

Mafic-Ultramafic Igneous Rocks
And Associated Carbonatites
of the Gem Park Complex,
Custer and Fremont Counties,
Colorado

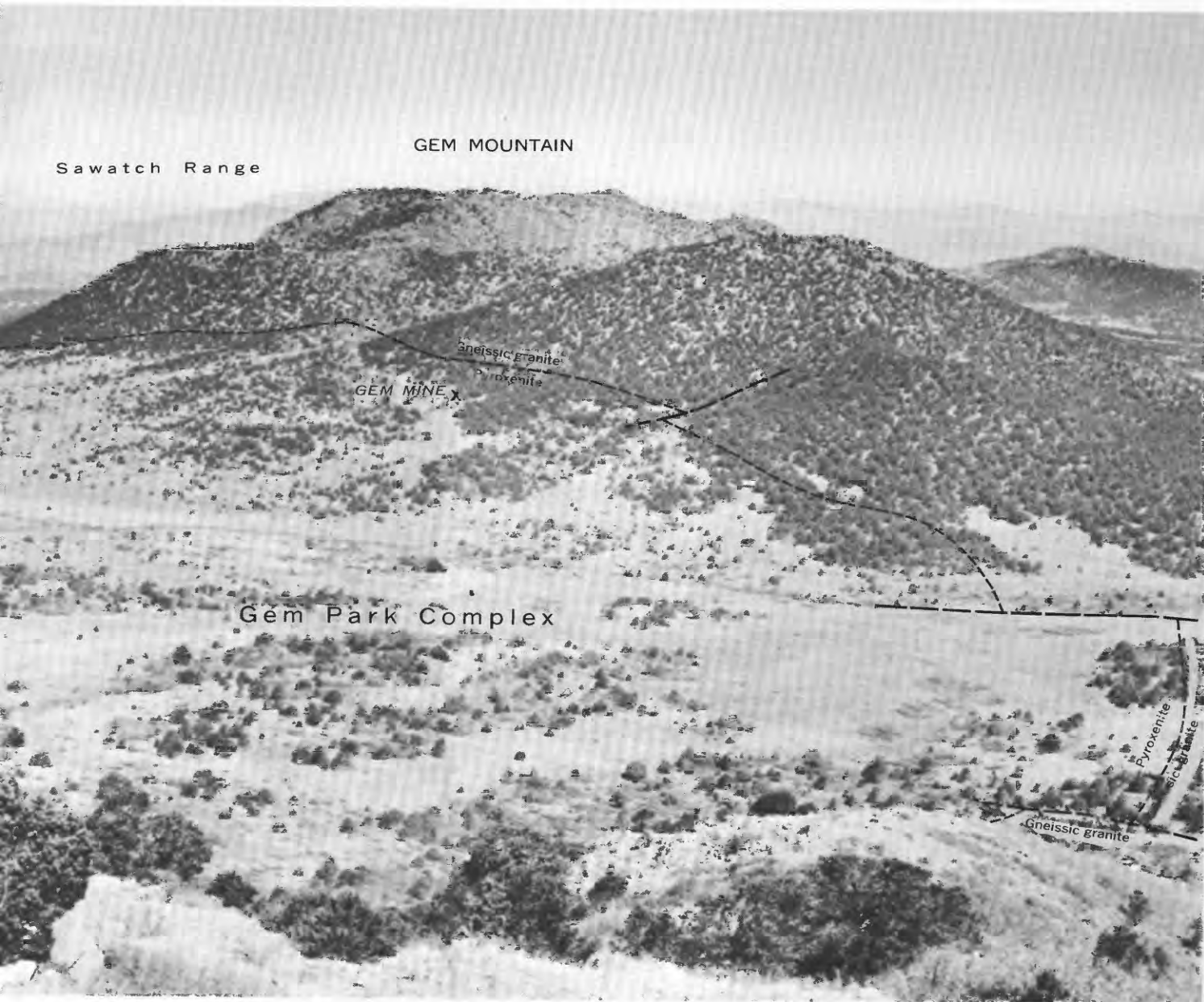
GEOLOGICAL SURVEY PROFESSIONAL PAPER 649



**MAFIC-ULTRAMAFIC IGNEOUS ROCKS
AND ASSOCIATED CARBONATITES
OF THE GEM PARK COMPLEX,
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COLORADO**



Gem Park, Colo. View northwestward from Democratic Mountain



Showing pyroxenite and gabbro of the Gem Park Complex.

Mafic-Ultramafic Igneous Rocks And Associated Carbonatites of the Gem Park Complex, Custer and Fremont Counties, Colorado

By RAYMOND L. PARKER *and* WILLIAM N. SHARP

GEOLOGICAL SURVEY PROFESSIONAL PAPER 649

*The Gem Park Complex—its geology
and mineralogy, and its niobium
distribution*



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MAFIC-ULTRAMAFIC IGNEOUS ROCKS AND ASSOCIATED CARBONATITES OF THE GEM PARK COMPLEX, CUSTER AND FREMONT COUNTIES, COLORADO

By RAYMOND L. PARKER and WILLIAM N. SHARP

ABSTRACT

The Gem Park Complex (a new name in this report), which lies about 11 miles northwest of Westcliffe, Colo., is a small funnel-shaped composite body related to the McClure Mountain Complex a few miles to the northeast. The Gem Park Complex consists mostly of pyroxenite and gabbro with minor dikes and bodies of lamprophyre, syenite porphyry, and nepheline syenite pegmatite, and abundant dikes and irregular bodies of carbonatite, all of Cambrian age. A mass of fenite lies near the center of the complex. The whole complex lies discordantly in Precambrian gneissic terrane and is overlain by Tertiary volcanic rocks. Large areas in the complex are covered by Quaternary alluvium and colluvium.

