
il	5.5	2.8	4.3	2.2	5.7

LEMITAR DIORITE/GABBRO - continued

	Lem 532	Lem 533
SiO2	54.2	58.9
TiO2	1.17	1.30
Al2O3	11.8	13.1
Fe2O3*	17.0	12.2
MgO	2.94	2.06
CaO	4.30	4.42
Na2O	3.75	3.16
K2O	1.19	2.00
TOTAL	96.35	97.14
Rb	82	41
Sr	745	211

CIPW Norms

Q	8.8	16.6
or	7.0	11.8
ab	31.7	26.7
an	11.9	15.6
di	8.0	5.4
hy	19.77	13.4
mt	5.7	4.1
il	2.2	2.5

GRANITIC ROCKS

	Lem 50	Lem 55	Lem 84	Lem 511	Lem 447A	Lem 108
SiO2	70.1	69.5	73.3	73.8	74.1	73.1
TiO2	0.73	0.85	0.43	0.48	0.50	0.56
Al2O3	12.2	12.1	13.0	13.3	13.8	14.6
Fe2O3*	7.06	9.04	5.00	3.86	3.86	3.57
MgO	0.94	0.91	0.40	0.49	0.60	0.79
CaO	1.90	2.06	1.14	0.93	1.51	0.99
Na2O	3.06	3.01	3.01	3.05	3.89	2.74
K2O	4.17	3.52	5.05	5.35	3.72	4.59
MnO	0.10	0.11	0.09	0.06	0.06	0.06
TOTAL	100.26	101.10	101.42	101.32	102.04	101.00
Mn	806	848	863	445	434	422
Ba	946	686	931	1378	1415	1248
Rb	173	120	194	242	208	191
Sr	105	115	77	78	154	85

CIPW Norms

Q	29.4	30.6	32.0	31.9	32.1	35.5
c	-	-	0.5	0.8	0.7	3.3
or	24.6	20.8	29.8	31.6	22.0	27.1
ab	25.9	25.5	25.5	25.8	32.9	23.2
an	7.2	9.2	5.6	4.6	7.5	4.9
di	1.8	0.9	-	-	-	-
hy	5.5	7.2	4.1	3.3	3.5	3.7
mt	3.8	4.9	2.7	2.1	2.1	1.9
il	1.4	1.6	0.8	0.9	3.0	1.1

GRANITIC ROCKS - continued

	Lem 126	Lem 423	Lem 203	Lem 302	Lem 438
SiO2	74.0	75.6	66.5	70.6	66.9
TiO2	0.44	0.39	0.77	0.94	0.64
Al2O3	13.1	13.2	13.9	13.1	16.0
Fe2O3*	4.52	2.89	6.46	7.39	5.54
MgO	0.22	0.40	1.20	0.66	1.30
CaO	1.38	0.83	1.55	1.62	2.91
Na2O	4.83	2.78	3.86	3.39	3.81
K2O	3.25	5.37	4.10	4.10	3.63
MnO	0.03	0.05	0.10	0.08	0.09
TOTAL	101.77	101.51	98.44	101.88	100.82
Mn	228	349	808	589	693
Ba	1248	1342	892	690	880
Rb	70	244	139	108	174
Sr	68	59	190	107	382

CIPW Norms

Q	29.5	35.8	21.6	28.9	21.3
c	-	1.3	0.3	0.1	-
or	19.2	31.7	24.2	24.2	21.5
ab	40.9	23.5	32.7	28.7	32.2
an	4.5	4.1	7.7	8.0	14.0
di	2.1	-	-	-	0.3
hy	2.1	2.5	6.6	5.6	6.2
mt	2.5	1.5	3.5	4.0	3.0

CARBONATITE DIKES

	Lem 305	Lem 427a	Lem 427b	Lem 500	Lem 506
SiO2	21.45	11.20	11.57	10.89	19.11
TiO2	1.13	0.40	0.13	0.28	0.20
Al2O3	4.32	2.44	2.14	2.61	4.35
Fe2O3	2.75	3.50	3.57	3.73	5.78
FeO	5.44	4.22	4.28	5.27	7.38
MgO	8.92	10.10	9.67	9.53	9.90
CaO	24.5	32.5	30.9	31.6	17.8
Na2O	0.70	0.19	0.19	0.41	1.13
K2O	1.45	0.22	0.47	0.37	2.20
MnO	0.53	0.72	0.67	0.65	0.30
CO2	22.66	29.10	29.01	26.31	18.14
P2O5	3.26	3.72	3.47	3.33	1.05
LOI	4.19	1.46	1.05	3.95	1.47
TOTAL	101.30	99.77	97.12	98.93	88.81

