THESIS

MINERALOGY AND GEOCHEMISTRY OF CARBONATITES FROM THE GEM PARK COMPLEX, FREMONT AND CUSTER COUNTIES, COLORADO

Submitted by

Ronald Paul Papson

Department of Earth Resources

In partial fulfillment of the requirements

for the Degree of Master of Science

Colorado State University

Fort Collins, Colorado

Summer, 1981

COLORADO STATE UNIVERSITY

Spring, 1981

WE HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER OUR SUPERVISION BY RONALD P. PAPSON ENTITLED MINERALOGY AND GEOCHEMISTRY OF CARBONATITES FROM THE GEM PARK COMPLEX, FREMONT AND CUSTER COUNTIES, COLORADO BE ACCEPTED AS FULFILLING IN PART REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE.

Committee on Graduate Work

Dale R. Winder

Tommy B. Thompson

Larry K. Burns
Adviser

ABSTRACT OF THESIS

MINERALOGY AND GEOCHEMISTRY OF CARBONATITES FROM
THE GEM PARK COMPLEX, FREMONT AND CUSTER COUNTIES, COLORADO

The Gem Park carbonatite complex is located 11 miles northwest of Westcliffe, Colorado and is hosted within Precambrian X metasedimentary gneisses and amphibolites. The complex of Cambrian age gabbros and pyroxenites contains a series of carbonatite dikes and masses. There are two other major carbonatite complexes in the Wet Mountain Valley.

Parker and Sharp (1970) and Armbrustmacher and Brownfield (1978) have surveyed the surface mineralization of the mafic rocks and carbonatites. The present study has dealt with the evaluation of three diamond drill holes in the south central portion of the complex.

A total of 29 samples were analyzed for mineralogic content, and geochemical analyses were performed. Results have been used to determine a rough paragenetic sequence for the development of the carbonatites.

Dolomitic carbonatites, with a wide range of iron contents, form the earliest stage of carbonatite development. Apatite, magnetite, and phlogopite are common constituents with associated pyrochlore and zircon. Later dikes contain strontianite, barite, celestite, dolomite, and calcite with associated monazite, ancylite, bastnasite, and low albite. Lamprophyllite has been identified as an alteration of phlogopite.

The total rare earth content in the samples studied ranges from 121 ppm to 757,000 ppm with an average of 13,700 ppm. Niobium ranges from 10 ppm to 7,000 ppm with an average of 740 ppm. Average thorium and uranium contents are 104 ppm and 18 ppm, respectively, with ranges from 2.0 ppm to 590 ppm and 0.2 ppm to 131 ppm.

Geochemical analyses indicate that the intercepts studied are enriched in the elements Cu, Sr, Ga, P, Co, Sc, and rare earth elements (REE) and depleted in Mo, Ti, Si, Al, Nb, Zr, and K as compared to the average values for carbonatites (Gold, 1963). These results do not necessarily represent the entire complex; the cores studied were chosen for their varied mineralogy and carbonatite occurrences.

Ronald Paul Papson
Earth Resources Department
Colorado State University
Fort Collins, Colorado 80523
Spring, 1981

ACKNOWLEDGMENTS

I extend many thanks to all those people who helped me get through this ordeal: Lary K. Burns, Tommy B. Thompson, and Dale Winder have been extremely helpful with their review and comments on the first draft. Ted Armbrustmacher proposed the project and, in conjunction with the U.S. Geological Survey, prepared thin sections and conducted the geochemical analyses. Dolf Fieldman and Pat Crowley of CoCa Mines (Congden and Carey Corporation) provided much needed guidance and financial assistance both in the field and during the study of the cores.

A special thanks goes to Beverly Klein for her extreme patience in typing the manuscript and tables and for plowing through my handwriting.

My most sincere thanks goes to my wife Amy, for her constant support and reassurance during the entire process. Our dog Bridgette has spent many long hours of neglect while waiting for an exciting hike which rarely came. Our new friends Max, Lady, and Sy have been extremely good friends in our new home in Oregon.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES (Continued)

INTRODUCTION

The term "carbonatite" was first proposed by Brögger in 1921 to encompass a series of carbonate-rich and silicate-carbonate rocks which he believed to be igneous in origin. Brögger, and other early workers, proposed the idea of a carbonate magma, but believed that the extreme amounts of carbon dioxide present were a result of limestone assimilation by a silicate magma. Daly (1933) in his studies of the Premier Mine, agreed that carbonatites were truly magmatic but suggested that the carbonates were derived from the "Great Dolomite" at depth. Larsen (1942) and others have suggested an hydrothermal origin for carbonatites, their mineralogy a result of "leaching" from surrounding country rocks with subsequent precipitation in fractures and open spaces. A review of carbonatite occurrences by Pecora (1956) led him to the conclusion that "a carbonate magma...is less likely to exist than carbonate-rich solutions...at elevated temperature and pressure." These solutions are derived from alkalic magmas during the process of silicate crystallization. Most authors agree that carbonatites form a unique and unusual group of rocks from both their petrogenic associations and their economic concentrations of rare metals.

According to Gold (1963) "carbonatites may be distinguished mineralogically by their high carbonate content and peculiar accessory minerals; geochemically by an abnormal concentration of P, Ba, Sr, Nb, and the rare earth elements." Additionally, concentrations of Th, U, Cu, Fe, Al, and F have been found. Their distribution and concentrations make them an important source for the rare elements and have been studied by Balashov and Pozharitskaya (1968) and Samoylov and Razvozzhayena (1972). Mineralization as a function of "stage" of carbonatite development is presented in Table 1 (Kapustin, 1966). Generally, the early carbonatites concentrate Nb, Ta, Zr, and Ti, with the late carbonatites concentrating REE, Sr, Ba, and the chalcophile elements.

This study was initiated to 1) determine the subsurface mineralogy of the Gem Park carbonatites; 2) determine mineral paragenesis and stages of carbonatite development with the complex; and 3) determine which stage or mineral assemblages may prove favorable for economic concentrations of niobium, rare earth elements, thorium, and to lesser amounts of uranium, lead, and zinc. Three diamond drill holes were chosen so as to intercept the widest possible range of carbonatite occurrences in the Gem Park Complex.

EARLY				LATE				
Unaltered		Dolomitized		Calcitic	Ankerite-dolomitic			Zeolite-calcitic
First stage	Second stage	First stage	Second stage		First stage	Second stage	Third stage	
		Calcite	Dolomite	Calcite	Ankerite-Dolomite		Calcite	Calcite
Diopside		Clinohumite	Actinolite-	Phlogopite	Vermiculite	Chlorite,Qtz,Sericite		Natrolite
Forsterite		Oxyphlogopite	Tremolite	Orthoclase	Serpentine	Orthoclase	Riebeckite	Mesolite
Biotite	Monticellite		Brucite	Chalcopyrite	Sphalerite	Galena	Hematite	Hisingerite
Phlogopite		Pyrrhotite		Pyrrhotite	Molybdenite	Tetrahedrite	Anglesite	Marcasite
(green)	(brown)	Pentlandite		Cerite/Thorite	Millerite	Jamesonite	Stilpnome-	Pyrite
Magnetite		Apatite		Burbankite	Pyrite	Bournonite	lane	Rhabdophane
Apatite		Pyrochlore-2		Norsethite	Podolite		Fluorite	Ancylite
Sphene	Hatchettolite	Niobozircono-	Calzirtite	Alstonite	Columbite	Boulangerite		Catapleite
Dysanalyte	Pyrochlore-1	lite	Ilmenite	Barytocalcite,	Carbocernaite,	Pyrochlore-3	Bastnasite	Vinogradovite
Lueshite	Baddeleyite		Zircon	wadeite	brookite	Aeschynite	Parisite	Niobolbunt-
								sovite
(niocalite)	Lavenite							
Zr-garnet	Thorianite			Labuntsovite	Strontiobarite,	Barite	Bastnasite	
Eudialyte				Calkinsite	brookite	Strontianite	Celestite	Ramsayite
				Natrofair-	Anatase, ilmen-			Isokite
				childite	orutile			

Table 1. Mineralogical composition of carbonatites - early to late stage (after Kapustin, 1966).

REGIONAL GEOLOGY

The Gem Park Complex is located in the Wet Mountain Valley (Fig. 1) on the DeWesse Plateau and is situated along a north to northwest trending belt of synclinal intermontane basins which include North Park, Middle Park, South Park, the Wet Mountain Valley, and the Raton Basin (Chapin and Epis, 1964). To the east, the valley is bordered by the Ilse fault which trends north-northwest. To the west, the high angle Westcliffe fault and the Texas Creek fault separate this area from the Sangre de Cristo Mountains which consist of highly folded Paleozoic sediments and several small Tertiary intrusives. The area is probably floored by Precambrian granite and metasediments with later Tertiary intrusives. This sequence is covered by a relatively thin veneer of alluvium derived from the bordering ranges (Munger, 1965). Rosita, Querida, and Silver Cliff areas contain vein gold, silver, lead, zinc, and copper associated with the Tertiary volcanic rocks.

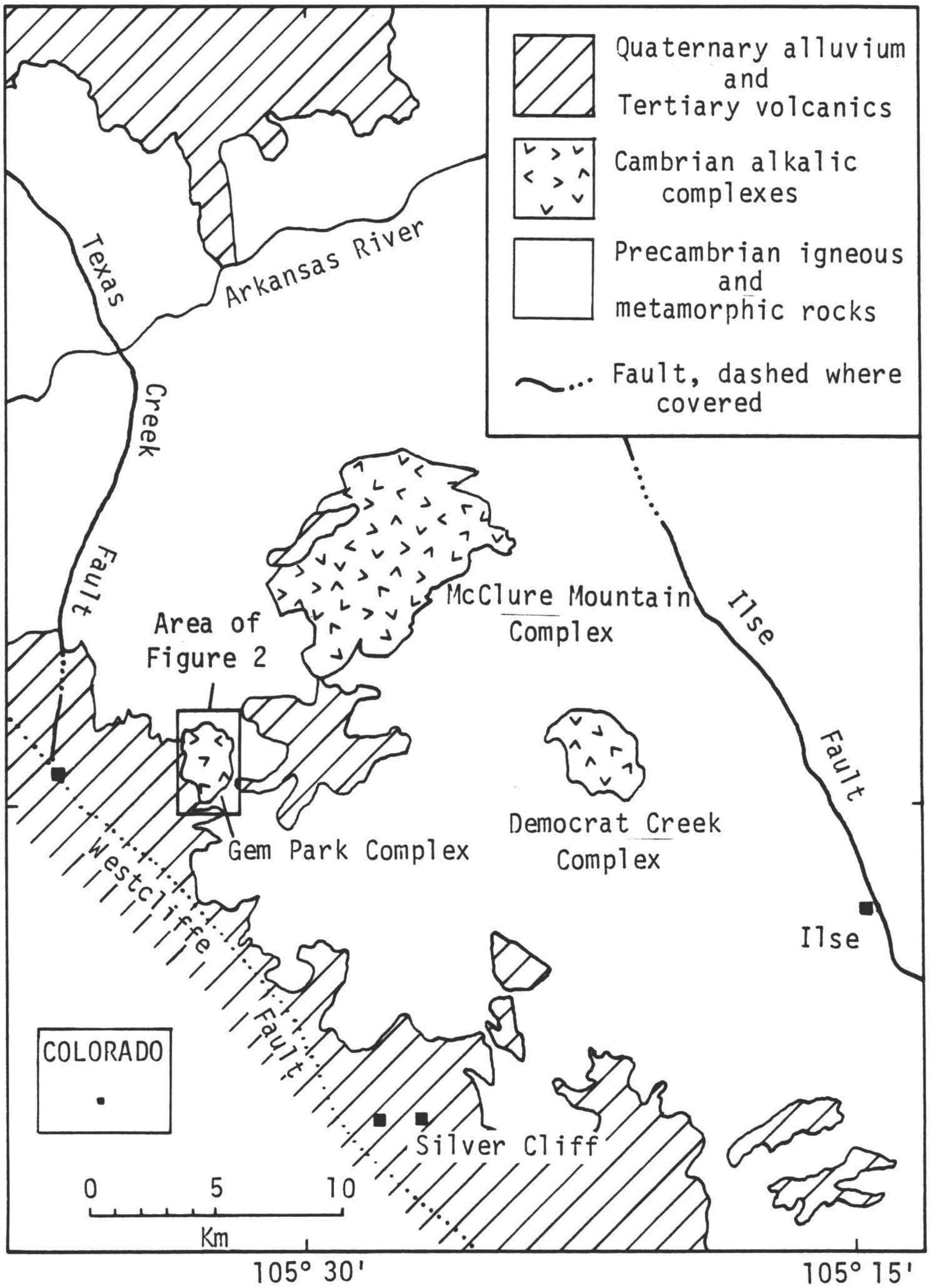


Figure 1. Regional geologic setting of the Gem Park, McClure Mountain, and Democrat Creek carbonatite complexes (after Scott et. al., 1976).

GEOLOGY OF THE GEM PARK COMPLEX

The Gem Park, Democrat Creek, and McClure Mountain-Iron Mountain complexes (Fig. 1) form the major alkalic igneous intrusive rocks of the Wet Mountain Valley. The province covers an area of approximately 400 square miles and contains numerous additional carbonatite dikes and occurrences. Geologic relationships between these igneous intrusives, and two radiometric age determinations, suggests an early Cambrian age for emplacement of these rocks. Potassium-argon ages for the syenite at the McClure Mountain complex yield a range in age of 508 (±15) to 532 (±27) million years before present. A less precise date for a crocidolite sample in the Vermiculite Mine at Gem Park yields an age of 551 (±55) million years before present (Parker and Sharp, 1970).

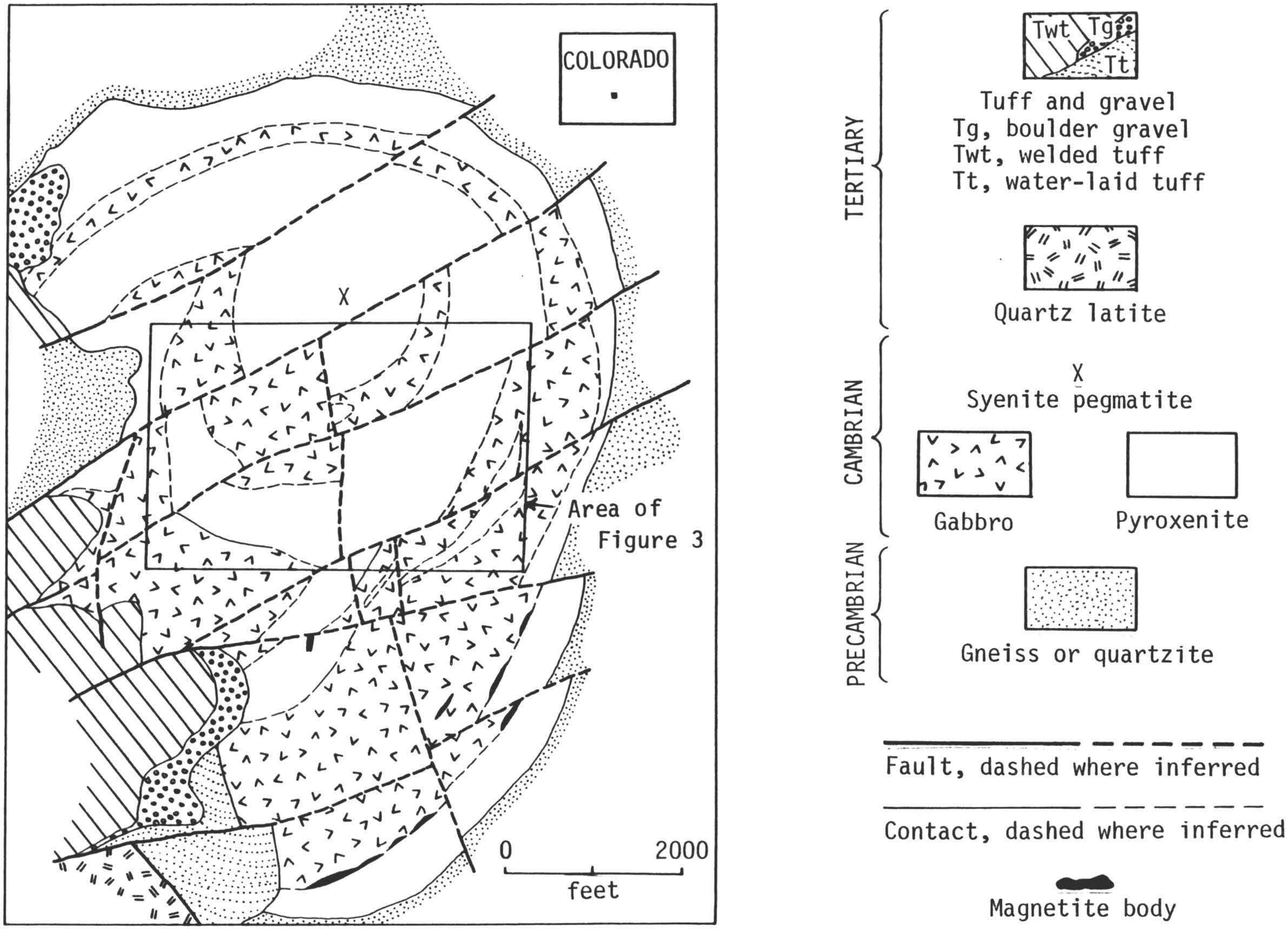
All alkalic igneous rocks in the Wet Mountain Valley intrude Precambrian X (1400 million years) metasedimentary rocks. These metamorphic rocks consist of layered gneisses, chiefly feldspathic biotite-quartz-plagioclase gneiss containing minor amounts of hornblende gneiss, calc-silicate gneisses, and garnetiferous and sillimanitic varities (Taylor et al., 1975). Quartzo-feldspathic gneisses, younger than the metasediments, occur along foliation of the metasediments, possibly the result of granitization of favorable layers (Christman et al., 1959).