Some carbonatite dikes and fenite contain concentrations of niobium, rare-earth elements, thorium, phosphorus, some other elements, and vermiculite.

The arrangement of carbonatite dikes, the position of the fenite, and other features suggest that a large carbonatite body lies beneath the surface near the center of the complex.

INTRODUCTION

The complex of mafic and ultramafic igneous rocks and associated carbonatites, herein formally designated the Gem Park Complex, underlies an area of about 2 square miles at Gem Park, a small oval valley in the northern Wet Mountains, Fremont and Custer Counties, Colo., about 21 miles southwest of Canon City and about 11 miles northwest of Westcliffe which is designated as the type area. The complex is similar in composition to part of the mafic and ultramafic rock complex at Iron Mountain, about 9 miles to the northeast in the McClure Mountain Complex (Shawe and Parker, 1967). (See fig. 1.)

Shawe and Parker (1967) have shown that the Iron Mountain rocks are related to and are formally part of the syenites and associated rocks of the McClure Mountain Complex; the Gem Park rocks are judged to be related to the McClure Mountain Complex. All these rocks were described in a preliminary report by Parker and Hildebrand (1963) and were reviewed by Heinrich and Dahlem (1966).

No organized geologic work was done in Gem Park until the series of studies began in 1962. The discovery in 1962 of a niobium mineral, lueshite, in Gem Park (Parker and others, 1962) led the authors to investigate

the geologic relationships in the region. With the discovery of the McClure Mountain Complex the senior author instigated the study reported here.

Gem Park has been the site of limited mining since the 1880's. The Gem mine, which consists of a group of shallow workings at the north edge of Gem Park, produced an unknown but small quantity of nickel-silver ore prior to 1885. The old vermiculite mine in the central part of the complex (called the Vermiculite mine in this report) and the Niles mine at the west edge of the complex produced a combined total of somewhat less than 3,000 tons of vermiculite during and just prior to World War II (A. L. Bush, oral commun., 1968). A minor tonnage of magnetite ore was scraped from the surface at the south border of the complex but the amount recovered and other data pertaining to that activity are not known.

We thank Mr. D. W. Fieldman, of the Congdon and Carey Co., and the Cleavenger Land and Cattle Co. for allowing access to properties in the Gem Park area, and Prof. A. G. Bulakh, of Leningrad University, who generously furnished information on natroniobite and other rare minerals from the Kola Peninsula, U.S.S.R. We also thank U.S. Geological Survey colleagues F. A. Hildebrand, who conducted both field and laboratory work early in the study, R. B. Taylor, who made some of the photomicrographs used in the report, and J. W. Adams, who advised on problems in mineralogy and in the preparation of the manuscript.

GENERAL GEOLOGY

The mafic and ultramafic rocks and related dikes of the Gem Park Complex discordantly intrude gneiss, amphibolite, and other metamorphic rocks of Precambrian age. Volcanic rocks of Tertiary age border Gem Park on the south and overlie both the Gem Park Complex, which is of Cambrian age, and the Precambrian metamorphic rocks. Large areas in Gem Park are covered by alluvium or colluvium. The complex weathers more readily than the enclosing gneissic rocks and consequently it is expressed as a topographic basin. The general geology of Gem Park is shown on plate 1.