CARBONATITE DIKES - continued

	Lem 530	Lem 531a	Lem 531b
SiO2	27.93	3.20	3.59
TiO2	1.79	<0.10	0.46
Al2O3	5.54	0.51	0.49
Fe2O3	9.58	2.23	3.86
FeO	6.36	12.0	11.51
MgO	3.70	7.64	6.47
CaO	17.5	30.2	27.1
Na2O	0.02	0.01	0.01
K2O	0.83	0.10	0.10
MnO	0.40	0.47	0.49
CO2	17.40	36.65	34.85
P2O5	1.59	0.06	0.07
LOI	3.47	4.67	4.11
TOTAL	96.11	97.84	93.11

LOI - Loss on ignition - CO2; includes H2O, F, Cl, and other volatiles.

NOTE: See Appendix A for analytical procedures.

CARBONATITE DIKES - continued

	Lem 305	Lem 427a	Lem 427b	Lem 500	Lem 506
Mn	410	560	520	500	230
Cr	20	10	24	10	64
Co	42	38	30	34	31
Ni	51	33	60	31	183
Sr	244	298	322	323	534
Ba	1262	1170	1516	1226	3200
Li	84	18	20	20	61
Zn	158	116	133	125	154
Cu	20	10	9.8	13	100
U	7.2	10.3	5.9	11.2	13.4
U308%	0.0023	0.0033	0.0019	0.0036	0.0045

CARBONATITE DIKES - continued

	Lem 530	Lem 531a	Lem 531b
Mn	400	470	490
Cr	398	25	5
Co	97	56	52
Ni	390	48	70
Sr	177	136	123
Ba	1779	3658	652
Li	19	7.4	6.5
Zn	397	436	619
Cu	26	24	2.5
U	3.4	5.0	4.4
U308%	0.0011	0.0016	0.0014

This thesis is accepted on behalf of the faculty of the Institute by the following committee:

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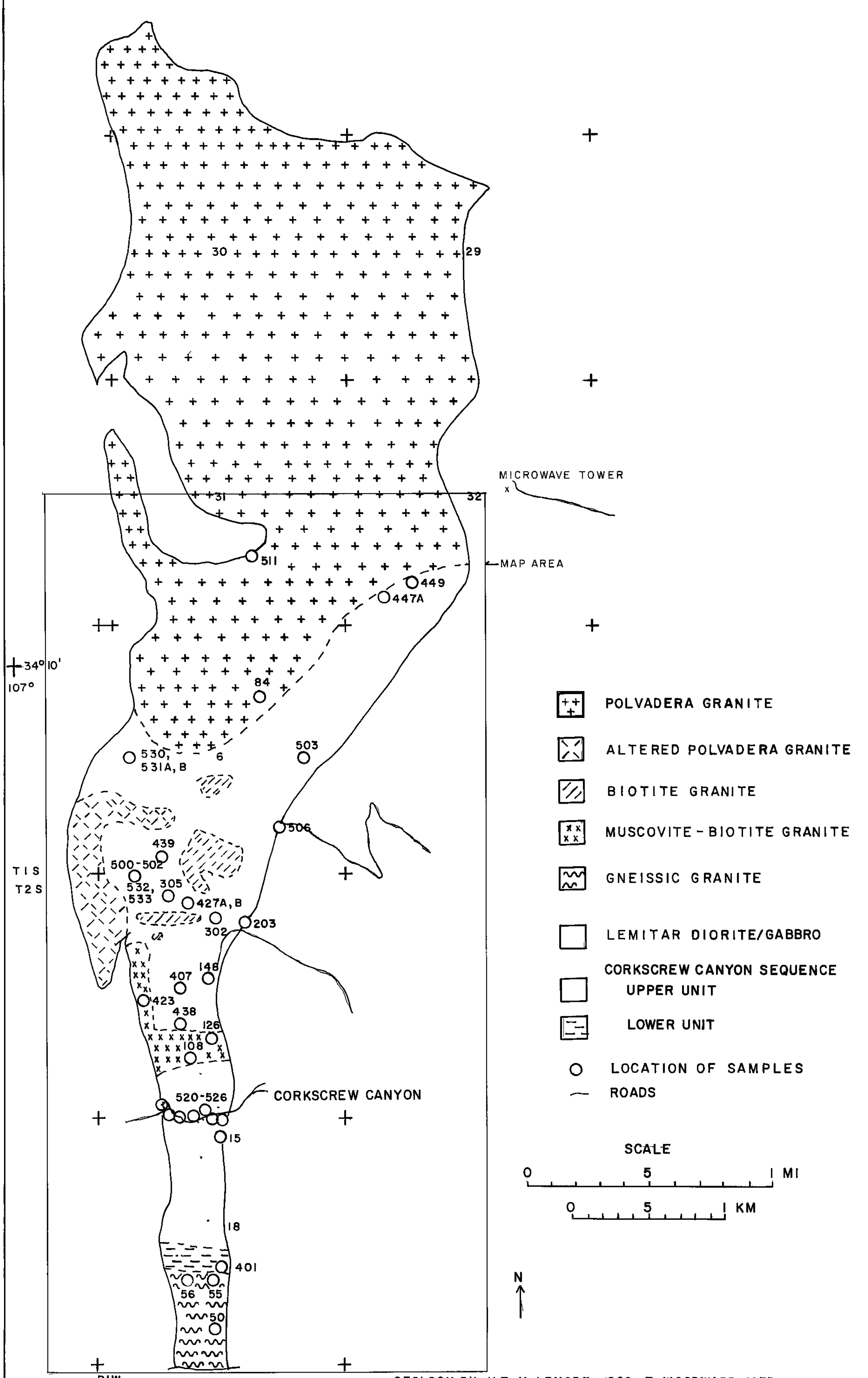
Date May 5, 1980