The country rock near Gem Park consists primarily of gneissic granite with lesser amounts of quartzo-feldspathic gneiss, amphibolite, and hornblende gneiss (Parker and Sharp, 1970). Inclusions of these rocks are found in a few places within the complex, some of which have been partially assimilated and altered to a gabbroic composition.

Cambrian intrusive rocks dominate the Gem Park complex. Pyroxenite and gabbro form faulted concentric bands roughly ellipsoidal in outline (Fig. 2). The pyroxenite forms both coarse and medium grained varieties dominantly composed of clinopyroxene with small amounts of brown and green amphibole, minor labradorite, and accessory magnetite, apatite, and rare sphene. The gabbro consists primarily of labradorite, clinopyroxene, olivine, brown amphibole, and magnetite (Parker and Sharp, 1970). A number of magnetite lenses can be found along favorable structures within the complex. A megascopic examination of these two rock types during the present study indicate that much of the gabbro is foliated or layered with weak to strong orientation of labradorite laths in a pyroxene and magnetite matrix. The pyroxenite shows no foliation and is composed dominantly of pyroxene and magnetite. The contact between pyroxenite and gabbro is gradational and often indistinct. The contact is characterized by a gradual decrease of plagioclase content from the gabbro to the pyroxenite end members. The pyroxenite also tends to be closely associated with the larger masses or dikes of carbonatite in one drill hole.

The pyroxenite and gabbro have been subsequently intruded by irregular lamprophyre, syenite porphyry, carbonatite dikes, and a minor nepheline syenite pegmatite. The nepheline syenite is a coarsely crystalline mesh of perthite, interstitial nepheline, and dark green pyroxene crystals. The lamprophyres are classified as spessartite and are composed of tabular sodic plagioclase with

Figure 2. Generalized geologic map of the Gem Park Complex (after Parker and Sharp, 1970).


COLORADO
X
Area of
Figure 3
0
2000
feet
Twt
Tg
Tt
Tuff and gravel
Tg, boulder gravel
Twt, welded tuff
Tt, water-laid tuff
TERTIARY
Quartz latite
X
Syenite pegmatite
CAMBRIAN
Gabbro
Pyroxenite
PRECAMBRIAN
Gneiss or quartzite
Fault, dashed where inferred
Contact, dashed where inferred
Magnetite body

abundant clinopyroxene, magnetite, brown amphibole, carbonate, and chlorite. The syenite porphyry is light orange and consists of sodium-potassium feldspar phenocrysts in a matrix of smaller similar crystals, all heavily turbid with hematite dust. Clots of green or blue fibrous amphibole are scattered throughout (Parker and Sharp, 1970).

Parker and Sharp separate the carbonatite dikes into four categories based on their mineralogy. The dolomite-pyrochlore dikes, the most abundant and widespread dikes at Gem Park, are composed of white to cream colored dolomite with minor barite and disseminated amber grains of pyrochlore. The dolomite-apatite dikes are similar to those above but contain irregular masses of light green, rare earth-bearing apatite. The dolomite-blue amphibole-pyrochlore dikes contain fibrous blue crocidolite, small grains of amber pyrochlore, and sparse ancylite. This type is commonly sheared with lenses of apatite "drawn out" in a planar direction. The dolomite-barite-monazite dikes contain dolomite with finer red brown concentrations of dolomite, barite, monazite, apatite, ancylite, strontianite, and calcite. Many of the carbonatite dikes intrude and cross cut the Precambrian country rock in portions of the complex.

The difficulties with applying a mineralogical classification to the carbonatites becomes apparent when trying to classify other carbonatites in the Wet Mountain Valley. Armbrustmacher (1979) has classified the Wet Mountain carbonatites into replacement and primary magmatic types. Replacement carbonatites exhibit textures of original rocks which have been pseudomorphously replaced by carbonate minerals and retain the trace element signature of the original rock types.

The primary magmatic types do not show replacement textures and are enriched in elements that are characteristic of carbonatites in greater amounts than the replacement types. The Gem Park system is dominated by the primary magmatic types in this classification.

Fenitization of carbonatite host rocks has been observed at Gem Park. The most extensive fenite occurs in an oval area approximately 1,500 feet long in the central part of the complex. The production of vermiculite from the Vermiculite Mine is a result of the fenitization of pyroxenite and gabbro. This study also indicates that fenitization is a common alteration, to varying intensities, around most of the carbonatite dikes.

Tertiary volcanic rocks overlie the complex on the western edges. From oldest to youngest the units include a porphyritic quartz latite flow, ashy water-laid tuffs, boulder gravel, and welded tuff. The welded tuff is rhyolitic and compact and has been correlated with Ash Flow 7 unit of the Thirty-nine Mile volcanic field (Chapin and Epis, 1964). This tuff in the Wet Mountain Valley, about two miles west of Gem Park, has been dated at 33.6 (±1.1) million years before present (MacNish, 1966).

Except for sparse bedrock outcrops, Gem Park is covered with alluvium and colluvium to a maximum thickness of about ten feet.

The paragenetic rock sequence, as proposed by Heinrich (1966), for the alkalic rocks of the Wet Mountain Valley is mafic-ultramafic series, syenite, nepheline syenite, lamprophyre, and carbonatites. Armbrustmacher et al. (1979), however, site an example of a carbonatite dike cut by lamprophyre at the McClure Mountain complex, suggesting a more complex paragenesis and intrusive sequence.

SCOPE OF PRESENT STUDY

The carbonatites of the Gem Park Complex were studied at depth by evaluation of cores from three diamond drill holes. Core from Gem Park is stored in Silver Cliff, Colorado by Congdon and Carey Company of Denver. Thirty-nine holes have been drilled with tens of thousands of core feet available for study from different parts of the complex.

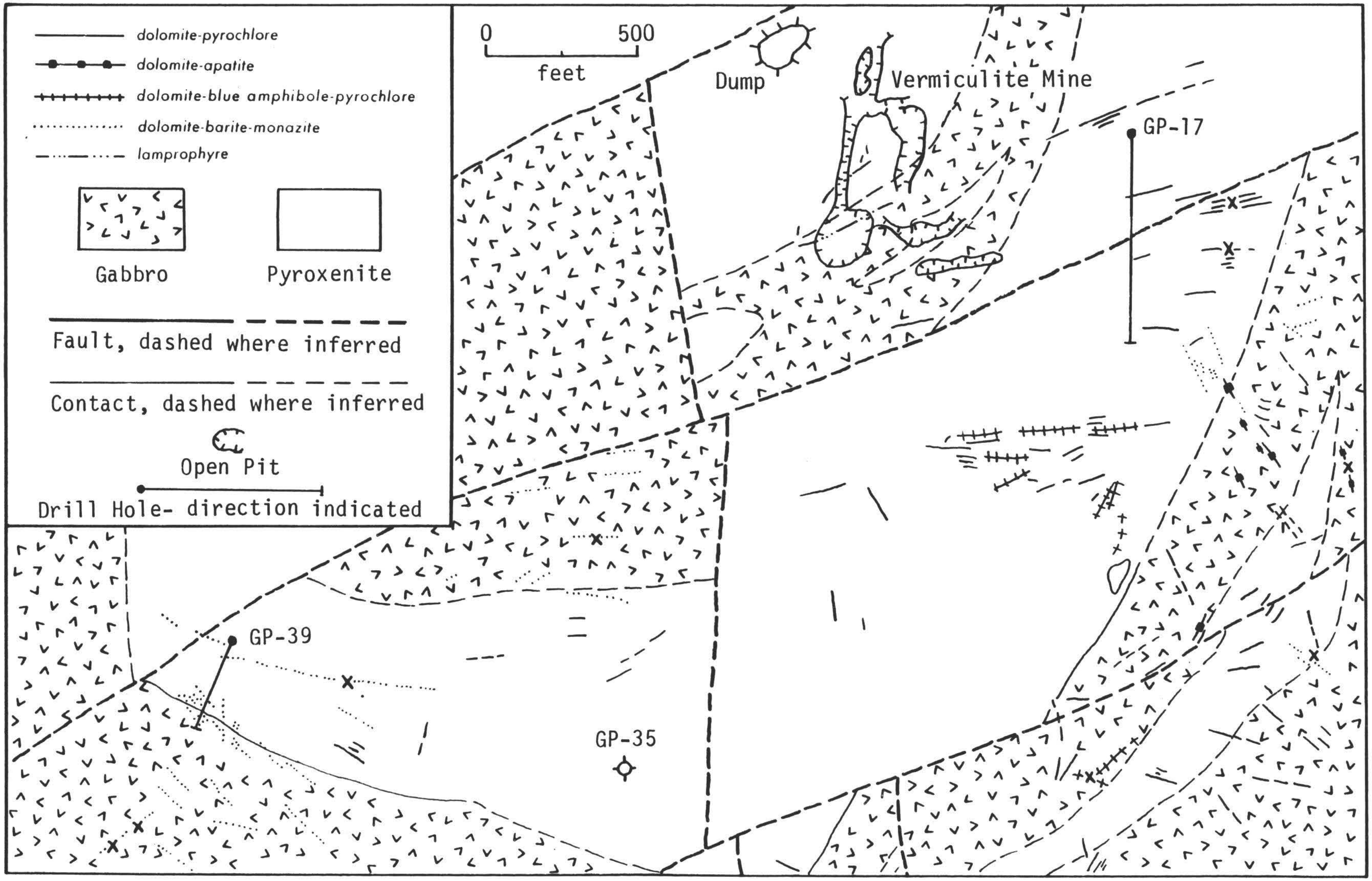
This study concentrated on three cores from the south-central portion of the complex (Fig. 3). Holes GP-17 and GP-39 are angle holes of length 400 and 600 feet, respectively. Hole GP-35 is a vertical hole with a total depth of 1,470 feet. Details of logging appear in Appendix A.

Samples were taken for geochemical analysis and thin section preparation at areas of interest. Along length, scintillometer measurements were recorded at areas significantly above background levels.

Hole GP-39 is completely hosted within gabbro; the upper section is pegmatitic in character, and the lower section is often layered or foliated. Carbonatite dikes in the cored interval contain abundant rare earth minerals, dominantly monazite, and give the dikes a reddish color. The major dikes occur near the upper part of the section; however, numerous small dikes are scattered throughout the core. The lower part of the core has a large interval of intruded lamprophyre which was subsequently intruded by carbonatite dikes.

Hole GP-17 cuts many carbonatite dikes throughout the section and massive intercepts in the lower section. The carbonatites show

Figure 3. Enlarged geologic map of the area near the Vermiculite Mine indicating location and orientation of drill holes studied. Surface exposures of carbonatite dikes are shown (after Parker and Sharp, 1970).



dolomite-pyrochlore
dolomite-apatite
dolomite-blue amphibole-pyrochlore
dolomite-barite-monazite
lamprophyre
Gabbro
Pyroxenite
Fault, dashed where inferred
Contact, dashed where inferred
Open Pit
Drill Hole- direction indicated
0
500
feet
Dump
Vermiculite Mine
GP-17
GP-39
GP-35

large areas of coarse grained cream colored dolomite which is often barren of minerals with economic potential. These have been intruded by dikes of blue, grey, or white dolomite with associated green (rare earth?) apatite, phlogopite, and magnetite. These are in turn cut by later dikes which may contain abundant rare earth minerals. This hole contains gabbro as the dominant host, some of which shows good orientation of plagioclase laths. An intrusive lamprophyre dike is noted in the upper section. The more massive carbonatites are closely associated with pyroxenites and this relation implies a similar genetic position.

In hole GP-35, medium- to coarse-grained gabbro is the dominant rock type, with orientation of plagioclase laths in the lower section. Carbonatite dikes are common but scattered throughout the section and generally thin. Dominant mineralization is a white dolomite with varying degrees of red monazite or ancylite. Pyrite is a common mineral throughout the core and concentrations or dikes of coarse biotite and magnetite can occur. There are sections of gabbro, possibly associated with faults, that show an intense fracture pattern with a fine stockwork of gypsum.

The main emphasis of this study was the detailed analysis of 29 polished thin sections from these cores to determine mineralogy and mineral relationships in the carbonatites. Both transmitted and reflected light microscopy were employed, and X-ray diffraction analysis was the key to identification of difficult or rare minerals.

CARBONATITE MINERALOGY

Mineralogically, carbonatites form an extremely heterogeneous group of rocks whose composition ranges from essentially monomineralic to complexly mineralized with numerous episodes of mineral formation. Gem Park is no exception with its highly variable mineralogy and textural relationships.

The extremely fine-grained or completely intergrown nature of many minerals, especially the minor accessory minerals, often prevented adequate determination of optical constants or purification for X-ray analysis. In these instances, the mineral identification is based on the data available and mineral relationships.

Table 2 is a listing of minerals found in this study and an estimate of their frequency of occurrence. The relative abundances given for the rhombohedral carbonates are subject to error due to the difficulty in separating the individual carbonate minerals optically. Modal data for all samples are given in Table 3.

The scale at which mineralogical and textural characteristics are viewed is extremely important. Large scale differences can be seen between drill holes; the large, mineralogically varied masses or dikes of carbonatite in hole GP-17 contrast the dominantly small, dike-like mineralogically consistent intrusions of carbonatite in holes GP-35 and GP-39. Recrystallization and replacement textures are visible only at the microscopic level.

Table 2. Listing of minerals found in the Gem Park core.

E - Essential

C - Common

M - Moderately common

r - rare

vr - very rare

Albite (low)	$NaAlSi_3O_8$	r
Ancylite	$Ce_4Sr_3(CO_3)_7(OH)_4.3H_2O$	vr
Ankerite	$Ca(Fe,Mg)(CO_3)_2$	r
Apatite	$(Ca,Mg,Na,K)_{10}(P,C)O_{4\ 6}(F,OH)_2$	E
Barite	$BaSO_4$	r
Bastnasite	$(Ce,La)FCO_3$	r
Bornite	Cu_5FeS_4	vr
Calcite	$CaCO_3$	M
Celestite	$SrSO_4$	r
Chalcopyrite	$CuFeS_2$	M
Dolomite	$CaMg(CO_3)_2$	E
Edenite	$Ca_2NaMg_5(AlSi_7O_{22})(OH,F)_2$	C
Fluorite	CaF_2	r
Hematite	Fe_2O_3	M
Lamprophyllite	$(Ba,Sr,K)Na(Ti,Fe)TiSi_2(O,OH,F)_9$	r
Magnetite	Fe_3O_4	E
Marcasite	FeS_2	vr
Monazite	$(Ce,La,Y,Th)PO_4$	r
Phlogopite	$KMg_3(AlSi_3O_{10})(OH)_2$	E
Pyrochlore	$(Na,Ca,Ce)_2(Nb,Ti,Ta)(O,OH,F)_7$	C
Pyrite	FeS_2	C
Pyrrhotite	$Fe_{1-X}S$	r
Quartz	SiO_2	vr
Siderite	$FeCO_3$	vr
Sphalerite	ZnS	vr
Strontianite	$SrCO_3$	r
Zircon	$ZrSiO_4$	C

	17-77.5	17-222.4	17-276.1	17-280.5	17-296.5	17-350.5	17-353.4	17-355.8	17-366	17-376.5	17-406.3	17-411.3	17-425.4	17-434.5	17-450	17-499	17-504.3	17-515.9	17-537.5	17-541.2A	17-541.2B	17-570.5
Dolomite	51.2	31.4	51.2	21.5	27.5	51.5	23.3	59.4	39.2	85.7	60.8	23.7	79.9	80.4	26.4	79.0	74.3	39.8	22.0	38.1	28.1	54.2
Apatite	33.7	39.6	19.4	54.5	32.8	39.2	41.0	20.3	39.8	5.9	8.3	42.0	4.4	0.2	44.5	1.1	7.6	10.3	36.9	25.0	50.0	10.1
Fluorite		8.4	0.7					20.3	7.3				0.3	0.2	0.8	0.1	3.7	X		0.6		3.1
Phlogopite (fresh)		15.3		6.8	4.6	2.0			8.1		5.3				24.2		0.2	X	3.2	5.4	8.8	25.0
Phlogopite (altered)			2.8	3.2	15.4		9.3			5.8		20.1	11.8	11.7		4.9	7.1	2.2				
Pyrochlore		2.1		0.4	1.6	0.3	1.7		0.5	0.4				0.4		0.8	0.3	0.3	1.8	1.4	2.8	1.9
Zircon		3.1							X									0.1	0.4	0.3	1.0	
Pyrite	1.3	X	12.7	0.4	X	X	4.0				12.3	0.8	X	1.0		X				12.5	6.5	
Magnetite		X	6.5	8.6	16.9	0.1	20.5		3.3	1.8	6.8	0.7	2.4	0.5	2.3	6.6	3.9	43.7	11.9	8.0	1.2	0.1
Hematite	8.1			4.6	0.2						X	10.5			X	X				X		
Chalcopyrite			X																	X	0.1	
Calcite																						
Bastnasite																						
Monazite																						
Low albite																						
Strontianite																						
Ancylite																						
Others	5.7	0.1	6.7		1.0	6.9	0.2		1.8	0.4	6.5	2.2	1.2	5.6	1.8	7.5	2.9	3.6	23.8	8.7	1.5	5.6
Points Count	1230	1854	1466	1508	1336	1404	1419	1340	1931	1522	1464	1462	1485	1725	1449	1436	1303	1959	1641	1977	2000	1350

Table 3. Modal analyses of 29 Gem Park polished sections.