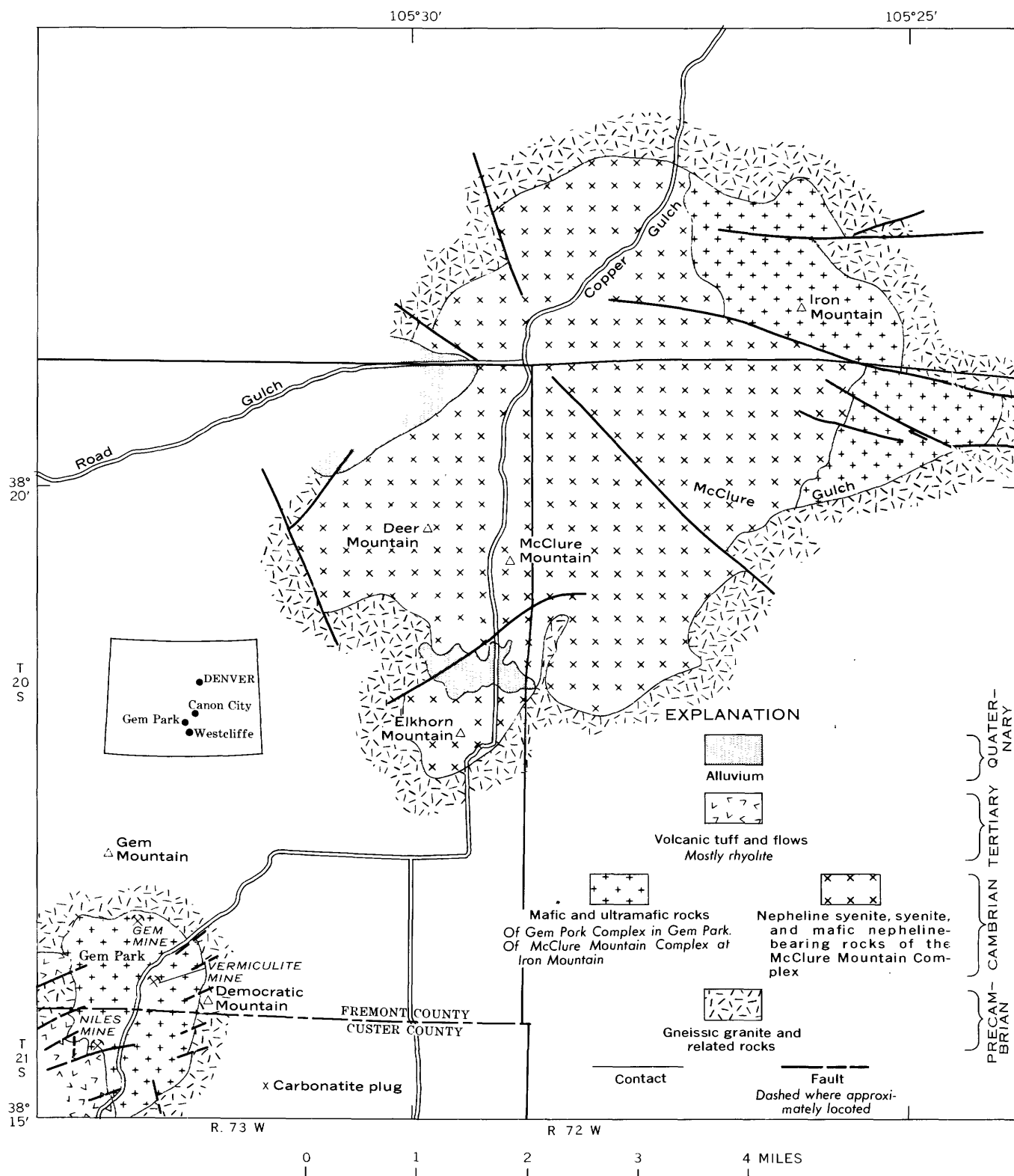


FIGURE 1.—Location and geologic setting of the mafic-ultramafic Gem Park Complex and the McClure Mountain Complex. Fremont and Custer Counties, Colo.

PRECAMBRIAN ROCKS

The country rocks that enclose the Gem Park Complex are part of a sequence of metamorphic rocks, most of which lies north of Westcliffe and Silver Cliff, that was inferred by Christman, Brock, Pearson, and Singewald (1959) and Brock and Singewald (1968) to be Precambrian in age. These rocks are mostly metasedimentary, and in the vicinity of Gem Park are chiefly gneissic granite with greatly subordinate granitic gneiss, amphibolite, and hornblende gneiss.

Inclusions of metamorphic rocks, commonly less than a few tens of feet across, are found in a few places in the south part of the complex. The most distinctive inclusions are composed of quartzite in which the original quartz is largely unaltered but in part has been replaced by aegirine. Other inclusions, which were originally gneiss and which retain their original texture, have been partly assimilated and made over to the composition of gabbro.

CAMBRIAN ROCKS

Pyroxenite and gabbro make up most of the Gem Park Complex. These rocks are intruded by lamprophyre and syenite porphyry dikes and abundant discontinuous dikes and plugs of carbonatite, and all are considered to be Cambrian in age. The Precambrian country rocks are also intruded by the dikes.

Pyroxenite, of medium- and coarse-grained varieties but mapped as a single unit (pl. 1), makes up about half of the Gem Park Complex. Gabbro, of several varieties but also mapped as a single unit (pl. 1), makes up most of the remainder of the complex. These rocks and others composing the Gem Park Complex are described in detail in subsequent sections of the report.

The Gem Park Complex is considered, on the basis of recent isotopic age determinations, to be Cambrian in age. Potassium-argon ages for syenites in the related McClure Mountain Complex have been determined, by R. F. Marvin of the U.S. Geological Survey, in the range 508(± 15) to 532(± 27) million years before present. A less precise determination by Marvin on crocidolite from fenitized pyroxenite at the Vermiculite mine in Gem Park is 551(± 55) m.y. B.P., close to the age of the syenites and in support of a genetic relationship between the McClure Mountain and Gem Park Complexes.

TERTIARY VOLCANIC ROCKS AND GRAVEL

Gem Park is bordered on the west by Tertiary volcanic rocks and interlayered boulder gravel. The volcanic rocks exposed at the edge of Gem Park are chiefly rhyolitic welded tuff and less abundant porphyritic biotite latite flows and ashy water-laid tuff. The stratigraphic sequence from oldest to youngest seems to be: porphyritic latite flows, ashy water-laid tuff, boulder gravel, and welded tuff. These rocks dip gently west, and in most

places they cover the west contact between the Gem Park Complex and the gneissic granite and related country rocks. The volcanic rocks extend to the west for about 2 miles, where they are covered by alluvium of the Wet Mountain Valley. These rocks have not been studied in detail in the present work, and therefore are only briefly described here.