FIGURE 2- PRECAMBRIAN GEOLOGY OF THE LEMITAR MOUNTAINS



GEOLOGY BY V T McLEMORE, 1980, T WOODWARD, 1973

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PLATE 1

MAP I

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

BY

VIRGINIA T. McLEMORE, 1979

PHANEROZOIC

Qa — ALLUVIUM
STREAM SANDS AND GRAVELS, ALLUVIAL FAN AND TALUS DEPOSITS, PEDIMENT GRAVELS

Tv — VOLCANIC ROCKS
UNDIFFERENTIATED

P — SEDIMENTARY ROCKS
UNDIFFERENTIATED

PROTEROZOIC

C — CARBONATITE DIKES AND VEINS

CARBONATITE STOCKWORK

M — MAFIC DIKES

GRANITIC COMPLEX

gg — GNEISSIC GRAINITE

mbg — MUSCOVITE-BIOTITE GRANITE

bg — BIOTITE GRANITE

lg — LEUCOGRANITE

gr / ag — POLVADERA GRANITE

pg — PEGMATITE AND QUARTZ VEINS AND DIKES

d — LEMITAR STOCK
DIORITE/GABBRO TO QUARTZ DIORITE/QUARTZ GABBRO

CORKSCREW CANYON METASEDIMENTS

ba — LOWER UNIT ARKOSE

cc / q — UPPER UNIT
cc INTERBEDDED ARKOSES, SUBARKOSES, AND QUARTZITES
q QUARTZITES

gs — GREEN SCHIST

EXPLANATION OF MAP SYMBOLS

CONTACT

EXTENT OF OUTCROP

DOWNTHROWN BLOCK

FAULT

BRECCIA ZONE

ZONE OF MIGMITIZATION

30 — STRIKE AND DIP OF FOLIATION

MINE OR SHAFT

PROSPECT PIT

TRENCH OR BULLDOZER CUT

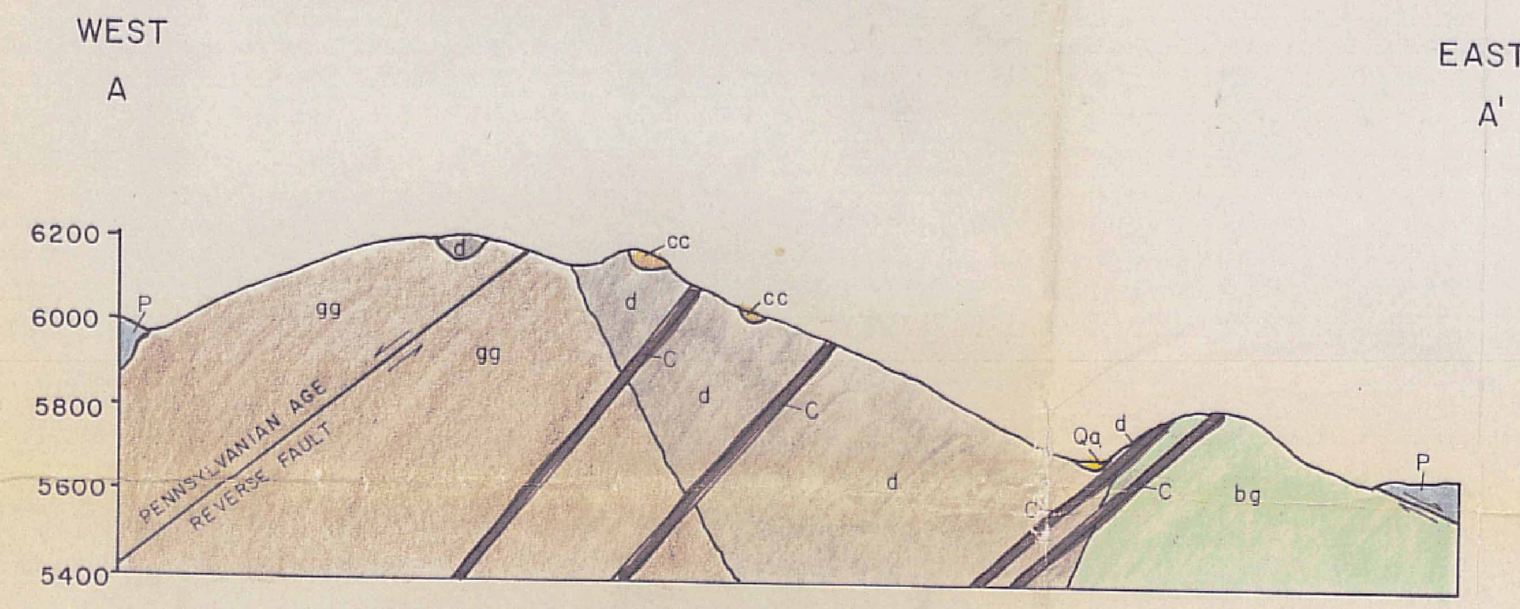
SCALE
1:6000
0 500 1000 FEET
0 1000 2000 3000 METERS

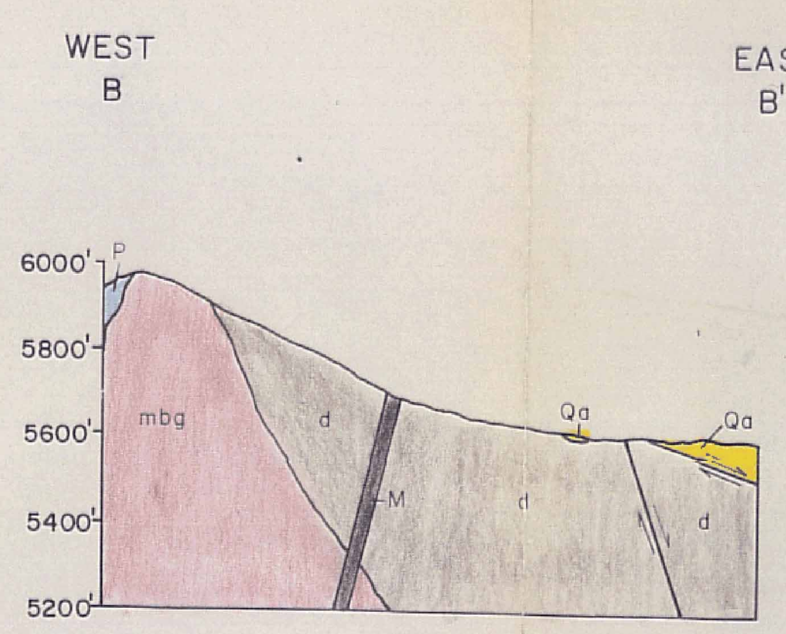
GEOLOGIC CROSS SECTIONS OF THE PRECAMBRAIN ROCKS OF THE LEMITAR MOUNTAINS, SOCORRO COUNTY, N. M.