	39-7	39-80	39-88	39-102	39-117	35-544.7	35-618	35-783.4
Dolomite	22.1	40.9	70.7	76.6	26.6	5.4	39.2	10.3
Apatite		29.3			27.1	13.6	9.9	
Fluorite								
Phlogopite (fresh)						39.8		
Phlogopite (altered)					1.2			
Pyrochlore			3.4					
Zircon								
Pyrite								
Magnetite								
Hematite			4.8	3.2				
Chalcopyrite								
Calcite	59.3				41.8		32.7	25.1
Bastnasite		7.0	5.4	2.6	1.2			6.2
Monazite	13.8		1.4	4.6	2.1	12.1	10.1	0.3
Low albite	4.1	19.7	14.3	11.9				
Strontianite						29.1		28.4
Ancylite								29.7
Others	0.7	3.1		1.1			8.1	
Points Count	1450	1461	1176	1512	1455	1079	1213	1300

Table 3. (Continued)

Rhombohedral Carbonates

Differentiation of species within the rhombohedral carbonate group, using thin section techniques, is extremely difficult. No completely satisfactory staining procedure exists for thin section studies of the carbonates. Three major problems with current techniques are 1) etches and stains tend to destroy polished surfaces making application directly to sections impossible, 2) etches destroy carbonate accessory minerals which are extremely critical in carbonatite studies, and 3) no rigorous study has been conducted to relate color and intensity of resultant stains to chemical composition of the carbonates, grain size factors, porosity, crystal development, valence state of iron in the lattice, etc.

Carbonatite sections from Gem Park were stained by a method modified from Warne (1962). Sections were immersed in a solution of 0.1 g Alizaren Red S and 2.0 g of potassium ferricyanide dissolved in 100 ml of 0.2% hydrochloric acid at room temperature for approximately three minutes. This method proved useful in discriminating between three major groups of carbonates: 1) pure, low Fe dolomites--no stain accepted; 2) high Fe dolomites, ankerite, and siderite--stained blue to varying amounts dependent upon iron content; and 3) calcite--stained brilliant red. Differentiation between members of the second group was not possible.

Calcite

Calcite is rare in the cores studied; in fact, dolomite is the dominant carbonate mineral in this study suite. Calcite is found in hole GP-35 and GP-39 associated with an increase in individual rare earth minerals. It generally forms as a late stage replacement of early formed dolomite and can often be seen veining earlier dolomite crystals (Fig. 4). It is with this introduction of calcite that the rare earth minerals are emplaced or crystallized and corresponds to the late stage zeolitic-calcitic phase in Kapustin's (1966) classification.

Dolomite

A wide compositional range of dolomites occurs at Gem Park from the magnesium end member to members high in total iron content. Staining methods, as previously mentioned, can indicate distinctions between the iron-free dolomites and those which contain iron, but no quantitative results pertaining to iron content were obtained.

A few samples (e.g. 17-222.4 and 17-366.0) show a total lack of iron in the dolomite lattice. All others show iron substitution to varying degrees. X-ray diffraction analysis of some carbonates indicates the presence of the ankerite end member.

Crystal forms of the dolomites vary from the euhedral rhombs to the more common anhedral interlocking mosaic of crystals. The zones of dolomite may be barren or may have other associated minerals, commonly apatite and phlogopite.

There are a few cases in which two or more stages of dolomite crystallization are observable in thin section. The most common distinction is between a turbid, inclusion-rich dolomite and a realtively clean, inclusion-free variety. The turbid inclusions are unidentifiable by optical or X-ray diffraction methods but may be either carbonaceous inclusions or iron-rich alterations such as goethite or limonite. In other instances the different dolomite stages can be observed by characteristic mineral associations or lack thereof. Some stages of dolomite are closely associated with disseminated pyrite. Other stages are recognized by the presence

Figure 4. Calcite vein (stained dark) cutting dolomite and apatite (section GP 39-117, transmitted light, uncrossed polars).

Figure 5. Euhedral hematite crystals randomly oriented within dolomite (section GP 17-280.5, reflected light, uncrossed polars).

Figure 6. Apatite crystals exhibiting fluxion structure (section GP 17-537.5, transmitted light, crossed polars).

Figure 7. Apatite crystals (A) as cavity lining. Dolomite (D) and quartz (Q) are filling material (section GP 17-77.5, transmitted light, uncrossed polars).

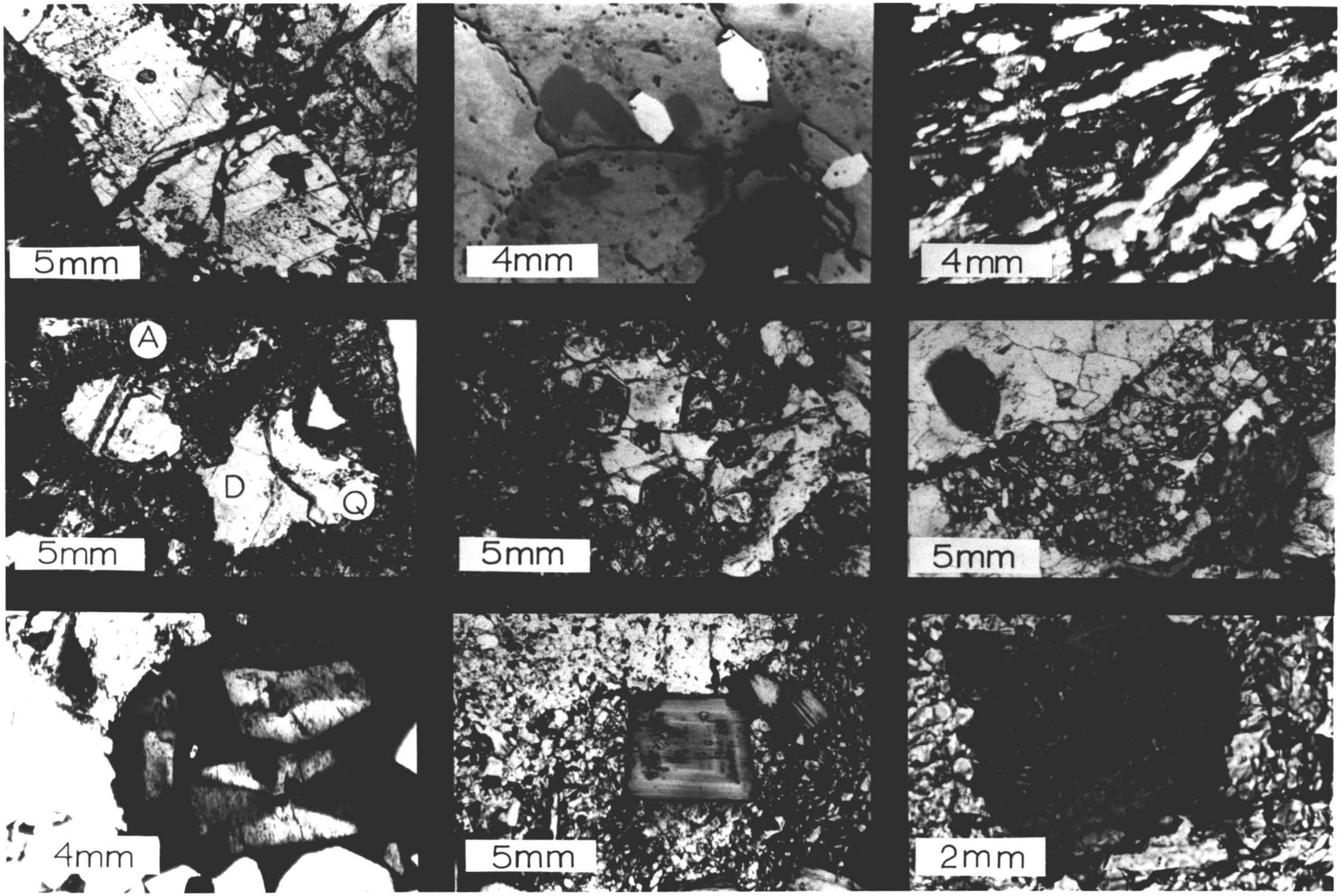
Figure 8. Blocky apatite crystals (dark) within a matrix of dolomite (section GP 17-77.5, transmitted light, uncrossed polars).

Figure 9. A clot of apatite crystallites in a matrix of interlocking dolomite crystals. Sheared phlogopite forms a partial border around the clot (section GP 17-504.8, transmitted light, uncrossed polars).

Figure 10. Sector twinning in blocky francolite (section GP 17-276.1, transmitted light, crossed polars).

Figure 11. Zoned phlogopite in apatite matrix (section GP 17-366, transmitted light, uncrossed polars).

Figure 12. Inclusion rich phlogopite surrounded by apatite (section GP 17-222.4, transmitted light, uncrossed polars).


5mm
4mm
4mm
A
D
Q
5mm
5mm
5mm
4mm
5mm
2mm

of euhedral hematite crystallites (Fig. 5). The subtle differences between dolomite stages may reflect changing fluid chemistry during emplacement of the carbonatite magma.

Siderite

The presence of siderite has not been confirmed optically but only by X-ray analysis of sample 35-783.4. Goethite, probably as an alteration of the siderite, is disseminated throughout the sample.

Overall, the rhombohedral carbonates pose an interesting problem in the development of the Gem Park complex. A detailed sequence of crystallization or replacement events would be of extreme value and more work is needed in the area of carbonate determination by simple methods.

Another important carbonate at Gem Park is strontianite, identified in hole GP-35. Its optical properties are so similar to the rhombohedral carbonates that detection in thin section is difficult. The slightly lower birefringence and small 2V angle for strontianite are not always discernable. Additionally, slightly strained dolomite, common in carbonatite emplacement, would appear nearly identical to strontianite, even possessing a slight 2V angle. The presence of strontianite, however, is indicated by anomalously high Sr values in the geochemical analyses (see Geochemistry chapter).

Apatite

A common mineral, if not an essential mineral, in the Gem Park system is apatite. It takes on a wide variety of crystalline forms and can range from green, pink, blue, to clear in hand specimen. It generally forms as either 1) finely crystalline, massive, randomly oriented aggregates of matted microlites, often exhibiting fluxion structure (Fig. 6); or as 2) blocky subhedral to euhedral crystals associated and intergrown with the carbonates or as cavity linings (Figs. 7 and 8).

The finely crystalline "felty" variety occurs in distinct zones or as dikes of dominantly apatite mineralogy. This apatite is often closely associated with shear zones in the carbonatite and may be a result of breaking and recrystallization of previously formed apatite crystals. Many of these felty clots exhibit weak alignment of crystals or fluxion structure. In some cases the clots appear as segregated islands within a matrix of carbonate minerals (Fig. 9). The felty crystals are often closely associated with phlogopite and magnetite and are generally the colored variety in hand specimen.

The more blocky, equant variety of apatite usually occurs intimately intergrown with the carbonates and often appears to be coprecipitated with them. Their generally good crystalline form and random dispersion within the carbonates indicates a slightly earlier stage for apatite. Many of these apatite areas are indiscernible in hand specimen and are colorless. Some of the crystals appear to be turbid with inclusions, like the turbid carbonates previously mentioned, and may be genetically related.

X-ray analysis of apatite samples indicates that the variety of apatite common to Gem Park is the carbonate fluorapatite-rich francolite $(Ca, Mg, Na, K)_{10} [(P, C) O_4]_6 (F, OH)_2$. Both blocky and felty varieties give similar X-ray diffraction patterns and agree with standard patterns (Table 4) catalogued by the Joint

17-411.3		carbonate-apatite		carbonate fluorapatite	
dÅ	I/I_o	dÅ	I/I_o	dÅ	I/I_o
8.12	16	8.13	18	8.04	18
4.70	4	4.69	4	4.67	2
4.07	20	4.06	10	4.04	16
3.45	40	3.43	16	3.43	20
3.07	36	3.08	25	3.05	35
2.81	80	2.81	80	2.79	55
2.78	19	2.77	25	2.77	16
2.71	100	2.72	100	2.69	100
2.63	12	2.63	12	2.62	8
2.25	38	2.26	35	2.24	45
2.14	5	2.15	6	2.13	4
1.94	18	1.94	16	1.93	12
1.89	6	1.89	8	1.89	8
1.84	16	1.84	12	1.83	10
1.80	16	1.80	16	1.79	12
1.77	27	1.78	12	1.78	25
1.75	6	1.75	8	1.75	8

Table 4. X-ray diffraction analysis of a francolite sample from Gem Park, sample GP 17-411.3, as compared to standard patterns catalogued by the Joint Committee on Powder Diffraction Standards of the American Society for Testing and Materials (JCPDS-ASTM) (Berry, 1974).

Committee on Powder Diffraction Standards of the American Society for Testing and Materials (JCPDS-ASTM) (Berry, 1974).

The crystalline, blocky francolite exhibits well developed sector twinning typical of francolite (Fig. 10) and shows a slight biaxial character. The felty variety shows no such twinning, but the X-ray diffraction pattern is similar. The felty variety may be a result of shearing, reorientation, and possible recrystallization of the original blocky apatite with no chemical changes.

The color of the felty apatite masses may be due to the introduction of rare earth elements into the apatite lattice. Parker and Sharp (1970) give a chemical analysis of a green apatite from Gem Park (Table 5) and Armbrustmacher (1980) suspects that apatite from the Powderhorn carbonatites contain rare earth elements. Although no analyses were made on the apatites in this study, a similar rare earth substitution may occur.

In hole GP-39, finely crystalline apatite appears extremely weathered or altered to a reddish fine grained mass and may be an alteration of a rare earth apatite to an earthy monazite, similar to that reported by Rose et al. (1958).

Phlogopite

Phlogopite in the Gem Park cores is extremely common and occurs in numerous varieties from fresh, unaltered to completely altered and possibly relict grains. The fresh, unaltered variety is distinctive due to its peculiar reverse pleochroism with $\alpha > \beta = \gamma$; α = orange to deep red-orange and $\beta = \gamma$ = green, yellow-green, to light yellow-green. This variety generally occurs in the felty

Element	Content (percent)
Ca	>10
P	>10
Fe	.1
Mg	.2
Mn	.07
Si	.02
Al	.02
Na	.3
F	.23
Ba	.007
Pb	.001
Cu	.0001
Sr	2
La	.3
Ce	.7
Nd	.5
Sm	.1
Dy	.03
Eu	.015
Ho	.003
Yb	.002
Gd	.03
Y	.07

Table 5. Semiquantitative spectrographic analysis of green rare earth apatite from the Gem Park Complex (Harriet Neiman, analyst, Lab. No. D130116).

apatite zones but is not solely restricted here. It is commonly growth zoned in concentric rectangular bands (Fig. 11), alternating between orange and white. This zoning is most distinctive with a crystallographic orientation such that the basal cleavages are prominent. Generally, the fresh phlogopite is full of inclusions (Fig. 12) which are possibly small needles of apatite or rutile randomly oriented in the phlogopite lattice.

The fresh phlogopite can grade into a slightly more altered variety, especially near contact zones with the carbonates (Fig. 13). This phlogopite shows slightly expanded micaceous layers along the "c" crystallographic direction and exhibits a slight loss of pleochroism. The micaceous phlogopite structure becomes contorted or bent along the "c" direction. Often, the inclusions within the lattice or inclusion rich cores alter to a nondescript mass.

Phlogopite within the carbonate zones is highly altered, commonly with a complete loss of pleochroism and highly contorted and expanded crystal structures (Fig. 14). The curvilinear nature of this alteration can become so intense that a "vermicular" texture will dominate (Fig. 15), especially in the smaller crystals.

The phlogopite seems to be prone to shearing effects due to emplacement or post-emplacement movements. Many crystals become extended or sheared until the micaceous structure is no longer observable. Slippage along basal cleavages in phlogopite may make areas rich in this mineral highly susceptible to stress. Many "sheared" apatite zones contain abundant stringers of an unidentified material in a subparallel arrangement that could be a fine grained phlogopite.

Figure 13. Phlogopite with partially expanded micaceous layers (section GP 17-296.5, transmitted light, uncrossed polars).

Figure 14. Phlogopite with expanded micaceous layers in dolomite (section GP 17-366, transmitted light, uncrossed polars).

Figure 15. Vermicular texture of phlogopite (section GP 17-406.3, transmitted light, uncrossed polars).

Figure 16. Replacement of phlogopite by lamprophyllite (section GP 17-276.1, transmitted light, uncrossed polars).