The basal latite flows are pale purple to light gray and contain abundant oligoclase crystals, averaging about 3 millimeters in length, and biotite laths, both in a dense groundmass.

The overlying ashy tuff, found only at the southwest corner of the area mapped (pl. 1), is friable and light gray to white. It is heterogeneous and is composed principally of ash and of lithic tuff fragments mostly less than 10 mm across. Crystal fragments are subordinate to ash and rock fragments, and therefore the rock has generally a lusterless ashy appearance. Some lenses or layers appear to be water sorted. The localized distribution suggests that this tuff filled in drainages and low areas in the pre-volcanic and intravolcanic topography.

The boulder gravel above the ashy tuff consists of poorly sorted fragments of gneissic granite, amphibolite, and other gneissic rocks as well as gabbro and pyroxenite. Fragments range in size from silt and sand to boulders several feet across. Many fragments are fenite apparently derived from near the contact with the Gem Park Complex or from gneissic wallrock bordering carbonatite dikes. The fragments of the gravel are more rounded, more deeply weathered, and more heterogeneous than the slope debris found on present gneissic granite slopes. The boulder gravel is believed to represent channel fillings or terraces developed prior to the deposition of the overlying welded tuff.

The welded tuff, which is rhyolitic and very compact, has a pale-brownish-gray groundmass of devitrified material that contains abundant crystal fragments of clear feldspar and quartz and widely scattered compressed pumice fragments and small lithic fragments.

The welded tuff has been correlated with ash flow 7 of the Thirtynine Mile volcanic pile (Chapin and Epis, 1964) by G. R. Scott (oral commun., 1968) of the U.S. Geological Survey. Welded tuff at the edge of the Wet Mountain Valley about 2 miles west of Gem Park has been dated by the potassium-argon method as 33.6 (± 1.1) m. y. old or Oligocene in age (MacNish, 1966, p. 36).

QUATERNARY ALLUVIUM AND COLLUVIUM

Except for the bedrock outcrops (shown on pl. 1), Gem Park is covered with alluvium consisting mostly of light-brownish-gray clay and silt with subordinate rock fragments derived from surrounding terrain as well as from the Gem Park Complex itself. The thickness of the allu-

vium is variable but in places is as much as 10 feet, as in the walls of the Vermiculite mine in the center of the complex.

STRUCTURE

The Gem Park Complex is roughly circular in plan though somewhat elongated northward. The west contact between the rocks of the complex and the enclosing Precambrian rocks, where concealed by Tertiary volcanic rocks, is not far west of the volcanic contact, as indicated by exploratory magnetometer traverses by J. E. Case of the U.S. Geological Survey.

The gabbro and pyroxenite form units that are generally concentric with the circular outline of the complex (pl. 1). Planar structure in the gabbro is also concentric and dips consistently toward the center of the complex. These features suggest that the Gem Park Complex may be a funnel-shaped layered body, like the mafic-ultramafic complex at Iron Mountain, about 9 miles to the northeast. Distinct layers have not been recognized in outcrop, however, because of limited exposures and slight topographic relief in Gem Park. The concentric arrangement of pyroxenite and gabbro can be interpreted either as an expression of layers in a stratiform mass or as discordant ring structures or cone sheet multiple intrusions. Ring structures and cone sheets are common in many alkalic rock complexes in various parts of the world, and may well occur at Gem Park. Possibly both stratiform and discordant bodies are present.

Several northeast-trending high-angle normal faults cut the Gem Park Complex and also the younger volcanic rocks that border the complex on the west. These faults are therefore Oligocene or younger in age (if rejuvenation of prevolcanic faults along the same zones is discounted). At least one northwest-trending fault offsets the south border of the complex, but the relation of this fault to others cutting the complex is obscured by cover. Faults are conspicuous at the borders of the complex, but do not stand out in Gem Park itself because of alluvial and colluvial cover and the massive nature of the pyroxenite and gabbro, in which offsets are mostly unrecognizable.

GEM PARK COMPLEX PYROXENITE

Two principal varieties of pyroxenite—coarse and medium grained—are present in the Gem Park Complex. The coarse-grained pyroxenite forms a conspicuous peripheral zone at the north, east, and south sides of the complex, and it forms discontinuous masses throughout the complex. Whether it also forms a zone at the west border of the complex is not known, inasmuch as this contact is concealed by volcanic rocks.

Pyroxenite, in both coarse- and medium-grained varieties, is also conspicuous in the central part of the

complex in the area surrounding the Vermiculite mine and in the low hills to the south and east of the mine. Here pyroxenite units form a concentric ring-shaped map pattern which is centered approximately at the Vermiculite mine; locally they enclose small bodies of gabbro a few hundred feet or less in length.