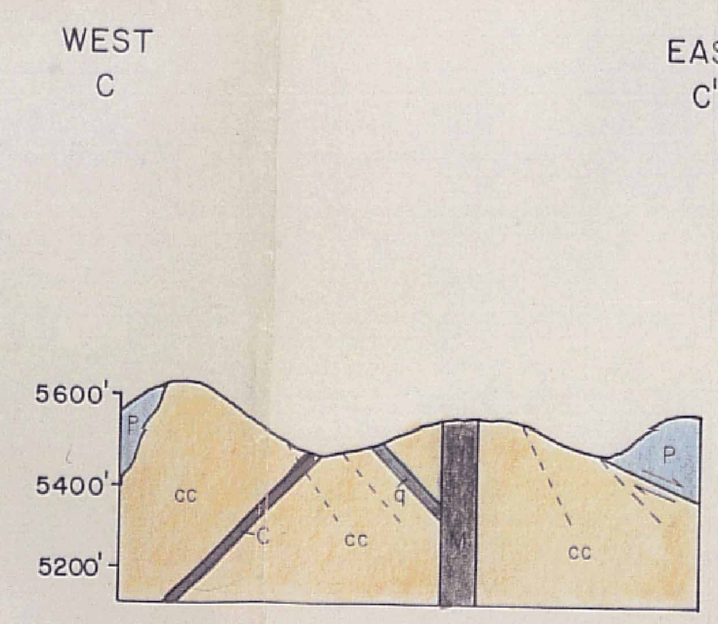
BY

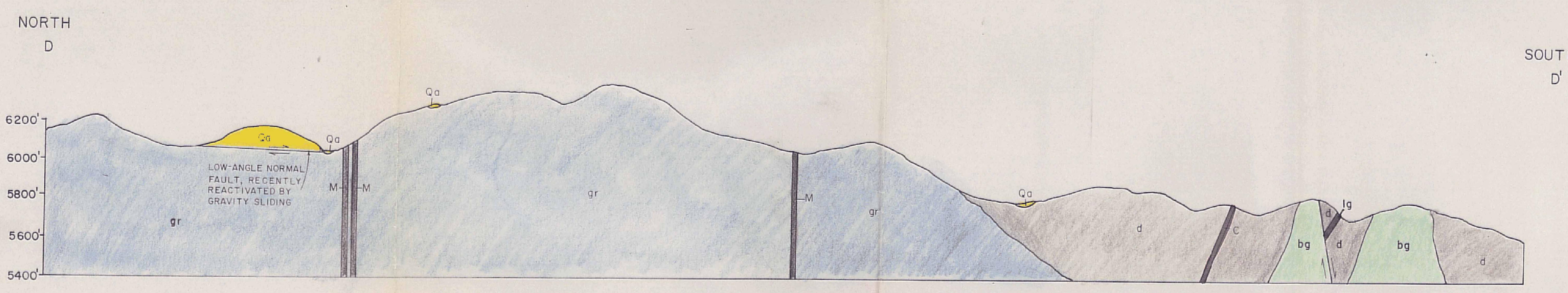
VIRGINIA T. McLEMORE, 1980

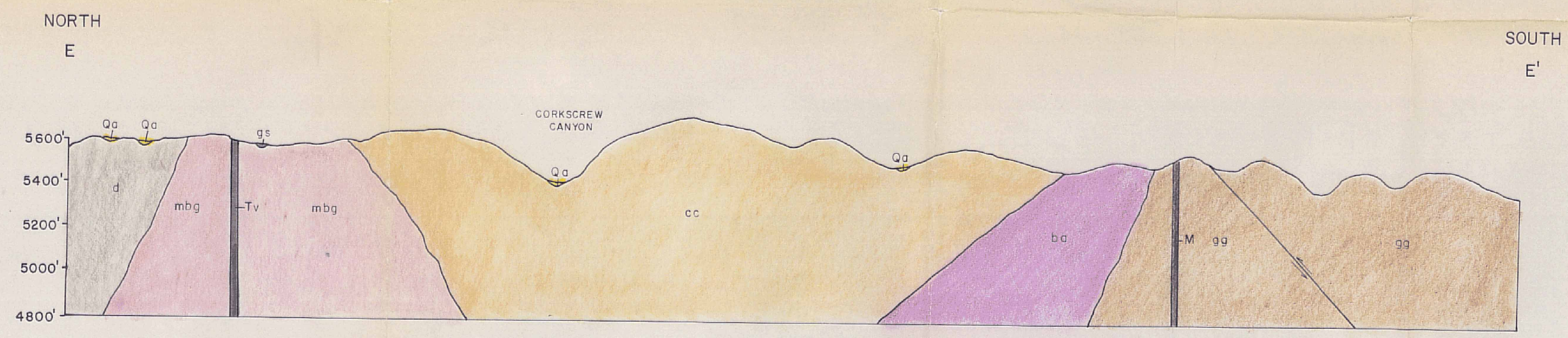
STRUCTURE MODIFIED IN PART AFTER CHAMBERLIN, 1978











HORIZONTAL SCALE

0 500 1000 FEET

0 1000 2000 3000 METERS

SEE MAP I FOR EXPLANATION OF MAP SYMBOLS