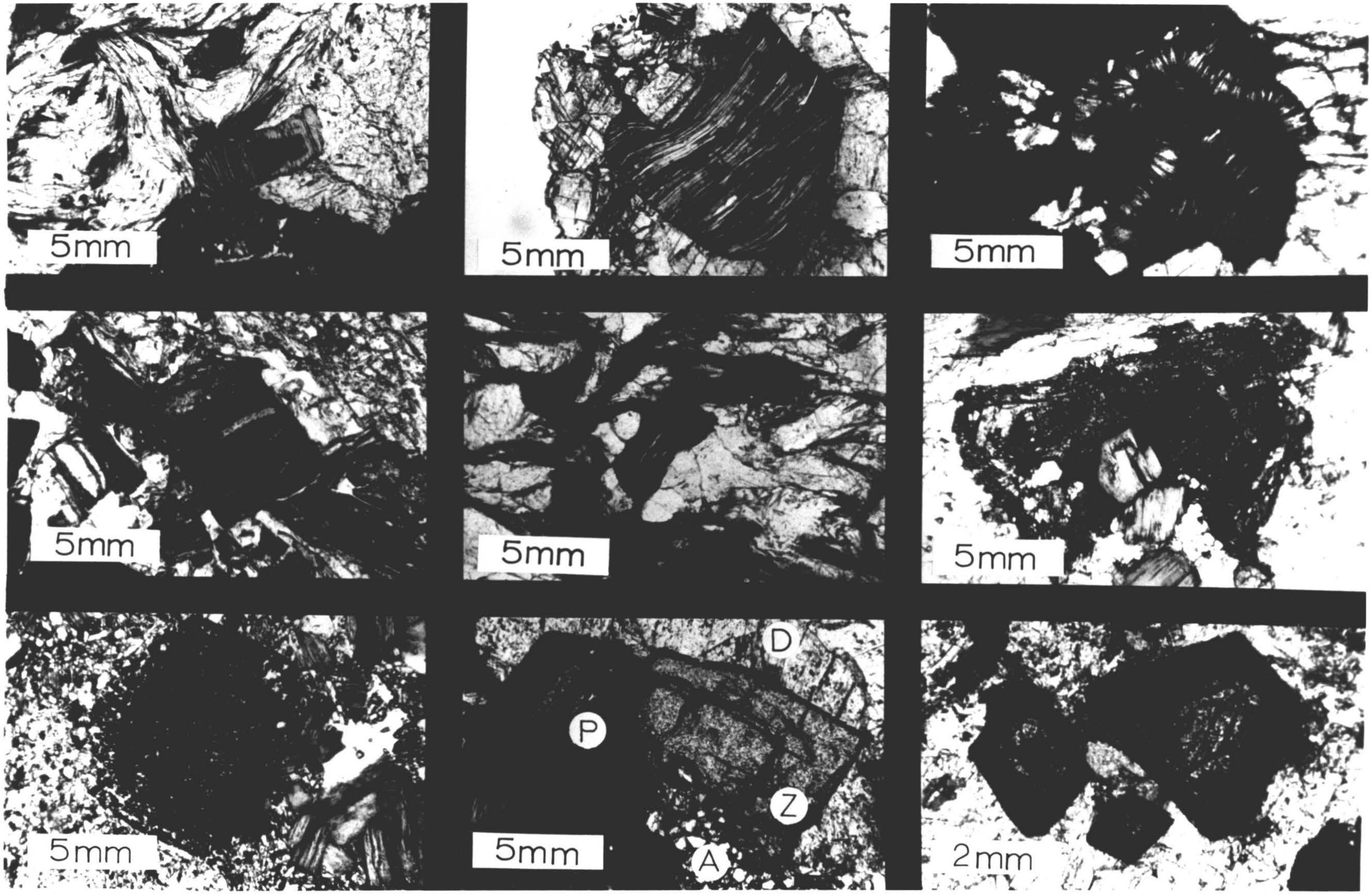
Figure 17. Edenite as alteration of phlogopite in a sheared carbonatite (section GP 17-425.4, transmitted light, uncrossed polars).

Figure 18. Randomly oriented zircon microlites with phlogopite (section GP 17-541.2A, transmitted light, uncrossed polars).

Figure 19. Randomly oriented microlites of zircon in a hexagonal outline (section GP 17-222.4, transmitted light, uncrossed polars).

Figure 20. Well developed crystalline zircon (Z) with pyrochlore (P), dolomite (D), apatite (A), and phlogopite (section GP 17-222.4, transmitted light, uncrossed polars).

Figure 21. Well developed crystalline pyrochlore (section GP 17-376.5, transmitted light, uncrossed polars).


5mm
5mm
5mm
5mm
5mm
5mm
5mm
D
P
Z
5mm
A
2mm

Many altered varieties of phlogopite appear to have been replaced along lattice planes. Commonly, replacement of phlogopite consists of dolomite and fluorite, but a unique type of replacement is also visible. Lamprophyllite, (Ba, Sr, K) Na (Ti, Fe) Ti Si_2 $(O, OH, F)_9$, occurs as partial or complete replacement of the micaceous lattice (Fig. 16). The lamprophyllite has high relief, a deep yellow-brown color, and high birefringence. The maximum birefringence and optic sign are undetermined due to the intense coloration of the mineral. X-ray diffraction data fit closely with JCPDS-ASTM standards (Table 6), and its optical properties are similar to those listed by Vlasov (1966).

In many cases, the shearing of primary phlogopite has produced the sodic amphibole edenite along shears (Fig. 17). X-ray diffraction lines agree well with JCPDS-ASTM standards (Table 7). The extremely fine-grained nature of the edenite prevents adequate determination of its optical properties. It is generally concentrated within the shear zone as tiny microlites subparallelly aligned. They are generally clear as isolated grains but masses of crystals often show a grey to brown color with occasional tints of blue. The exhibited birefringence is extremely low, but this may be due to the small thicknesses of individual grains. The edenite often occurs as isolated microlites or needles which penetrate surrounding carbonate grains.

Fluorite

Fluorite is a minor constituent in the rocks studied and occurs as 1) replacement laths in altered phlogopite or 2) minute grains scattered throughout the felty apatite masses. As scattered grains

17-296.5		Lamprophyllite standard	
dÅ	I/I$_o$	dÅ	I/I$_o$
		3.73	40
3.45	50	3.43	55
		3.27	40
3.05	20	3.03	35
2.87	20	2.87	40
2.75	100	2.78	100
		2.66	40
2.63	30	2.60	40
2.13	20	2.13	45
2.05	30	2.02	35

Table 6. A comparison of lamprophyllite in sample GP 17-296.5 with JCPDS-ASTM standards.

17-425.4		Edenite standard	
dÅ	I/I$_o$	dÅ	I/I$_o$
8.43	75	8.43	80
3.24	65	3.27	40
3.14	100	3.12	100
2.80	20	2.80	18
2.72	45	2.70	20

Table 7. A comparison of edenite in sample GP 17-425.4 with JCPDS-ASTM standards.

it is recognized by its isotropic character and high negative relief, but may be overlooked or misidentified due to its small size.

Zircon

Zircon is a distinctive mineral in the Gem Park cores as to its occurrence and its optical characteristics. It is found in a number of sections associated with both dolomite and felty apatite. Pyrochlore is always associated with zircon mineralization, but the converse is not true. Magnetite is also a commonly associated mineral.

The optical properties of this zircon are unique. Megascopically, zircon aggregates appear a dull white in color on a cut surface. Intact crystals yield good crystal faces and structure with a deep red-brown color. The zircon characteristically exhibits an iridescent orange color under short wave illumination and is thus easily identified in hand specimen.

Thin section analysis indicates that the zircon is commonly an aggregate of small, randomly oriented microlites or needles thus giving a chatoyant appearance under crossed polars. The aggregate outline ranges from completely random (Fig. 18) to a random mass within a hexagonally outlined crystal (Fig. 19). This latter occurrence may be indicative of a replacement process.

Various stages of zircon are observable from this random orientation of aggregates to well developed crystalline form (Fig. 20). These crystalline forms have only been seen at the carbonate-apatite border zones; as the zircon occurs farther from this zone, the good crystalline form disintegrates to a more microlite-rich form. No zircon has been found totally within the carbonate zones, only within the apatite-phlogopite regions.

Pyrochlore

Pyrochlore is the most conspicuous and yet most variable component of the Gem Park cores. Indeed, no generalizations can be made about its occurrence; each sample offers some new change in its optical properties and mode of occurrence.

The only generalization that can be made is that optically, the pyrochlore can often be distinguished by its extreme positive relief in thin section. In transmitted light the pyrochlore can appear nearly opaque to translucent; dark brown, red, or yellow-green in color; good crystalline form (Fig. 21) to completely embayed (Fig. 22) or anhedral; zoned (Fig. 23) or massive; extremely minute grains to large grains; with or without pleochroic haloes. In reflected light, the pyrochlore can appear free of inclusions or full of irregular masses of rutile, pyrite, magnetite, and apatite. Internal reflections range from bright yellows or whites through red, red-brown, orange, and green. It can be closely associated with apatite, magnetite, or phlogopite or not associated with any; however, apatite seems to be a favored association. Some pyrochlore appears to be sheared or remobilized.

The most significant feature is that some small crystals of pyrochlore produce either red or green pleochroic haloes. This is coupled with significantly higher uranium values for these rocks and suggests that some pyrochlore may be uraniferous.

Figure 22. Embayed pyrochlore (section GP 17-570.5, transmitted light, uncrossed polars).

Figure 23. Zoned pyrochlore (section GP 17-276.1, transmitted light, uncrossed polars).

Figure 24. Magnetite with abundant exsolution lamellae of specular hematite (section GP 17-376.5, reflected light, uncrossed polars).

Figure 25. Skeletal magnetite crystals (section GP 17-434.5, reflected light, uncrossed polars).

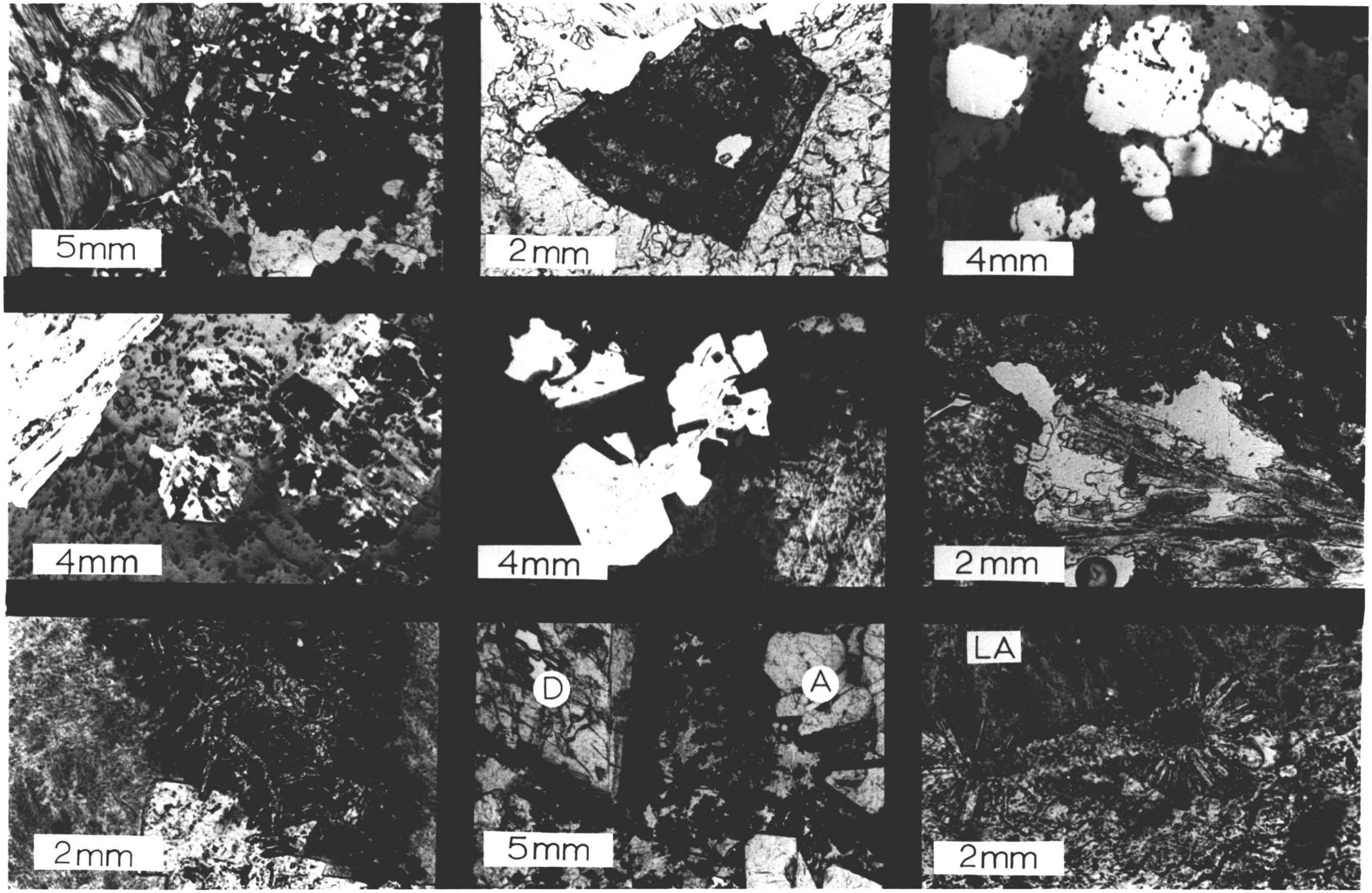
Figure 26. Pyrite crystal with curvilinear arrangement of inclusions (section GP 17-411.3, reflected light, uncrossed polars).

Figure 27. Needles of low albite filling void (section GP 39-7, transmitted light, uncrossed polars).

Figure 28. Bastnasite crystals with pleochroic haloes in low albite (section GP 39-80, reflected light, uncrossed polars).

Figure 30. Disseminated hematite in high iron dolomite with apatite (A) and early low iron dolomite (D) (section GP 17-276.1, transmitted light, uncrossed polars).

Figure 31. Radial apatite with dolomite and low albite (LA) (section GP 39-80, transmitted light, uncrossed polars).


5mm
2mm
4mm
4mm
4mm
2mm
2mm
D
A
5mm
LA
2mm

Sulfates

Both barite and celestite have been identified in hole GP-35 by X-ray diffraction methods and have been seen in thin section. Their similarity, however, does not enable distinctions of which is present by optical methods. The celestite shows a good X-ray pattern (Table 8) and is an unusual mineral in most carbonatites.

Monazite

Monazite has been identified by both X-ray diffraction and optical methods. Several habits are present and may be differentiated optically. One variety is a massive form, dark red-brown in color, often with somewhat of a spherulitic or radial habit. This type generally occurs in association with late stage calcite as mentioned previously.

Within dolomite zones, monazite is generally light green in color, blocky or equant, and exhibits its characteristic birefringence. Another variety, especially in section GP-35, shows monazite as brownish in color, fibrous with a radial or spherulitic appearance, and closely associated with strontianite. This variety may be the mineral rhabdophane, a closely related variety of monazite. The distinction between the two is difficult, even through X-ray diffraction analysis.

Monazite also occurs as an alteration product of rare earth-bearing apatite. In hole GP-39, the apatite takes on a mottled appearance with a finely disseminated dusting of monazite within the apatite crystals.

35-618		Celestite standard	
dÅ	I/I_o	dÅ	I/I_o
4.23	8	4.23	11
3.78	10	3.77	35
3.44	30	3.43	30
3.30	100	3.30	98
3.16	68	3.18	59
2.97	50	2.97	100
2.73	55	2.73	63
2.67	12	2.67	49
2.37	15	2.38	17
2.14	16	2.14	25
2.04	35	2.04	55
2.00	17	2.01	40
1.77	18	1.77	17
1.68	15	1.68	9
1.60	11	1.60	15
1.48	6	1.48	16
1.38	20	1.39	9

Table 8. A comparison of celestite from sample GP 35-618 with JCPDS-ASTM standards.

Magnetite

Magnetite is a dominant constituent of the cores. Its occurrence is rarely euhedral and commonly occurs as subhedral to anhedral grains. Under reflected light the magnetite appears brownish to tan in color with a slight anisotropy indicating that the magnetite is titanium rich. Many grains show exsolution blebs and lamellae, along crystallographic orientations, of specular hematite. The full range from a total absence of exsolution products to ones with abundant exsolved hematite lamellae (Fig. 24) are visible.

Magnetite most commonly appears in the apatite zones, especially those which show indications of shearing or the presence of felty apatite and sheared phlogopite. It often occurs at the border zone between carbonate and apatite. Magnetite commonly has poikilitic inclusions of apatite with occasional inclusions of phlogopite and carbonate.

In some cases, two stages of magnetite are visible with a younger stage possessing good exsolution lamellae and an older, degraded stage in which the magnetite is rough in appearance and is almost totally altered to hematite. Some large magnetite grains are so altered as to leave only skeletons of the former magnetite crystal structure (Fig. 25). Magnetite is often altered to siderite by-products and thus gives a turbid dark brown color to the rocks.

Pyrite

Pyrite seems to be related to late stage dolomite introduction and is found as small disseminated grains within or between carbonate grains and occasionally as large crystals or masses of pyrite. It can appear euhedral but is most commonly anhedral. Some grains appear to have been rotated during formation as seen by curvilinear arrangements of inclusions within individual grains (Fig. 26). Many pyrite grains contain exsolution blebs of chalcopyrite.

Chalocopyrite occurs as exsolution products in pyrite and occasionally as primary mineralization with an anhedral appearance. Other minor opaques include marcasite, bornite, high-iron sphalerite, and pyrrhotite.