The pyroxenite is composed largely of clinopyroxene, but it also contains small amounts of brown and green amphibole, minor plagioclase (labradorite), and accessory magnetite, apatite, and rare sphene. Some pyroxene-

TABLE 1.—*Chemical analyses and norms, in weight percent, of some rocks from the Gem Park Complex*
[Chemical analyses by Ellen Daniels]

Field No.	WM-64-843	WM-64-859	WM-64-875
Laboratory No.	D100999	D101000	D101001
Rock type	Syenite (dike)	Gabbro	Pyroxenite
Chemical analyses			
SiO ₂	62.27	39.16	45.31
Al ₂ O ₃	17.41	13.72	7.03
Fe ₂ O ₃	3.87	7.50	3.98
FeO .....	.79	9.79	6.05
MgO .....	.59	6.68	12.84
CaO .....	.70	12.12	19.99
Na ₂ O	7.63	2.56	.82
K ₂ O	3.97	.45	.17
H ₂ O+	1.10	1.06	.63
H ₂ O- .....	.66	.10	.21
TiO ₂ .....	.72	4.42	2.50
P ₂ O ₅ .....	.29	1.06	.14
MnO .....	.04	.21	.15
CO ₂ .....	.02	.99	.40
Cl .....	.02	.04	.02
F .....	.12	.12	.04
Subtotal	100.20	99.98	100.28
Less O .....	.05	.06	.02
Total	100.15	99.92	100.26
Norms			
Q	1.656	0.000	0.000
C .....	.351	.000	.000
Or	23.832	2.691	1.010
Ab	65.436	19.308	.155
An .....	.678	25.069	15.163
Ne .....	.000	1.253	3.616
Al .....	.033	.067	.033
Wo .....	.000	9.143	33.760
En	1.493	6.461	26.658
Fs .....	.000	1.893	3.311
Fe .....	.000	7.270	3.855
Fa .....	.000	2.347	.528
Mt .....	.599	11.004	5.803
Hm	3.518	.000	.000
Il	1.389	8.495	4.775
Ap .....	.698	2.541	.333
Fr .....	.223	.151	.070
Ce .....	.046	2.278	.915
Salic	91.986	48.388	19.976
Femic	7.967	51.583	80.008
Di .....	.000	17.497	63.730
Di-Wo .....	.000	9.143	33.760
Di-En .....	.000	6.461	26.658
Di-Fs .....	.000	1.893	3.311
Hy	1.493	.000	.000
Hy-En	1.493	.000	.000
Hy-Fs .....	.000	.000	.000
Ol .....	.000	9.616	4.382
Ol-Fe .....	.000	7.270	3.855
Ol-Fa .....	.000	2.347	.528
W-Ol .....	.000	.000	.000

TABLE 2.—Modes, in volume percent, of pyroxenite and gabbro from the Gem Park Complex

Rock type	Pyroxenite			Gabbro				
Grain size	Coarse	Medium	Medium	Fine	Medium	Coarse	Coarse	Coarse
Field No. WM-64	875	891	858	840	841	839	852	859
Plagioclase	Trace	2	5	55	56	55	52	37
(An content)				(An ₆₈₋₆₀)	(An ₆₈₋₆₀)	(An ₆₆₋₆₈)	(An ₅₄₊)	(An ₆₈₋₆₀)
Pyroxene	86	74	65	29	38	32	29	35
Olivine				6	5	4	6	
Magnetite	2	7	10	1	<1	6	9	11
Brown amphibole	10	7	15					13
Biotite	Trace	1	Trace	9	<1	2	3	<1
Pyrite (and other sulfides)		5						<1
Apatite	2		<1			<1	<1	2
Serpentine	<1			<1				
Carbonate-chlorite	<1		5					
Sericite		5		<1				

nite also contains minor disseminated sulfides—pyrite, pyrrhotite, and chalcopyrite. The norm and chemical analysis of a typical pyroxenite from Gem Park are given in table 1, and the modes of pyroxenites from Gem Park are given in table 2.

Typical pyroxenite near the periphery of the complex is composed of about 86 percent randomly oriented clinopyroxene crystals, which are strongly zoned concentrically or in an oscillatory fashion, about 10 percent strongly pleochroic brown amphibole, and about 4 percent apatite and anhedral magnetite. Scarce anhedral grains of calcic labradorite or bytownite with poorly developed albite twinning occur interstitially. Some plagioclase is strongly sericitized. Locally parts of the rock are altered to tiny aggregates of carbonate, chlorite, and possibly serpentine. Other varieties of pyroxenite in Gem Park are generally similar in mineral composition but vary somewhat in texture and grain size. Some contain minor brown biotite. A photomicrograph of coarsely crystalline pyroxenite is shown in figure 2.

The pyroxenite at Gem Park is similar to that at Iron Mountain (Shawe and Parker, 1967). Pyroxene from these rocks at both localities is monoclinic and commonly contains schiller structure formed by extremely small rods of a black opaque mineral, probably magnetite, oriented along crystallographic directions.