Accessory Minerals

Many minerals occur as minor constituents but may be important in deciphering paragenesis or mineralization of the Gem Park complex. Quartz is present in small quantities in many samples. Relationships with other minerals indicate a paragenetically late position for the quartz.

In hole GP-39, low albite appears as a light red to orange cluster of radial needles (Fig. 27), especially near voids. A comparison between X-ray diffraction analysis and JSPDS-ASTM standards is given in Table 9. The albite may be the latest stage in carbonatite development.

Some samples show abundant randomly-oriented needles of crystalline hematite disseminated generally within dolomite crystals. The hematite is a deep reddish-orange in color, is almost opaque in transmitted light, hexagonal in outline, has high relief, possibly uniaxial negative, and is light grey and isotropic in reflected light.

Bastnasite is present in hole GP-39 and appears as small, needle-like crystals with high relief, moderate birefringence, and clustered

39-80		Low albite standard	
dÅ	I/I_o	dÅ	I/I_o
6.37	20	6.39	20
4.00	13	4.03	16
3.86	5	3.86	8
3.77	13	3.78	25
3.66	21	3.66	16
3.54	6	3.51	10
3.49	5	3.49	2
3.19	100	3.20	100
2.96	6	2.96	10
2.92	4	2.93	16
2.64	3	2.64	6
2.56	6	2.56	8
2.12	4	2.12	8

Table 9. A comparison of low albite from sample GP 39-80 with JCPDS-ASTM standards.

in occurrence. Although not positively identified by X-ray diffraction analysis in this study, a sample collected by Armbrustmacher and Brownfield (1978) in the same area has been analyzed by the U.S. Geological Survey and shows good bastnasite peaks. Similarity in optical properties between his sample D-169181 and the GP-39 series justifies the analogy. The bastnasite at Gem Park shows abundant pleochroic haloes which may extend many times the crystal length into the surrounding minerals (Fig. 28). The haloes are a deep reddish-brown in color and generally obscure the host mineralogy, but relationships indicate that it is commonly hosted within the zones of low albite. The pleochroism may indicate a high amount of thorium within the bastnasite structure.

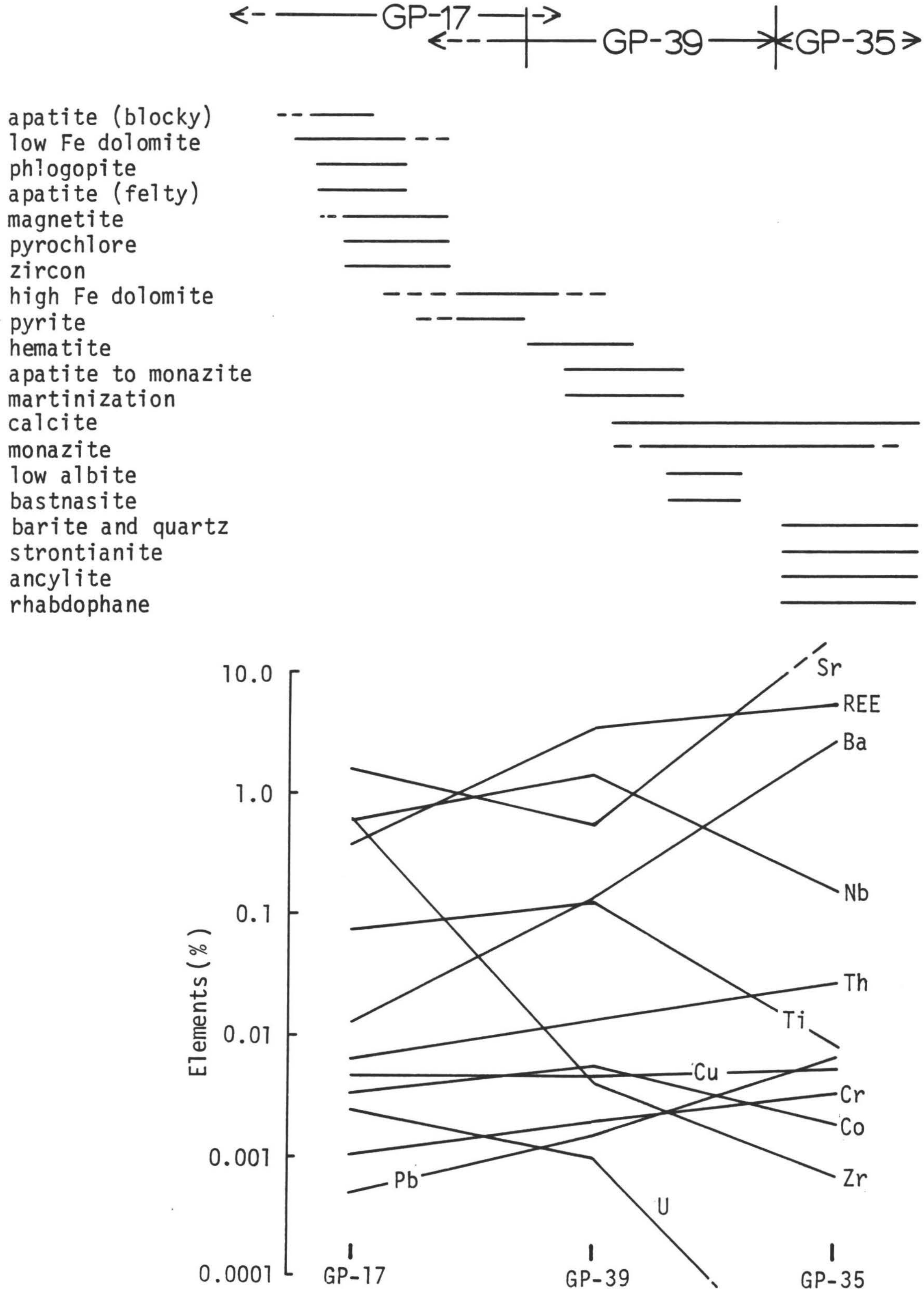
Ancylite has been positively identified in only one sample and is complexly intergrown with monazite. Many other occurrences may have gone undetected due to this relationship.

PARAGENESIS

A rough paragenetic sequence, constructed on the basis of mineral textures and fabrics, for the Gem Park carbonatites is shown in Figure 29 and includes a geochemical variation diagram for the three cores studied. Hole GP-17 represents the oldest carbonatites in this sequence and can be correlated with the early phases of carbonatite development as suggested by Kapustin (1966). Megascopically, the contact between carbonatite and host rock shows fenitized borders with pyroxenes altered to phlogopite. These phlogopites often occur as stringers within the carbonatite dikes. The carbonatite magma was possibly rich in carbonate (dolomite) and apatite as suggested by zones which contain only these minerals. Upon cooling, the euhedral apatite crystals are surrounded by a matrix of dolomite, suggesting coprecipitation or a slightly earlier phase for the apatite. Emplacement of the magma in a dike system causes shearing of the apatite with absorption and crystallization of phlogopite. Sharp borders occur between the sheared apatite and dolomite with occasional pods of apatite completely surrounded by dolomite. Coprecipitation of pyrochlore, zircon, and magnetite follow at this stage with concentrations of these minerals dominantly in the apatite zones. The latest stage here is the crystallization of high iron dolomites with pyrite, hematite exsolution in the magnetite, and alteration of dolomites to disseminated hematite (Fig. 30).

Hole GP-39 shows the next stage in carbonatite development with numerous dikes of dolomite and apatite (Fig. 31) and altered dikes of early phase carbonatites. The apatite is often altered to earthy monazite.

Figure 29. Paragenetic sequence for the Gem Park carbonatites. A geochemical variation diagram for important elements appears below and is an average value for each core studied.



Magnetite is altered to hematite or to skeletal crystals replaced by carbonates. Pyrochlore is also extremely altered. Monazite crystallization appears at this time and increases sharply with the introduction and crystallization of calcite. Later crystallization of low temperature albite with minute grains of thorium-rich bastnasite represents the latest stage in this hole.

Hole GP-35 represents the latest stages of carbonatite development observed with the further crystallization of calcite and the concentration of barium and strontium in barite and strontianite. Ancylite and monazite are the major rare earth minerals and make up large portions of the rocks. Late stage quartz and siderite are also present. The presence of barite and celestite in the carbonatites and gypsum in the gabbros indicates a strong late sulfate stage. The fibrous nature of monazite in this core suggests the presence of rhabdophane.

CARBONATITE GEOCHEMISTRY

Geochemical analysis of rock chip samples were done at the U.S. Geological Survey in Denver by a semiquantitative six-step spectrographic analysis for the majority of elements. Uranium and thorium values were determined by delayed neutron activation methods. A listing of data appears in Table 10 and a summarization of data for each hole evaluated appears in Table 11 with a comparison to average geochemical values for carbonatites (Armbrustmacher, 1980 after Gold, 1963) and average crustal igneous rocks (Wedepohl, 1971). Figure 29 shows a geochemical variation trend diagram for the cores studied.

As compared to the average chemical composition of carbonatites (Gold, 1963) the Gem Park carbonatites contain more than five times (5x) greater amounts of Cu (20x), La (10x), Sr, and Ga; and two to five times the amounts of P, Ce, Co, and Sc. They also contain equal or slightly greater amounts of Fe, Mg, Ba, Ni, Y, and Na. The carbonatites contain slightly less amounts of Mn; two to five times lesser amounts of Nb, Zr, and K; and more than five times lesser amounts of Ti, Si, and Al.

As compared to average crustal igneous rocks (Wedepohl, 1971) the Gem Park carbonatites contain more than five times greater amounts of La (120x), Sr (80x), P (35x), Ce (70x), Nd (90x), Ca, Ba, Th, and U; two to five times greater amounts of Mg, Mn, Co, Cr, Nb, Y, Zr, and Yb; with slightly greater amounts of Fe, Cu, and Sc. They also contain slightly lesser amounts of Pb and V; two to five times lesser amounts of K, Ga, Ni; and more than five times lesser amounts of Ti, Na, Si (-40x), and Al (-45x).

Table 10. Geochemical data for 29 Gem Park core samples.

Key to Geochemical Tables

Data were determined by six-step semiquantitative spectrographic analysis (M.J.M. and J.C.H., analysts) for all elements except U and Th which were determined by delayed neutron methods (H. T. Millard, Jr., R. B. Vaughn, S. W. Lasater, and B. A. Keaton, analysts).

Results are reported in percent and are identified with geometric brackets whose boundaries are 1.2, 0.83, 0.56, 0.38, 0.26, 0.18, 0.12, etc., but are reported arbitrarily as mid-points of these brackets, 1.0, 0.7, 0.5, 0.3, 0.2, 0.15, 0.1, etc. The precision of a reported value is approximately plus or minus one bracket at 68% or two brackets at 95% confidence.

>,<	Greater or less than value shown
blank	Not detected
L	Detected, but below limit of determination

The following elements were not detected in any samples: As, Au, B, Be, Bi, Cd, Mo, Pd, Pt, Sb, Te, W, Ge, Hf, In, Li, Re, Ta, Tl.

Field No.	17-77.5	17-222.4	17-276.1	17-280.5	17-296.5	17-350.5	17-353.4	17-355.8	17-366.0	17-376.5	17-406.3	17-411.3	17-425.4	17-434.5	17-450.0	17-499.0
Lab No.	D219664	D219666	D219668	D219669	D219667	D219670	D219671	D219672	D219673	D219674	D219675	D219676	D219677	D219678	D219679	D219680
Fe	7.0	3.0	10.0	10.0	10.0	5.0	10.0	5.0	7.0	3.0	>10.0	5.0	2.0	3.0	7.0	5.0
Mg	5.0	7.0	3.0	5.0	7.0	7.0	5.0	5.0	7.0	5.0	7.0	3.0	7.0	7.0	7.0	7.0
Ca	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	>10.0	>10.0	>10.0	>10.0	>10.0	>10.0	>10.0	>10.0
Ti	0.07	0.07	0.15	0.1	0.15	0.02	0.1	0.01	0.07	0.01	0.15	0.05	0.01	0.02	0.05	0.05
Mn	0.3	0.15	0.15	0.1	0.2	0.5	0.5	0.5	0.2	0.2	0.3	0.3	0.2	0.3	0.5	0.3
Ag	0.0002															
Ba	0.1	0.015	0.007	0.01	0.015	0.007	0.005	0.003	0.01	0.005	0.015	0.005	0.005	0.007	0.003	0.005
Co	0.02	0.0007	0.015	0.001	0.003	0.0005	0.007		0.002	0.0007	0.002		0.0007	0.001	0.0005	0.003
Cr	0.0015	0.001	0.0015	0.0007	0.0007	0.0002	0.007	0.0001	0.0007	0.0001	0.001	0.001	0.0001	0.0001	0.0005	0.0007
Cu	0.015	0.001	0.01	0.003	0.005	0.003	0.005	0.002	0.015	0.007	0.003	0.003	0.003	0.003	0.002	0.003
La	0.015	0.3	0.15	0.15	0.07	0.015	0.015	0.015	0.03	0.01	0.3	0.15	0.01	0.015	0.02	0.015
Nb	0.15	0.2	0.07	0.07	0.1	0.015	0.015	0.001	0.03	0.003	0.01	0.007	0.005	0.01	0.005	0.015
Ni	0.007	0.0005	0.003	0.0005	0.001	0.0005	0.002	L	0.001	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.001
Pb	0.001	0.0015	0.003		0.001				0.002							
Sc	0.002		0.001	0.005	0.01	0.003	0.005	0.002	0.0005	0.001	0.0015	0.003	0.002	0.002	0.003	0.001
Sn	0.001								0.001							
Sr	1.5	2.0	1.5	1.5	1.5	1.5	2.0	1.5	1.5	1.5	1.5	2.0	1.5	1.5	2.0	1.5
V	0.0015		0.015	0.007	0.015	0.003	0.02	0.0015	0.005	0.0015	0.015	0.005	0.0015	0.0015	0.01	0.007
Y	0.003	0.07	0.02	0.02	0.015	0.003	0.005	0.001	0.007	0.001	0.05	0.02	0.002	0.003	0.005	0.002
Zn			0.03													
Zr	0.005	0.7	0.02	0.1	0.2	0.005	0.015		0.002	0.005		0.003	0.002	0.02		0.02
Si	0.2	2.0	0.7	0.7	1.5	1.0	1.0	0.05	0.3	0.1	1.0	0.7	0.5	0.5	1.0	0.5
Al	0.05	0.7	0.2	0.05	0.05	0.07	0.15	0.01	0.07	L	0.3	0.01	0.01	0.02	0.07	0.02
Na	0.2	0.7	0.5	0.3	0.3	0.3	0.3	0.3	0.1	0.07	0.3	0.3	0.5	0.3	0.3	0.07
K		2.0	1.0								1.0					
P	3.0	10.0	3.0	5.0	5.0	5.0	5.0	3.0	0.5		5.0	5.0			5.0	
Ce	0.02	0.7	0.2	0.2	0.15	0.02	0.02	L	0.05		0.3	0.15		0.02	0.05	0.02
Ga		0.002	0.0015	0.0005	0.001	L	0.0005		L		0.0015				0.0005	L
Yb	0.00015	0.003	0.0015	0.002	0.0015	0.00015	0.0003	0.0001	0.0003	0.0001	0.0015	0.0005	0.0001	0.00015	0.0002	0.00015
Pr		0.07	0.03		0.02						0.05	0.02				
Nd		0.5	0.15	0.1	0.07	0.01		0.01	0.03		0.15	0.1		0.015	0.02	0.015
Sm		0.07	0.03	0.03	0.015						0.05	0.02				
Eu		0.015	L	L							0.01	L				
Gd		0.03	0.01	0.01	0.007						0.02	0.007				
Dy		0.015	0.005	0.005	L						0.01	L				
Ho		0.002									L					
Er		0.007									0.005					
Tm		0.003														
E LREE	0.035	1.655	0.56	0.48	0.325	0.045	0.035	0.025	0.11	0.01	0.86	0.44	0.01	0.06	0.09	0.05
E HREE	0.00315	0.13	0.365	0.037	0.0235	0.00315	0.0053	0.0011	0.0073	0.0022	0.0865	0.0275	0.0021	0.00315	0.0052	0.00215
Th	0.00056	0.0224	0.0101	0.0196	0.0249	0.00205	0.00331	0.001	0.0014	0.0002	0.00215	0.00162	0.00039	0.00067	0.001	0.00199
U	0.00008	0.0076	0.00474	0.00632	0.0131	0.00043	0.00015	0.00076	0.00564	0.00008	0.00025	0.00005	0.00023	0.00034	0.00024	0.0001

Table 10. (Continued)