Strongly pleochroic brown amphibole (probably kaersutite, a titanium-rich hornblende) is a conspicuous mineral of the pyroxenite at Gem Park as well as at Iron Mountain. Its presence reflects the alkalic affinity of these pyroxenites. The brown amphibole is commonly associated with magnetite and pyroxene; it commonly rims magnetite grains, but is enclosed in pyroxene which it seems to replace (fig. 2). In some pyroxenite this amphibole forms large poikilitic plates enclosing magnetite, partly replaced pyroxene grains, and minor aggregates of green amphibole, carbonate, and sphene. The

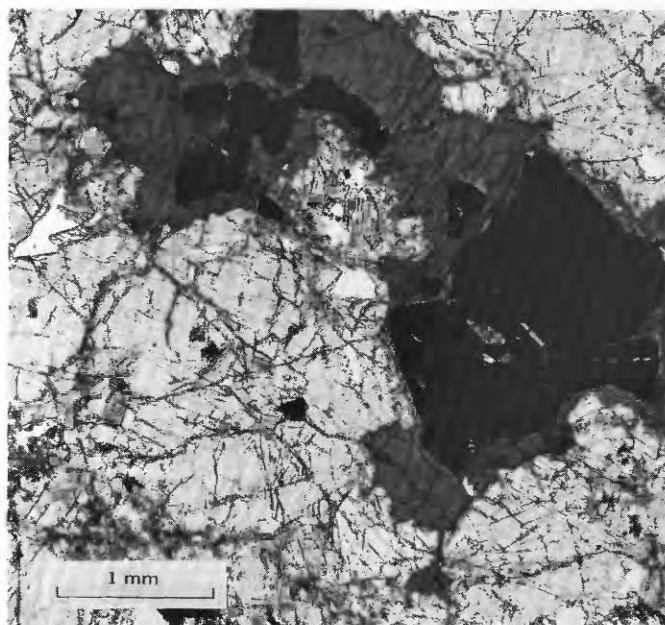


FIGURE 2.—Photomicrograph of coarsely crystalline pyroxenite showing relations among clinopyroxene (white), brown amphibole (gray), and magnetite (black).

green amphibole is probably altered from the brown variety.

GABBRO AND ASSOCIATED ROCKS

Gabbro makes up a large part of the Gem Park Complex and is approximately as abundant as pyroxenite. These two rock types are mutually associated and at various places in the complex either may be enclosed in the other as layers, lenses, or discordant bodies. Gabbro is predominant in the south half of the complex and forms a large mass at the center of the complex west of the Vermiculite mine. Planar structure shown by the orientation of plagioclase and pyroxene crystals is concentric

with the outer contact and dips toward the center of the complex (pl. 1).

Several varieties of gabbro are present in the Gem Park Complex; the variation among them is due mostly to differences in proportions of pyroxene, plagioclase, and olivine and to differences in grain size. These rocks range in composition from those that contain abundant pyroxene (near pyroxenite) to those that are predominantly plagioclase (near anorthosite). Some gabbros are rich in olivine. Modal analyses of several gabbros from Gem Park are given in table 2. Chemical analysis and norm of a typical brown amphibole- and magnetite-rich variety of gabbro from Gem Park are given in table 1.

The gabbro at Gem Park is composed principally of labradorite (An_{54-60}), clinopyroxene, olivine, brown amphibole, and magnetite. Of those gabbros analyzed, labradorite comprises 37–55 percent; clinopyroxene, 29–35 percent; olivine, 0–6 percent; brown amphibole, 0–13 percent; and magnetite, <1–11 percent. Brown amphibole similar to that found in the pyroxenite is an abundant constituent of some gabbro; however, in some varieties of gabbro, brown biotite is found in the same association as the brown amphibole.

The texture of the gabbro is mostly hypautomorphic-granular, although in some medium-grained rocks the crystals are xenomorphic and equant and produce an equigranular texture. Grain size ranges from coarse to fine. Some coarse-grained gabbro consists of long labradorite crystals arranged in a jackstraw manner which

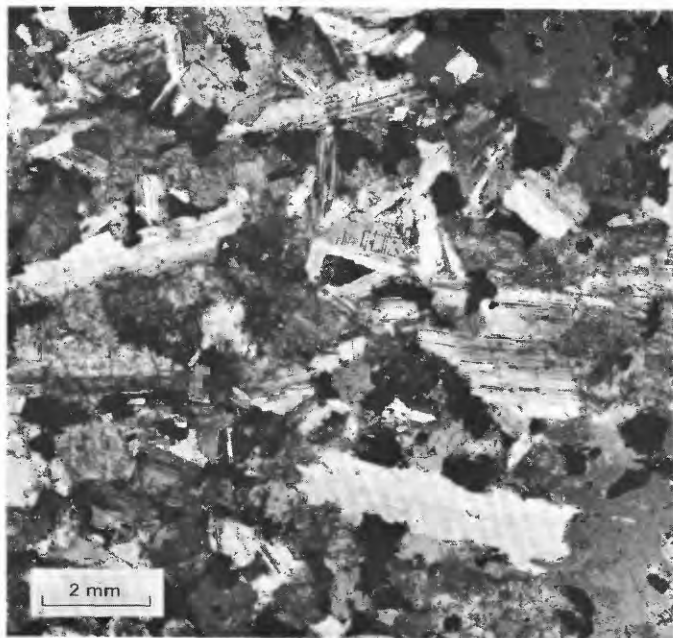


FIGURE 3.—Photomicrograph of gabbro. Brown amphibole crystals (gray) shown in upper and lower right corners. Crossed nicols.

are separated by intervening clinopyroxene (fig. 3). Some medium- or fine-grained gabbro is composed of equant grains of both labradorite and clinopyroxene either dispersed homogeneously or arranged in layers. Commonly grains of pyroxene are clustered together in composite groups.

Locally within the gabbro masses are small irregular bodies or possibly layers of granular anorthosite composed principally of prismatic plagioclase about 0.03–0.2 mm long (fig. 4) of bytownite composition (as deter-

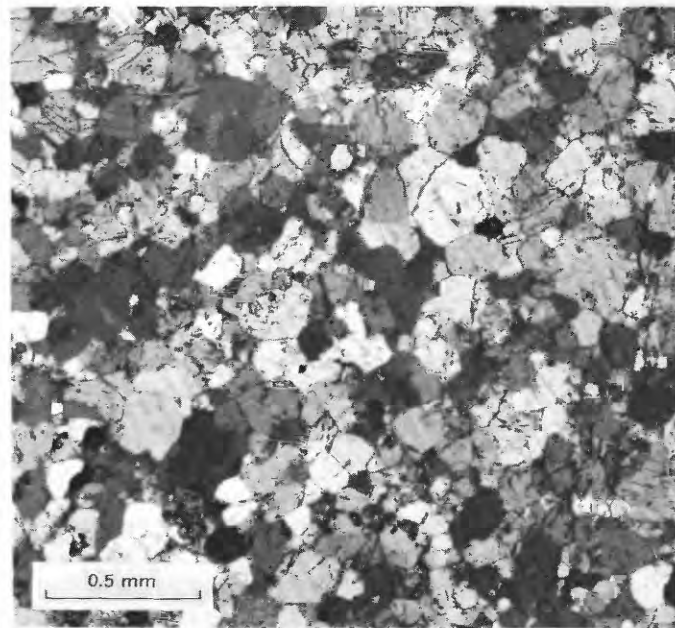


FIGURE 4.—Photomicrograph of plagioclase-rich rock; most grains are untwinned plagioclase. Crossed nicols.

mined microscopically from extinction angles on albite twinning laminae). Also present in these rocks are subordinate clinopyroxene, sphene, apatite, and wollastonite(?). Geologic relations of these rocks are not clear and it is not certain whether they are crystal accumulates or discordant differentiates of the gabbro. They are mapped as part of the gabbro.

NEPHELINE SYENITE PEGMATITE

Nepheline syenite pegmatite has been found in a single area in the center of Gem Park—about 1,000 feet northwest of the Vermiculite mine. This rock is exposed by one shallow pit, but syenite fragments can be found in the soil in the bordering area for a few hundred feet to the north and to the west of the pit. The syenite apparently intrudes pyroxenite.

The nepheline syenite pegmatite is coarsely crystalline, consisting of a mesh of perthite crystals, some more than

2 inches long, interstitial nepheline, and dark-green pyroxene crystals. Much of the nepheline is altered to an opaque white to pinkish-orange mineral. Natrolite is abundant in the pegmatite and minor analcite surrounds sparse blue sodalite. Other minor accessory constituents are magnetite and sphene.

LAMPROPHYRE AND SYENITE PORPHYRY DIKES

Lamprophyre and syenite porphyry dikes intrude Gem Park mafic and ultramafic rocks, although their exposures are not abundant. Lamprophyre dikes tentatively classed as spessartite are found 500 feet southeast of the Niles mine at the southwest edge of the complex and in the Vermiculite mine in the center of the complex. Probably these dikes occur in other places in the complex but are not detected because most of the complex is poorly exposed. The dikes range in thickness from 2 to 10 feet, and at the Vermiculite mine they pinch, swell, and branch along a northeastward trend.

The spessartite near the Niles mine is holocrystalline and composed of tabular turbid sodic plagioclase (probably oligoclase), abundant subhedral to euhedral clinopyroxene, magnetite, pleochroic brown amphibole, carbonate, and chlorite. Conspicuous white circular spots, rimmed by chlorite and magnetite, possibly represent the site of former olivine crystals now replaced by carbonates. Chlorite is also scattered through the rock in the interstices of plagioclase and pyroxene crystals (fig. 5).

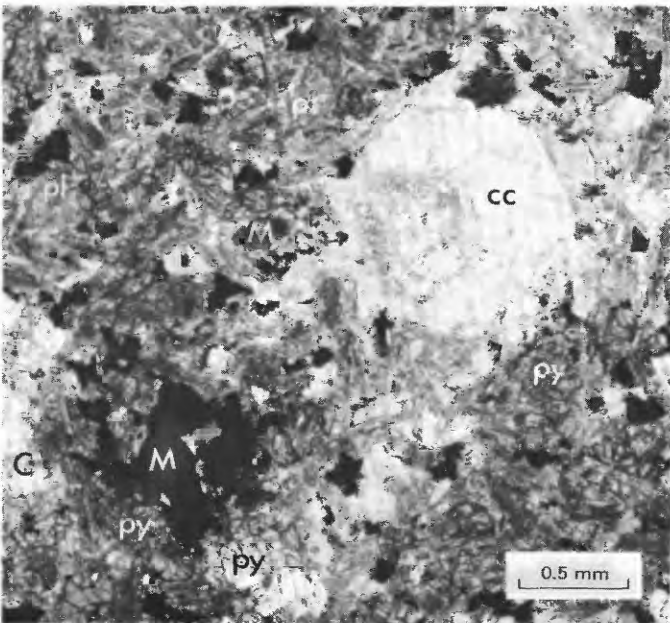


FIGURE 5.—Photomicrograph of lamprophyre (spessartite) showing carbonate-chlorite mass (cc, white, right of center) and aggregate of pyroxene (py, gray, high relief), chlorite (G, white), plagioclase (pl, gray, low relief), and magnetite (M, black).