Field No. / Lab No.	17-504.3 D219681	17-515.9 D219682	17-537.5 D219683	17-541.2 D219684	17-570.5 D219685	Mean	Lowest Value	Highest Value
Fe	2.0	>10.0	10.0	>10.0	3.0	>6.52	2.0	>10.0
Mg	5.0	3.0	5.0	3.0	5.0	5.48	3.0	7.0
Ca	>10.0	>10.0	>10.0	>10.0	>10.0	>10.0	>10.0	>10.0
Ti	0.1	0.2	0.1	0.1	0.05	0.0776	0.01	0.2
Mn	0.2	0.15	0.55	0.15	0.2	0.281	0.1	0.5
Ag						0.00001	<0.00005	0.0002
Ba	0.015	0.005	0.01	0.015	0.007	0.0128	0.003	0.1
Co	0.0005	0.002	0.003	0.01	0.0007	0.0035	>0.0005	0.02
Cr	0.0003	0.0015	0.0007	0.0005	0.002	0.001	0.0001	0.007
Cu	0.003	0.003	0.005	0.007	0.002	0.0049	0.001	0.015
La	0.015	0.1	0.15	0.3	0.02	0.0888	0.01	0.3
Nb	0.05	0.07	0.1	0.2	0.1	0.0584	0.001	0.2
Ni	L	0.0007	0.001	0.0015	0.0007	0.00111	<0.005	0.007
Pb			0.0015	0.001		0.00052	<0.001	0.003
Sc	0.0015	0.001	0.007	0.001	0.0005	0.00252	<0.0005	0.01
Sn						0.0001	<0.001	0.001
Sr	1.5	1.5	2.0	2.0	1.0	1.619	1.0	2.0
V	0.001	0.05	0.01	0.01	0.003	0.00874	<0.0007	0.05
Y	0.002	0.01	0.03	0.07	0.005	0.0164	0.001	0.07
Zn		0.03				0.00286	<0.03	0.03
Zr	0.005	0.01	0.05	0.05	0.002	0.0578	<0.001	0.7
Si	0.3	0.5	1.5	1.0	0.5	0.7643	0.05	2.0
Al	0.01	0.05	0.1	0.3	0.1	0.1114	<0.01	0.7
Na	0.1	0.2	0.5	0.5	0.2	0.3019	0.07	0.7
K				1.5		0.2619	0.7	2.0
P	1.0	1.5	5.0	10.0	1.0	3.476	<0.2	10.0
Ce	0.03	0.15	0.3	0.5	0.05	0.1395	<0.02	0.7
Ga		0.0015	0.001	0.0015	0.0005	0.00057	<0.0005	0.002
Yb	0.00015	0.0005	0.001	0.002	0.0002	0.0008	0.0001	0.003
Pr			0.05	0.07		0.0148	0.02	0.07
Nd	0.015	0.07	0.15	0.3	0.02	0.0821	0.01	0.5
Sm		0.015	0.03	0.07		0.0157	0.015	0.07
Eu			0.01	0.015		0.002	0.01	0.015
Gd		0.005	0.015	0.03		0.0064	0.005	0.03
Dy		L	0.007	0.015		0.0027	0.005	0.015
Ho				0.002		0.0002	0.002	0.002
Er				0.005		0.0008	0.005	0.007
Tm				0.002		0.0002	0.002	0.003
E LREE	0.06	0.335	0.69	1.255	0.09	0.3438	0.01	1.655
E HREE	0.00215	0.0155	0.053	0.126	0.0052	0.0275	0.0011	0.13
Th	0.00572	0.00508	0.0117	0.0161	0.00885	0.0067	0.0002	0.0249
U	0.00016	0.00178	0.00366	0.00556	0.00067	0.00247	0.00005	0.0131

Table 10. (Continued)

Field No. Lab. No.	35-544.7 D219687	35-618.0 D219688	35-783.4 D219690	Mean	39-7.0 D219693	39-80.0 D219695	39-88.0 D219696	39-102.0 D219697	39-102.0 D219698	Mean
Fe	2.0	5.0	1.0	2.667	5.0	7.0	5.0	7.0	2.0	5.2
Mg	3.0	5.0	0.5	2.833	2.0	5.0	5.0	5.0	3.0	4.0
Ca	10.0	>10.0	10.0	>10.0	>10.0	>10.0	>10.0	>10.0	>10.0	>10.0
Ti	0.007	0.01	0.007	0.008	0.015	0.02	0.5	0.2	0.005	0.148
Mn	0.3	0.5	0.1	0.3	0.5	0.5	0.5	0.3	0.5	0.46
Ag					0.0002	0.001				0.00024
Ba	7.0	0.5	1.0	2.833	0.15	0.1	0.1	0.3	0.1	0.15
Co	0.0005	0.001	0.0005	0.002	0.007	0.02	0.001	0.002	0.0005	0.0061
Cr	0.007	0.002	0.003	0.004	0.005	0.0015	0.002	0.001	0.001	0.0021
Cu	0.003	0.01	0.005	0.006	0.015	0.002	0.002	0.002	0.002	0.0046
La	>2.0	>2.0	>2.0	>2.0	>2.0	>2.0	1.5	1.0	0.7	>1.44
Nb	0.005	0.05	0.002	0.019	0.005	0.02	0.7	0.15	0.002	0.1754
Ni					0.01	0.005	0.0005	0.0005	L	0.0032
Pb	0.015	0.003	0.003	0.007	0.005	0.001	0.002			0.0016
Sc						0.001	0.005	0.001	0.001	0.0016
Sn							0.001			0.0002
Sr	>10.0	10.0	>10.0	>10.0	0.7	0.15	0.3	0.3	1.5	0.59
V						0.05	0.007	0.015		0.0144
Y	0.015	0.01	0.015	0.0133	0.02	0.015	0.005	0.005	0.02	0.013
Zn										
Zr	0.002			0.0007			0.015	0.003		0.0036
Si	0.7	0.15	0.2	0.35	0.3	1.0	1.0	1.5	0.3	0.82
Al	0.7	0.03	0.02	0.25	0.05	0.5	0.5	0.7	0.3	0.41
Na	0.5	0.5	1.0	0.667	0.1	1.0	0.5	0.7	0.5	0.56
K		2.0	3.0	1.667	2.0	1.5	1.0	1.0	0.7	1.24
P	3.0	1.5		1.5	0.5	3.0			1.5	1.0
Ce	>2.0	2.0	>2.0	>2.0	>2.0	1.5	1.0	1.0	0.7	>1.24
Ga	0.0005	L		0.0002		0.001	0.0005	0.002		0.0007
Yb	0.0015	0.0003	0.0005	0.0008	0.0005	0.0005	0.00015	0.00015	0.0007	0.0004
Pr						0.1	0.07	0.07		0.096
Nd	1.5	0.7	1.0	1.067	1.0	0.7	0.3	0.3	0.3	0.52
Sm	0.15	0.07	0.1	0.107	0.15	0.07	0.03	0.03	0.03	0.062
Eu	0.02	0.015	0.015	0.017	0.03	0.015	L	L	0.01	0.055
Gd	0.02	0.01	0.015	0.015	0.03	0.01			0.01	0.01
Dy	0.01	0.005	0.005	0.0067	0.007	L			0.005	0.0024
Ho										
Er										
Tm										
E LREE	>5.67	>4.785	>5.115	>5.19	>5.18	>4.385	2.9	2.4	1.74	>3.321
E HREE	0.0465	0.0253	0.0355	0.0358	0.0575	0.0255	0.00515	0.00515	0.0357	0.0258
Th	0.059	0.00948	0.019	0.0292	0.0252	0.0132	0.0173	0.0109	0.00645	0.0146
U	0.00003	0.00002	0.00002	0.00002	0.00005	0.00005	0.00006	0.0003	0.00002	0.0001

	Average of 29 Gem Park Samples	GP-17 21 Samples	GP-35 3 Samples	GP-39 5 Samples	Average chemical composition of carbonatites (Armbrustmacher after Gold, 1963)	Average igneous rocks of upper continental crust (Wedepohl, 1971)
Fe	5.89	>6.52	2.667	5.2	5.12	3.54
Mg	4.95	5.48	2.833	4.0	3.40	1.39
Ca	>10.0	>10.0	>10.0	>10.0	25.10	2.87
Ti	0.083	0.078	0.008	0.148	0.48	0.47
Mn	0.314	0.281	0.3	0.46	0.47	0.069
Ba	0.328	0.0128	2.833	0.15	0.23	0.059
Co	0.0038	0.0035	0.002	0.0061	0.0017	0.002
Cr	0.0015	0.001	0.004	0.0021	0.0048	0.007
Cu	0.005	0.0049	0.006	0.0046	0.00025	0.003
La	>0.519	0.0888	>2.0	>1.44	0.0516	0.0044
Nb	0.074	0.0584	0.019	0.1754	0.1951	0.002
Ni	0.0014	0.0011	---	0.0032	0.0008	0.0044
Pb	0.0014	0.0005	0.007	0.0016	---	0.0015
Sc	0.0021	0.0025	---	0.0016	0.001	0.0014
Sr	>2.31	1.619	>10.0	0.59	0.34	0.029
V	0.0088	0.0087	---	0.0144	---	0.0095
Y	0.015	0.0164	0.0133	0.013	0.0096	0.0034
Zr	0.0425	0.058	0.0007	0.0036	0.112	0.016
Si	0.731	0.764	0.35	0.82	5.66	30.54
Al	0.179	0.111	0.25	0.41	1.88	7.83
Na	0.384	0.302	0.667	0.56	0.31	2.45
K	0.576	0.262	1.67	1.24	1.24	2.82
P	2.84	3.476	1.5	1.0	0.90	0.081
Ce	>0.522	0.14	2.0	>1.24	0.15	0.0075
Ga	0.0006	0.0006	0.0002	0.0007	0.0001	0.0017
Yb	0.0007	0.0008	0.0008	0.0004	---	0.00034
Na	0.259	0.0821	1.067	0.52	---	0.003
Th	0.0104	0.0067	0.0292	0.0146	---	0.0011
U	0.0018	0.00247	0.00002	0.001	---	0.00035
EREE	>1.39	0.3713	>5.226	>3.3468	---	0.0225

Table 11. A summarization of geochemical data for the Gem Park samples with a comparison to average geochemical values for carbonatites (Armbrustmacher, 1980 after Gold, 1963) and for average crustal igneous rocks (Wedepohl, 1971). All values are reported in percent.

The distribution of the elements among the mineral constituents in the carbonatites is an area in need of further consideration. For example, it is probable that Ba and Sr will be found as substitutions in the dolomite structure; Ti and Fe may be the cause of the unusual pleochroic scheme for phlogopite; and determination of the iron content in the carbonates would be useful.

Niobium is a distinctive element in the pyrochlore sturcture and has been used as a correlation parameter for some elements. There seems to be a strong correlation between niobium content and rare earth content in those samples in which pyrochlore has been identified (Fig. 32). There is also a strong correlation between niobium and thorium in these same samples (Fig. 33). There seems to be no correlation between niobium and uranium or the other elements.

A chondrite normalized graph of rare earth concentrations (Coryell et al., 1963) from the data available appears in Figure 34 and shows the general trends for the rare earth elements in the holes studied. The light rare earths (LREE) are strongly enriched over the heavy rare earths (HREE) and are similar to results obtained by Loubet et al. (1972) for samples from Fen, Norway. All samples show a slightly negative cerium anomaly. Hole GP-39 shows a significant positive europium anomaly and may be related to the presence of low albite. The plagioclase series is selective for europium, the Eu anomaly larger for the more alkaline feldspars (Schnetzler and Philpotts, 1968).

These geochemical results may not necessarily represent the entire carbonatite complex at Gem Park since this study was conducted on three holes chosen for their differing mineralogies and genetic relationships. Indeed, areas of carbonatite with greater amounts of niobium have been found in the southeastern section of the complex.

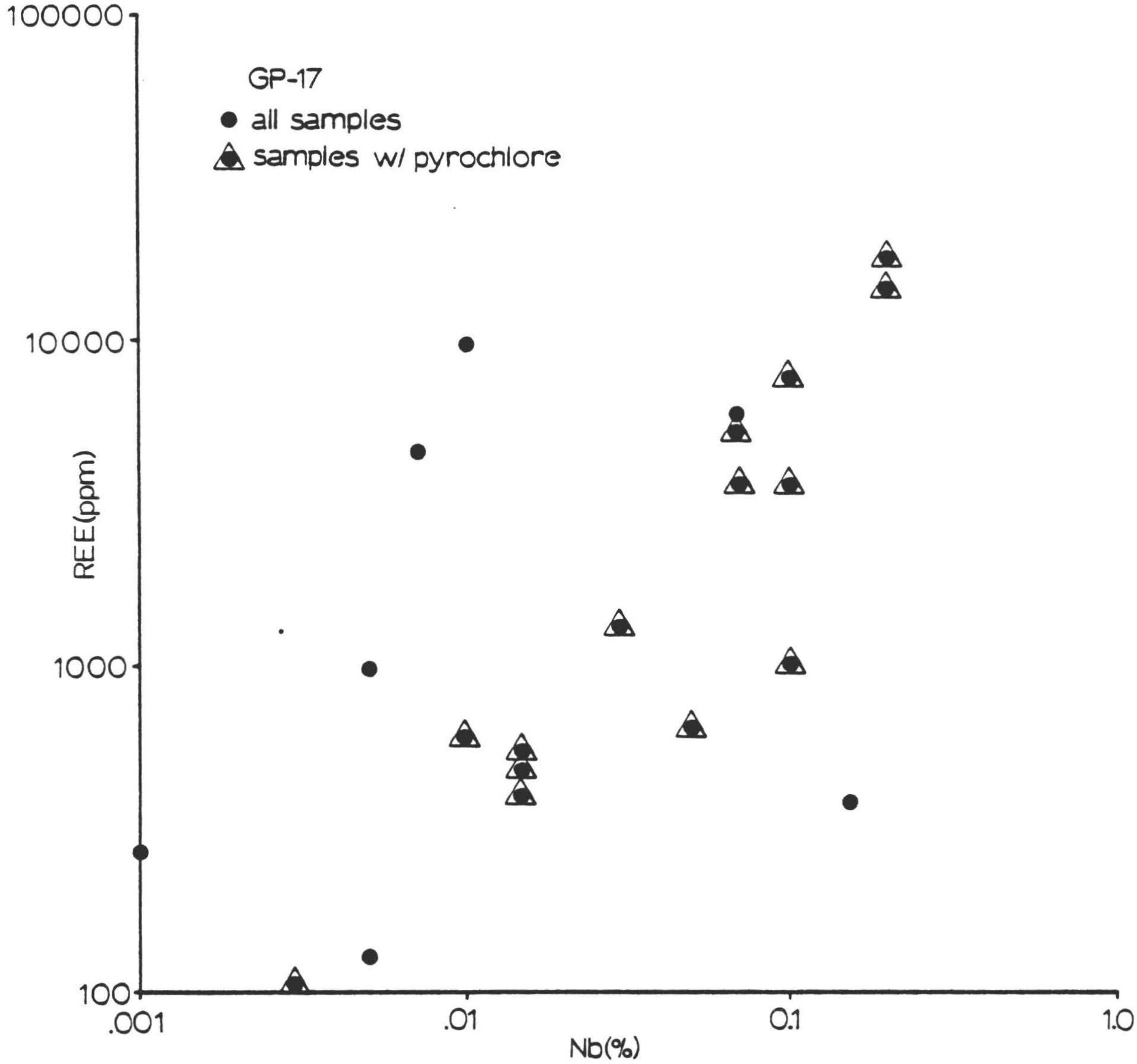


Figure 32. Graph of Nb content versus REE content for samples from hole GP-17. Those samples with pyrochlore show a strong correlation (r = 0.917) between Nb and REE.

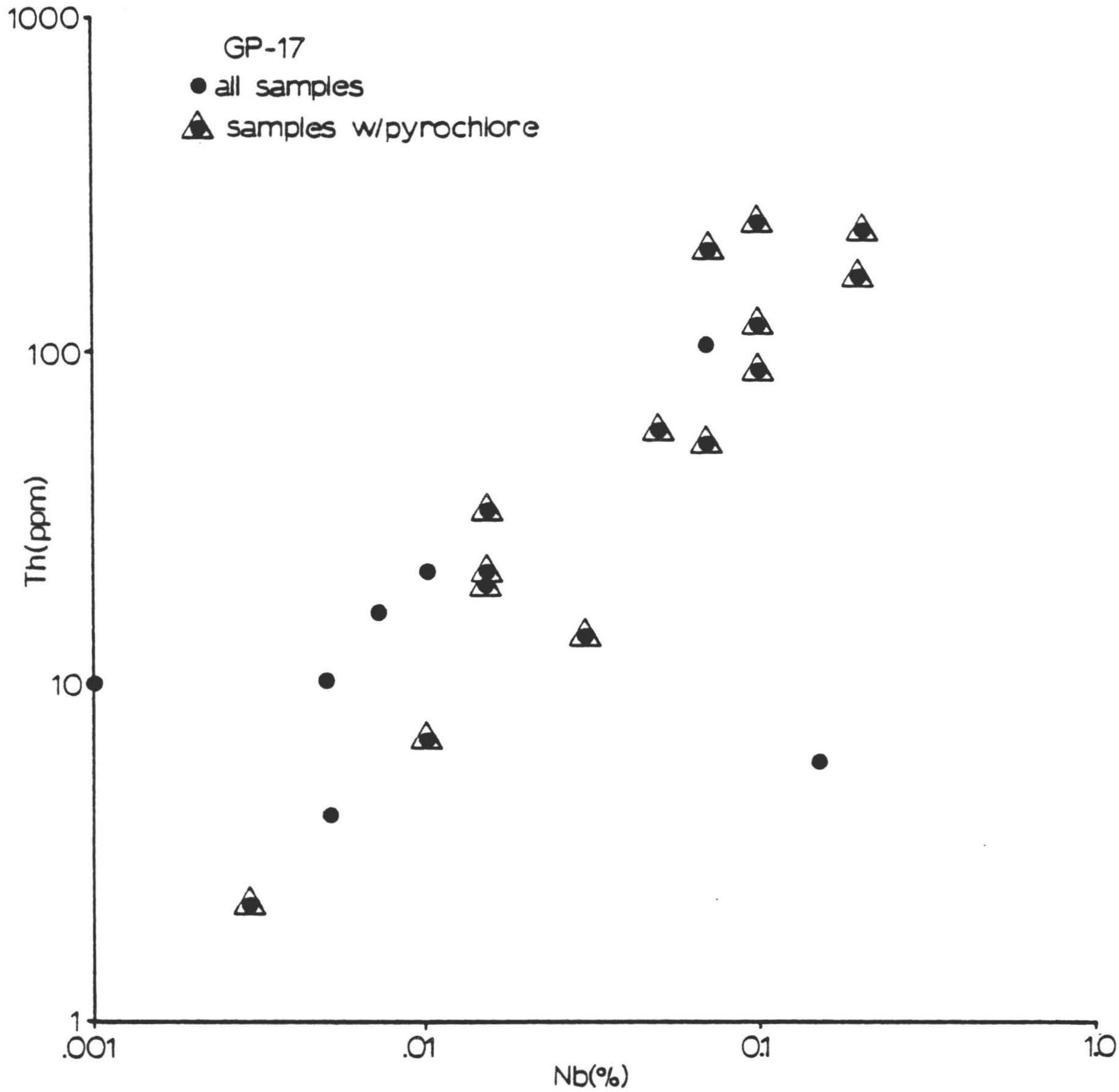


Figure 33. Graph of Nb content versus Th content for samples from hole GP-17. Those samples with pyrochlore show a correlation (r = 0.785) between Nb and Th.

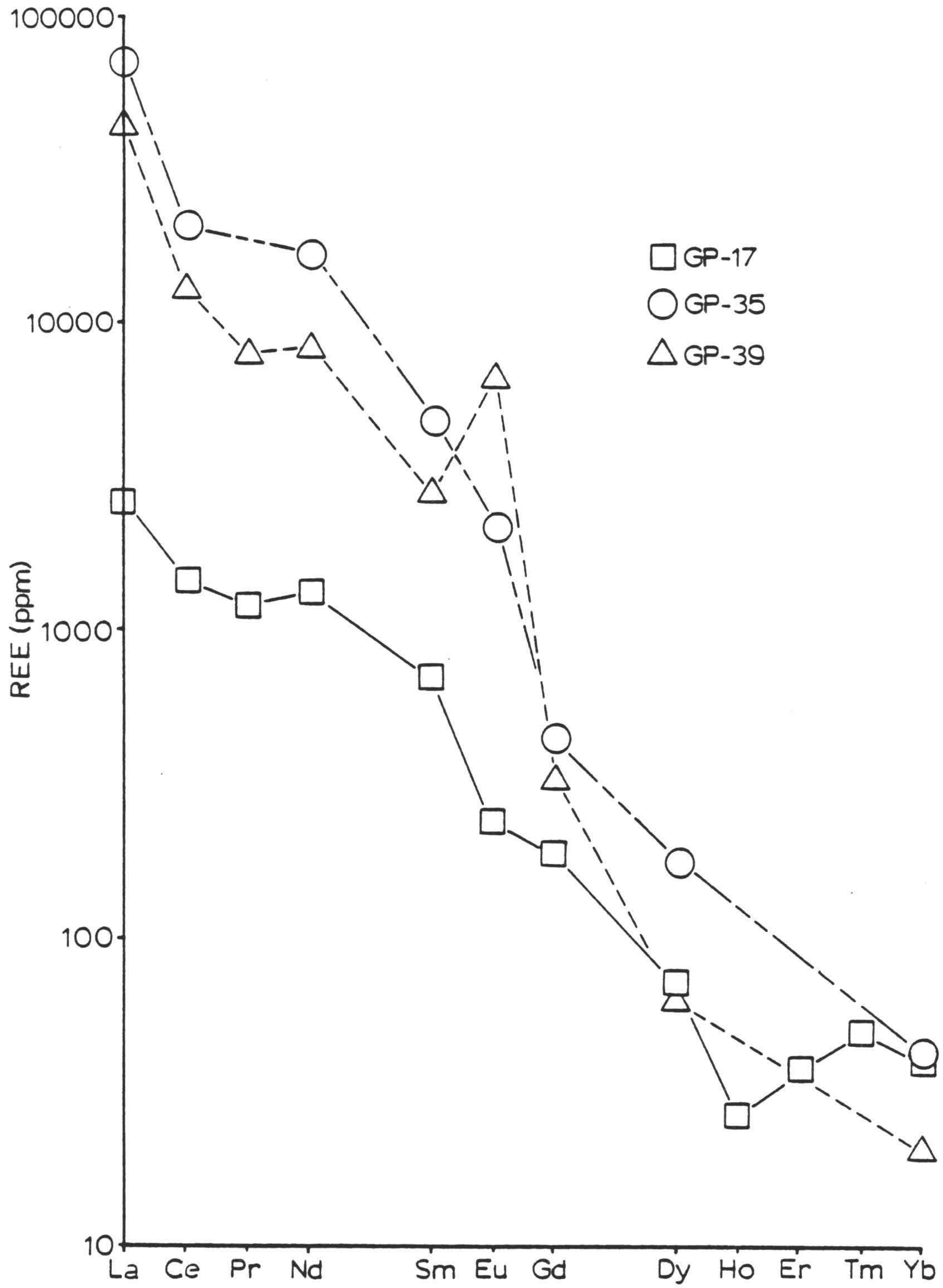


Figure 34. Chondrite normalized graph of rare earth contents at Gem Park. Note the slight negative cerium anomaly in all holes and the strong positive europium anomaly for hole GP-39.

SUMMARY

The Gem Park Complex can be characterized by at least three stages of carbonatite development. The early stage consists of dolomite, apatite (francolite), magnetite, and phlogopite with accessory pyrochlore and zircon. The large intercepts of this carbonatite type in hole GP-17 indicate that similar masses or plugs may exist elsewhere within the complex. The onset of the next stage is marked by the alteration of apatite to monazite and the alteration of magnetite. Hematite and pyrite are common. Calcite and monazite predominate towards the end of this stage with minor bastnasite and low albite. The latest stage occurs as dikes of calcite, barite, and strontianite with accessory celestite, ancylite, and rhabdophane. Fenitization around carbonatite borders and the size of carbonatite dikes decreases as the complex develops. An extremely late sulfate stage is noted by the presence of barite and celestite in the carbonatites and a gypsum stockwork within the host gabbro.

Each stage is represented by a particular rock type with a specific mineralogy and geochemistry. Favorable rock types for economic mineralization appear to be the late phases of the first stage and the earliest phases of the second stage.

The first stage is characterized by large masses of low grade niobium (mean - 584 ppm) and rare earth elements (mean - 3713 ppm). Both the niobium and the REE occur in pyrochlore. The presence of uranium (high value - 131 ppm) in core samples of carbonatite is significant since no such concentrations have been reported in previous

studies of the Gem Park Complex. Anomalous values of copper (mean - 49 ppm) suggest that significant quantities may be found elsewhere within the complex.

The second stage shows a dramatic increase in the rare earth content (mean >3.35%) and a threefold increase in niobium content (mean - 1754 ppm). Copper values remain consistent but the uranium content decreases substantially (highest value 3 ppm). Although of higher grade for niobium and rare earths, this stage is characterized by smaller dike-like occurrences in the holes studied. Larger masses of this stage of carbonatite may occur elsewhere within the complex and could prove a potential source for these elements.

The latest stage shows further enrichment in the rare earths (mean - >5.23% REE) but a dramatic decrease in niobium (mean - 190 ppm). Copper remains approximately constant but uranium is negligible. This coupled with the sparse nature of the dikes gives little economic potential to this stage.

The greatest economic potential lies in the discovery of large masses of low grade niobium and rare earths similar to those found in GP-17 or to larger occurrences of slightly higher grades as in GP-39. The potential for lead and zinc is minimal. Thorium content is high and might be recovered as a by-product.

The Gem Park carbonatites are mineralogically diverse and their genetic association with alkali gabbros make them an unusual complex; however, some comparisons with other carbonatite complexes can be made. Most other carbonatites have an overall mineralogy similar to Gem Park and contain calcite, dolomite, ankerite, apatite, magnetite, pyrite, and the dark micas (phlogopite and biotite) as common constituents.

Each complex differs by the amount of elemental substitution into these components or by the types and concentrations of accessory mineral assemblages.

In the Wet Mountain area of Colorado, other carbonatite occurrences such as the McClure Mountain and Democrat Creek Complexes are early Cambrian in age (Olson et al. 1977) and have similar mineralogies. The major difference, as with all other carbonatites, is that the Gem Park country rock consists of alkali gabbros with calcic plagioclase. Accessory minerals such as bastnasite, monazite, and pyrochlore occur in most carbonatites from the Wet Mountain area, only their quantities vary. Thorite is found at McClure Mountain but not at Gem Park (Armbrustmacher, 1979).

The Powderhorn (Iron Mountain) carbonatite complex of Colorado (Larsen, 1942) has an age of 580-520 m.y. (Jaffee et al., 1959), a carbonate mineralogy of dolomite with some calcite, and abundant titanium magnetite and rare earth apatite; all similar to Gem Park. Bastnasite and pyrochlore are present but in insignificant quantities. The Powderhorn district also contains thorite in veins with some minor perovskite. Magnet Cove, Arkansas (Erickson and Blade, 1963), is much younger (approximately 95 m.y.) and is dominantly a calcite-perovskite carbonatite. The Mountain Pass, California (Olson et al., 1954), occurrence is much older (1400 $\pm$50 m.y.) than Gem Park. The most common carbonatite type is a grey calcite-pink barite variety with monazite and bastnasite, and is almost identical to the late second stage of carbonatite development at Gem Park (core GP-39) as proposed in this study. Rare-earth element concentrations in the

Mountain Pass carbonatites vary from 0.0-18.64% with an average of 5-10%. At Gem Park, the available data suggests that average REE concentrations in the late stage carbonatites are at least greater than 5%.

The Mountain Pass carbonatites, like the Gem Park samples at this stage, lack niobium minerals and have low geochemical niobium values. Thorite is also present in shear zones.

Carbonates at Fen, Norway (Heinrich, 1966), are principally calcitic and contain the accessories pyrochlore, barite, zircon, albite, and sphene (not reported at Gem Park). An age of 565 m.y. (Faul, 1959) has been determined for the complex. The Palabora Igneous Complex of South Africa (Palabora Mining Company, Ltd., 1976) is greater than 200 m.y. in age with carbonatites of calcite, apatite, and titaniferous magnetite. The copper at Palabora reaches economic grade in the form of chalcopyrite and bornite. Unlike the Gem Park carbonatites; however, Palabora has no pyrochlore or niobium minerals.

The most important comparison to Gem Park can be made with a recent study by Secher and Larsen (1980) of the Sarfartog carbonatite complex of West Greenland. Carbonatite activity occurred between 500-600 m.y. ago and has a mineralogy almost identical to the early carbonatites at Gem Park: dolomite, titanium magnetite, rare earth apatite, U-REE bearing pyrochlore, and reverse pleochroic phlogopite. Late stage mineralized veins contain calcite, pyrite, hematite, siderite, sphalerite, galena, and the sulfates barite and gypsum; possibly analogous to samples in core GP-35. Temperature estimation by Secher and Larsen put these late stage veins into a hydrothermal realm and may suggest a similar hydrothermal occurrence for the late stage vein systems (GP-35) at Gem Park.

REFERENCES

Armbrustmacher, T.J. 1979. Replacement and primary magmatic carbonatites from the Wet Mountain area, Fremont and Custer Counties, Colorado. Econ. Geol. 74:888-901.

__________. 1980. Abundance and distribution of thorium in the carbonatite stock at Iron Hill, Powderhorn District, Gunnison County, Colorado. U.S.G.S. Prof. Pap. 1049-B. 11 pp.

Armbrustmacher, T.J. and I.K. Brownfield. 1978. Carbonatites in the Wet Mountains area, Custer and Fremont Counties, Colorado: analytical and mineralogical data. U.S.G.S. Open-File Rept. 78-177. 6 pp.

Armbrustmacher, T.J., I.K. Brownfield, and L.M. Osmonson. 1979. Multiple carbonatite dike at McClure Gulch, Wet Mountain alkalic province, Fremont County, Colorado. Mtn. Geol. 16(2):37-45.

Balashov, Y.A. and L.K. Pozharitskaya. 1968. Factors governing the behavior of rare-earth elements in the carbonatite process. Geochem. Int. 5:271-288.

Berry, L.G., ed. 1974. Selected powder diffraction data for minerals: data book. Joint Comm. on Powder Diffraction Standards, Pennsylvania. 833 pp.

__________. 1974. Selected powder diffraction data for minerals: search manual. Joint Comm. on Powder Diffraction Standards, Pennsylvania. 262 pp.

Chapin, C.E. and R.C. Epis. 1964. Some stratigraphic and structural features of the Thirty-nine Mile volcanic field, central Colorado. Mtn. Geol. 1(3):145-160.

Christman, R.A., M.R. Brock, R.C. Pearson, and Q.D. Singewald. 1959. Geology and thorium deposits of the Wet Mountains, Colorado. U.S.G.S. Bull. 1072-H. P. 491-535.

Coryell, C.D., J.W. Chase, and J.W. Winchester. 1963. A procedure of geochemical interpretation of terrestrial rare-earth abundance patterns. Jour. Geo. Research 68(2):559-566.

Daly, R.A. 1933. Igneous rocks and the depths of the earth. McGraw-Hill, New York.

Erickson, R. L. and L. Blade. 1963. Geochemistry and petrology of the alkalic igneous complex at Magnet Cove, Arkansas. U.S.G.S. Prof. Pap. 425.

Faul, H., P. Elmore, and W. Brannock. 1959. Age of the Fen carbonatite (Norway) and its relation to the intrusives of the Oslo region. Geochem. Cosmoschem. Acta. 17:153-156.

Gold, D.P. 1963. Average chemical composition of carbonatites. Econ. Geol. 58:988-996.

Heinrich, E.W. 1966. The Geology of carbonatites. Rand McNalley and Company, Chicago, Illinois. 555 pp.

Jaffee, H.W., D. Gottfried, C.L. Waring, and H.W. Worthing. 1959. Lead-alpha age determinations of accessory mineral of igneous rocks (1953-1957). U.S.G.S. Bull. 1097-B.

Kapustin, Y.L. 1966. Geochemistry of rare-elements in carbonatites. Geochem. Inst. 3(6):1054-1064.

Larsen, E.S. 1942. Alkalic rocks of Iron Hill, Gunnison County, Colorado. U.S.G.S. Prof. Pap. 197-A. 64 pp.

Loubet, M., M. Bernat, M. Javoy, and C.J. Allegre. 1972. Rare earth contents in carbonatites. Earth and Planet Sci. Let. 14:226-232.

MacNish, R.D. 1966. The Cenozoic history of the Wet Mountain Valley, Colorado. Dissert. Abs. Sec. B, Sci. and Eng. 27(7):2414B.

Munger, R.D. 1965. Structural geology of the Spread Eagle Park area, Sangre de Cristo Mountains, Colorado. Mtn. Geol. 2(1):3-21.

Olson, J.C., D.R. Shawe, L.C. Pray, and W.N. Sharp. 1954. Rare-earth mineral deposits of the Mountain Pass district, San Bernardino County, California. U.S.G.S. Prof. Pap. 261, 75 pp.

Olson, J.C., R.F. Marvin, R.L. Parker, and H.H. Mehnert. 1977. Age and tectonic setting of lower Paleozoic alkalic and mafic rocks, carbonatites, and thorium veins in south-central Colorado. U.S.G.S. Jour. Research. 5:673-687.

Palabora Mining Company, Ltd. 1976. The geology and the economic deposits of copper, iron, and vermiculite in the Palabora igneous complex: a brief review. Econ. Geol. 71:177-192.

Parker, R.L. and W.N. Sharp. 1970. Mafic-ultramafic igneous rocks and associated carbonatites of the Gem Park complex, Custer and Fremont Counties, Colorado. U.S.G.S. Prof. Pap. 649. 24 pp.

Pecora, W.T. 1956. Carbonatites, a review. Bull. Geol. Soc. Am. 67:1537-1556.

Rose, H., L. Blade, and M. Ross. 1958. Earthy monazite of Magnet Cove, Arkansas. Am. Min. 43:995-997.

Samoylov, V.S. and E.A. Rozvozzhayena. 1972. Behavior of rare elements in formation of carbonatites of rare metals. Int. Geol. Rev. 14(5): 440-449.

Schnetzler, C.C. and J.A. Philpotts. 1968. Partition coefficients of rare earth elements and barium between igneous matrix material and rock-forming mineral phenocrysts-I. Pages 929-938 in L.H. Ahrens, ed. Origin and distribution of the elements. Pergamon Press, New York.

Secher, K. and L.M. Larsen. 1980. Geology and mineralogy of the Sarfartôg carbonatite complex, southern West Greenland. Lithos 13:199-211.

Scott, G.R., R.B. Taylor, R.C. Epis, and R.A. Wobus. 1976. Geologic map of the Pueblo 1° x 2° quadrangle, south central Colorado. U.S.G.S. Misc. Field Studies Map, MF-775.

Taylor, R.B., G.R. Scott, R.A. Wobus, and R.C. Epis. 1975. Reconnaissance geologic map of the Cotopaxi 15-minute quadrangle, Fremont and Custer Counties, Colorado. U.S.G.S. Misc. Inv. Ser., Map I-900.

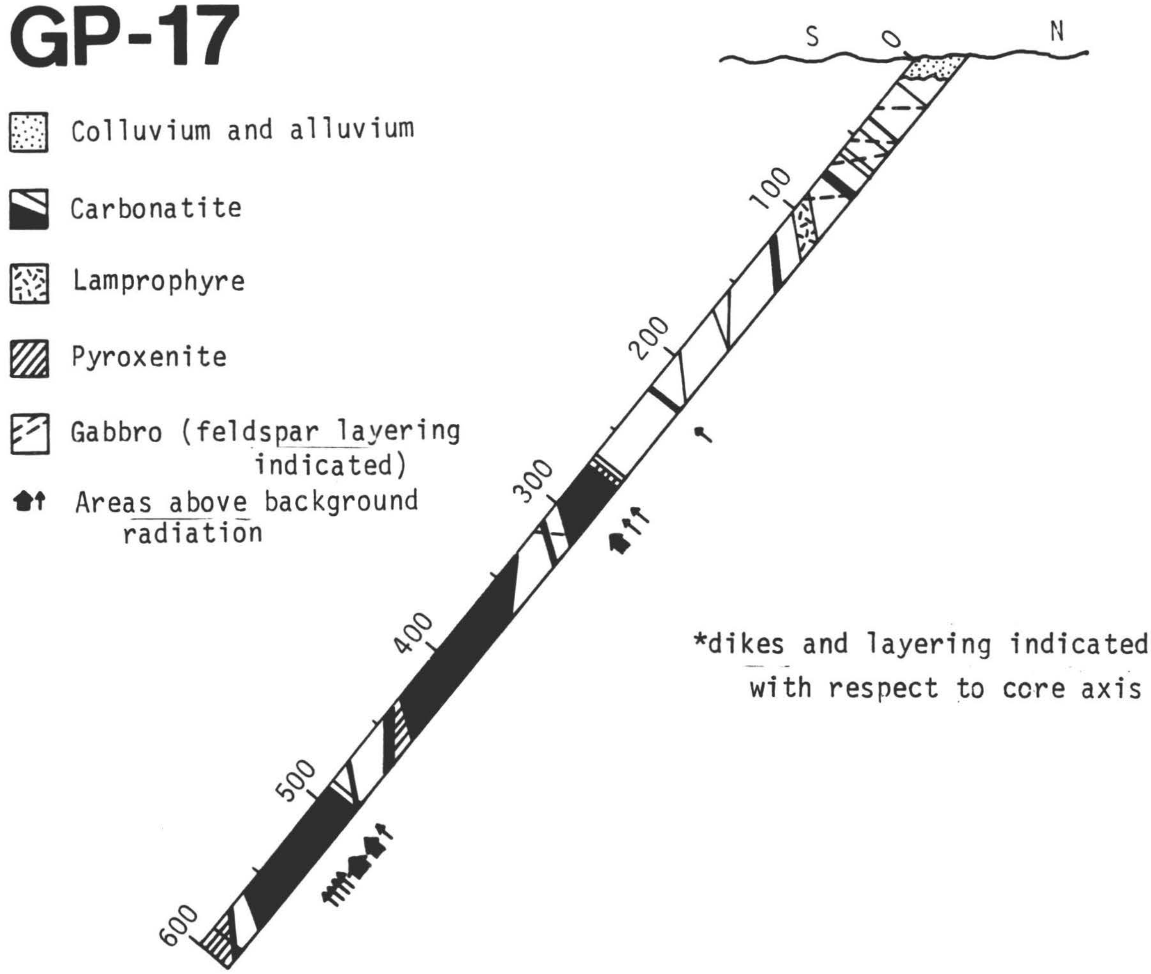
Vlasov, K.A. 1966. Mineralogy of rare elements. Israel Program for Scientific Translations, Inc., Jerusalem. 945 pp.

Warne, S. St. J. 1962. A quick field or laboratory staining scheme for the differentiation of the major carbonate minerals. J. Sed. Petrol. 32:29-38.

Wedepohl, K.E. 1971. Geochemistry. Holt, Rinehart, and Winston, New York. 231 pp.

APPENDIX

GP-17



Core Description

Feet	
0.0-12.0	No recovery - colluvium and alluvium
12.0-99.0	Gabbro - coarse grained; layering or foliation of plagioclase common; approximately 25% plagioclase, 75% pyroxene; oxidized in upper section
13.2-16.0	Questionable carbonatite dike; phlogopite and dolomite grains common but highly oxidized
30.0	5" white dolomite dike with minor magnetite and phlogopite
37.5-40.0	Dolomite dike with dispersed red-green phlogopite; pyrolusite dendrites present
44.0-47.0	Granular dolomite and phlogopite; near 47.0, dolomite "pebbles" are extremely rounded
55.5	6" white dolomite dike
57.2-58.6	Highly altered zone of dolomite and phlogopite
63.4-65.8	Soft, friable green phlogopite with associated dolomite
71.0-78.0	Granular dolomite at upper contact with some magnetite and pyrochlore; upper section contains disseminated black acicular mineral which reacts with HCl; down section from white dolomite to blue-grey in color

with inclusions of pyrite and magnetite and possibly columbite

90.0-94.5 Irregular dikes and flooded gabbro; 2% pyrite with minor chalcopyrite

99.0-113.3 Lamprophyre - gradational contact; fine grained and equigranular; six small carbonatite dikes, some laminated parallel to borders with phlogopite

113.3-183.2 Gabbro - layering absent or indistinct; pyrite up to 3% in areas; small carbonatite dikes generally irregular in distribution, 1-3 dikes per 10'

122.4-126.3 Highly fractured gabbro with abundant carbonatite dikes; larger dikes contain gabbro xenoliths

126.3-129.6 Fairly barren white dolomite carbonatite

129.6-135.0 Abundant small carbonatite dikes generally at 45° to CA; flooded gabbro high in feldspar and pink mineral

135.0-138.6 Carbonatite dikes at 0-10° to CA; abundant green apatite, phlogopite, and pyrite

166.0-167.4 Carbonatite with xenoliths of gabbro

175.0-176.0 Carbonatite with white and blue dolomite

183.2-184.1 Lamprophyre

184.1-195.0 Gabbro and/or lamprophyre - highly fractured and fenitized

195.0-270.0 Gabbro - medium grained with fine grained intervals; small carbonatite dikes generally widely spaced

206.5 6" fine grained dolomite and phlogopite dike

220.4-224.2 Carbonatite with coarse (up to 2 cm) phlogopite in upper section; white dolomite and sugary apatite with associated pyrochlore and zircon

266.3-268.4 Coarse grained blue dolomite dike with zircon; pyrite and magnetite increase down section

270.0-273.9 Pyroxenite - medium grained pyroxene and magnetite

273.9-306.4 Carbonatite - highly variable mass of dolomite; fenitized carbonate and country rock at borders

273.9-276.1 Blue and white dolomite with minor pyrite and phlogopite; green apatite down section

276.1-280.0 Massive magnetite and green apatite

280.0-285.0 Magnetite disseminated in dolomite and green apatite; pink mineral (zircon?) common

285.0-290.7 Pegmatitic dolomite and phlogopite; coarse magnetite; pods of coarse phlogopite and magnetite; barren dolomite down section with magnetite content minimal

290.7-292.9 Blue dolomite; green phlogopite; minor pyrite

292.9-296.6 Massive magnetite with abundant pyrite

296.6-306.4 White dolomite; green apatite; minor pyrite, magnetite, and pink mineral; some barren sections

306.4-312.0 Gabbro with abundant small carbonatite dikes; fenitized

312.0-314.6 Gabbro - coarse with plagioclase foliation

314.6-341.2 Gabbro - medium grained; no visible foliation; small carbonatite dikes common

318.0-322.4 Barren blue dolomite except for minor phlogopite, pyrite, and magnetite; magnetite increases down section

329.0-330.7 Gabbro highly fractured with abundant hairline carbonatite dikes

341.2-346.1 Gabbro with abundant hairline carbonatite dikes; mild fenitization throughout

346.1-436.0 Carbonatite - highly variable mineralogy; carbonates vary from very coarse white dolomite to medium and fine grained blue and white dolomite; green apatite, phlogopite, and magnetite common; some dolomite is barren or vuggy, clay minerals fill some vugs; many small colored minerals present

362.8-364.9 Barren white dolomite

377.9-390.3 Barren white to blue dolomite

392.1-393.4 Barren white dolomite with local concentrations of magnetite

408.2-421.4 Barren white dolomite cut by dikes of apatite and magnetite

430.1-436.0 Blue dolomite with phlogopite and apatite; near contact are fenitized gabbro xenoliths

436.0-445.2 Pyroxenite - medium grained; minor fenitization along borders

445.2-453.6 Carbonatite - blue dolomite with apatite and magnetite; xenoliths of pyroxenite; areas of barren white dolomite common

453.6-488.9 Gabbro - medium grained with magnetite present; fenitized in upper section; scattered carbonatite dikes, some with possible RE mineralizations; gabbro coarser grained down section

480.3-482.1 White carbonatite; possible RE minerals; minor fenitized borders

486.8-487.9 Blue dolomite; pyrite; magnetite; phlogopite

488.9-568.5 Carbonatite - variable mineralogy; blue and white dolomite common along section; apatite, phlogopite, and magnetite common; minor RE minerals possible

500.2-502.0 Massive magnetite; abundant phlogopite

504.0-505.8 Massive magnetite

508.0-509.0 Barren white dolomite; vuggy in spots

512.9-515.1 Massive magnetite

524.0 Rare earth dike?

544.3 Possible rare earth mineralization in vugs

550.7-557.6 Coarse white dolomite with pyrite stringers

558.4-559.5 Massive magnetite

568.5-576.4 Gabbro - medium grained with fenitized borders; abundant hairline carbonatite dikes

576.4-580.0 Carbonatite - blue dolomite grading towards white down section

580.0-600.0 Pyroxenite - medium grained; carbonate stringers along contact; very few carbonatite dikes

586.9-590.0 White dolomite with minor phlogopite and pyrite; magnetite borders with pyroxenite

GP-35

Colluvium and alluvium

Gabbro (feldspar layering indicated)

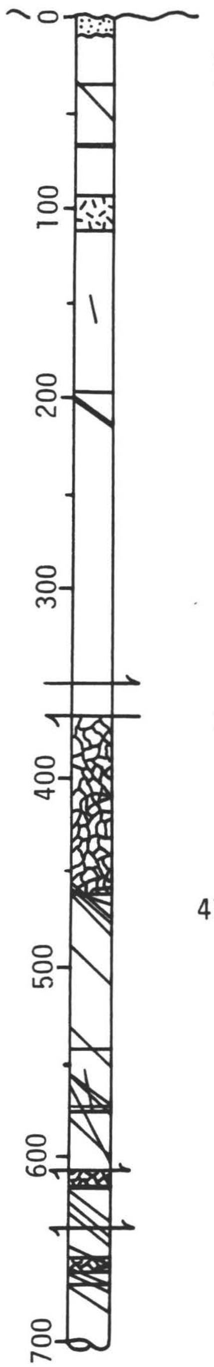
Carbonatite

Gabbro w/gypsum stockwork

Lamprophyre

Fault

*dikes and layering indicated with respect to core axis



Feet

0.0-10.0 No recovery - colluvium and alluvium

10.0-366.0 Gabbro - medium to coarse grained; no visible layering of plagioclase; altered for most of section; small number of small carbonatite dikes

- 66.0-68.0 Carbonatite dike; 6" radioactive red dike
- 93.5-111.0 Lamprophyre with some magnetite and pyrite
- 121.0-123.0 Blue amphibole; green phlogopite; apatite abundant pyrite
- 217.2-219.4 Blue and white dolomite; magnetite; apatite; phlogopite; green RE? mineral
- 220.0 Blue amphibole and plagioclase
- 249.1-309.0 Blue amphibole and mica concentrations; sugary texture; highly fractured; calcite in fractures
- 309.0 Fracturing less common
- 348.8-367.0 Highly fractured and granulated; fault?

367.0-471.0 Gabbro with gypsum stockwork - highly fractured zone with abundant (2-3 per inch) gypsum veins which range from 1/8 to 1/4" in width; pyrite abundant; phlogopite locally abundant

471.0-1470.0 Gabbro - pyroxene and plagioclase; medium grained; blue amphibole in areas; dikes abundant but often widespread; many have red rare earth minerals; fenitization intensity varies widely

- 529.1-554.8 Highly fenitized gabbro
- 573.9-576.4 White dolomite dike with abundant monazite
- 610.0-617.3 Gabbro with gypsum stockwork
- 617.3-618.9 White to blue dolomite with pink RE? mineral
- 638.0-640.0 Possible fault; granulated gabbro
- 654.4-661.1 Gabbro with gypsum stockwork

GP-35 (con't.)

755.7-761.2	White dolomite with minor red RE mineral; pyrite; minor phlogopite
781.5-783.9	White dolomite with pink mineral and dark red RE mineral
860.0	Plagioclase laths become foliated or layered from here down section
922.5	5" grey to white dolomite with minor pink mineral, phlogopite, and pyrite
1003.0	Concentration of biotite and magnetite
1014.5	Small lamprophyre dike
1028.2	Small lamprophyre dike
1050.3	8" dolomite, RE mineral, magnetite
1066.3	12" dike with RE mineral and biotite
1164.2	8" upper white dolomite, RE mineral, and phlogopite; lower blue dolomite and apatite
1293.1	Lamprophyre dike
1316.9-1318	Layered carbonatite; white dolomite; green apatite; minor RE mineral
1347.0	Small lamprophyre dike
1423.2-1431	Zone of massive magnetite and biotite
1438.2	6" white dolomite dike with red RE mineral

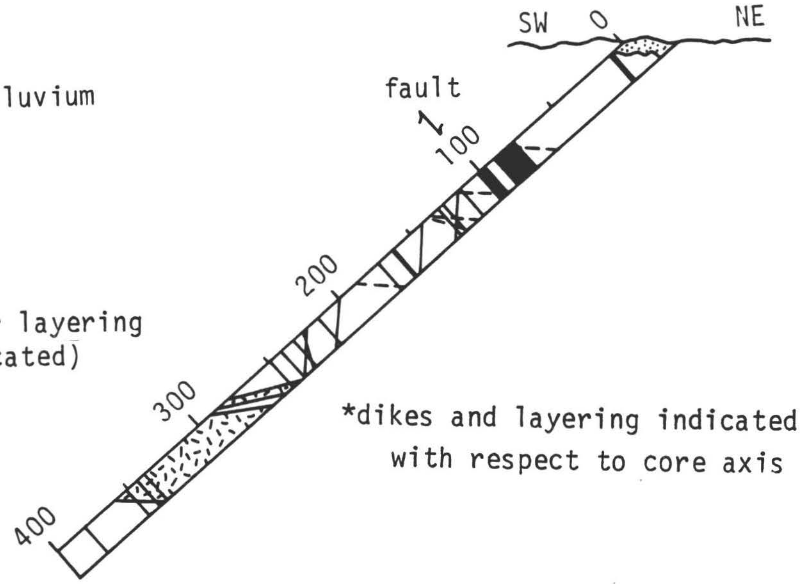
GP-39

Colluvium and alluvium

Carbonatite

Lamprophyre

Gabbro (feldspar layering indicated)



Core Description

Feet	
0.0-6.0	No recovery - colluvium and alluvium
6.0-9.0	Carbonatite - white dolomite often in rounded clasts monazite in red mineral matrix
9.0-78.2	Gabbro - dominantly pyroxene and plagioclase with minor phlogopite; magnetite extremely rare; medium to coarse grained gabbro often pegmatitic with randomly oriented apatite needles and minor olivine associated with plagioclase; these zones often high in magnetite
78.2-90.2	Carbonatite - red and pink mineralization with abundant iron staining and alteration of pyrite to hematite; dolomite grey in color; pyrite in local concentrations
81.0	Approximately 20% RE minerals
85.0	No RE minerals; 1' section of white to grey dolomite
88.0	1' section of extremely dark dolomite with dark red to brown minerals; minor chalcopyrite
90.2-98.0	Gabbro - layered plagioclase with 2-4' fenitized borders
96.4	Possible fault
98.0-103.0	Carbonatite - grey dolomite with dispersed RE minerals; minerals green, dark brown, pink, and orange red
103.0-213.5	Gabbro - often layered; fenitized upper border; medium to coarse grained; pyrite, magnetite, and minor chalcopyrite; irregular carbonatite dikes often with fenitized borders
117.0	6" carbonatite dike with RE mineralization
163.0	2' carbonatite dike; highly oxidized with fenitized borders
263.5-270.0	Lamprophyre - fine grained pyroxene and plagioclase with no apparent orientation

270.0-275.0	Gabbro - medium to coarse grained; no layering
275.0-345.0	Lamprophyre - fined grained; highly fractured with small carbonatite dikes scattered sporatically throughout
300.0	Hairline RE dikes, one or two per foot
343.0	1¼' zone of massive magnetite with minor phlogopite
345.0-400.0	Gabbro - medium to coarse grained with periodic foliation
353.0	6" zone of coarse grained biotite and/or phlogopite