Lamprophyre dikes noted by Heinrich and Dahlem (1966) in the border region of the McClure Mountain Complex are no doubt related genetically to the complex. Some carbonatite dikes are associated with highly altered mafic dikes.

Syenite porphyry dikes cut across gabbro and pyroxenite in the extreme northwest corner of Gem Park and extend into the bordering gneissic granite. These dikes are similar to others that are widely distributed in the Wet Mountains region.

The syenite porphyry is light orange and holocrystalline. Phenocrysts of sodium-potassium feldspar as much as 8 mm long are enclosed in a granular matrix mostly of sodium-potassium feldspar crystals about 0.3 mm long. The feldspar is heavily charged with hematite dust, rendering it nearly opaque and imparting the orange color to the rock. Clots of green and blue fibrous amphibole are scattered through the rock.

A chemical analysis and norm of the syenite porphyry are given in table 1. The norm indicates that this rock is barely saturated with respect to SiO_2 and that normative albite greatly exceeds normative orthoclase.

CARBONATITE DIKES

Dikes and irregular bodies of carbonatite, some enriched in niobium and rare-earth minerals, are abundant in the Gem Park Complex and intrude both pyroxenite and gabbro. A few of these dikes extend beyond the complex into the enclosing gneissic terrane. The dikes range in thickness from less than an inch to more than 15 feet and in length from a few feet to nearly 1,000 feet. Locally subparallel intersecting dikes form composite zones tens of feet across. The Gem Park dikes can be classed as beforites or ankeritic beforites, a nomenclature suggested by Verwoerd (1966a, p. 121).

ATTITUDE, ORIENTATION, AND DISTRIBUTION OF DIKES

The outcrop pattern of carbonatite dikes in the Gem Park Complex is shown on plate 1. The dikes can be divided into groups on the basis of their trends. Dikes forming a group in the southeast part of the complex appear to trend roughly parallel to the contact of the complex and are tangential to its concentric structure. The strike of these dikes is also parallel to the strike of the planar structure of the gabbro, and to the outcrop trend of the gabbro mass itself. The dikes dip more steeply toward the center of the complex than does the planar structure, however, suggesting independent concentric relations of the dikes and the gabbro. These dikes appear to be arranged concentrically about a zone in the central part of the complex.

Another group of dikes along the east side of the complex is roughly perpendicular to the tangential dike set and is radially arranged about the zone mentioned above.

Other groups consisting of radial dikes and tangential dikes along the west side of the complex appear to be arranged with respect to a point in the north-central part of the complex in the vicinity of the Vermiculite mine. A few dikes seem to have no preferred arrangement and some have sinuous strike.

The concentric and radial disposition of the dikes may be a reflection both of the preexisting structure of the Gem Park Complex and of a centrally located unexposed carbonatite source.

COMPOSITION OF DIKES

The carbonatite dikes generally can be grouped also on the basis of their composition, although composition classes overlap and some dikes vary in composition along their strike. Different compositional types are localized in different parts of the complex. Inasmuch as most of the carbonatite dikes at Gem Park are composed chiefly of dolomite, differences among them are principally in the accessory assemblages. The dikes are classed conveniently as dolomite-pyroxhlore, dolomite-apatite, dolomite-blue amphibole-pyroxhlore, and dolomite-barite-monazite.

The *dolomite-pyroxhlore* dikes are the most abundant and widespread dikes in the Gem Park Complex and are the simplest in composition. As shown on plate 1, they are concentrated in an arcuate belt along the east and south parts of the complex. Individual dikes have mostly radial and tangential trends, although many dikes deviate from these orientations.

The dolomite-pyroxhlore dikes are composed of coarse-textured white to cream-colored brown-weathering dolomite with scattered clots of barite and locally disseminated sparse amber grains of pyroxhlore. Commonly grains of magnetite and ilmenite are sparsely disseminated through the rock. The absence of noticeable radioactivity in most of these dikes indicates a dearth of thorium- or uranium-bearing accessory minerals which are present in some other rocks at Gem Park. Many dikes of this type are devoid of visible accessory minerals in outcrops and appear to be barren granular dolomite.

The *dolomite-apatite* dikes are similar to the dolomite-pyroxhlore dikes, except that they contain conspicuous irregular masses of light-green rare-earth-bearing apatite. Other accessory minerals include those listed for dolomite-pyroxhlore dikes. The apatite is locally concentrated in the dikes and is not visible in all outcrops; consequently this mineral likely has escaped detection in some dikes and therefore this type of dike may be more widespread than is shown. The dikes that contain conspicuous green apatite occur in two clusters, one southeast of the Vermiculite mine and the other southeast of the Niles mine.

Dolomite-blue amphibole-pyroxhlore dikes are conspicuous because fibrous blue amphibole (crocidolite)

predominates over all other accessory minerals. Pyroxhlore, in small amber grains and crystals 1–4 mm in diameter, speckles the rock, and ancylite in small pink grains is present but sparse. The rock as a whole is strongly sheared and commonly schistose. Lenses of apatite are drawn out along the planar direction and crocidolite is developed along shear fractures in the dolomite (figs. 6, 7). These dike rocks are bluish green even in

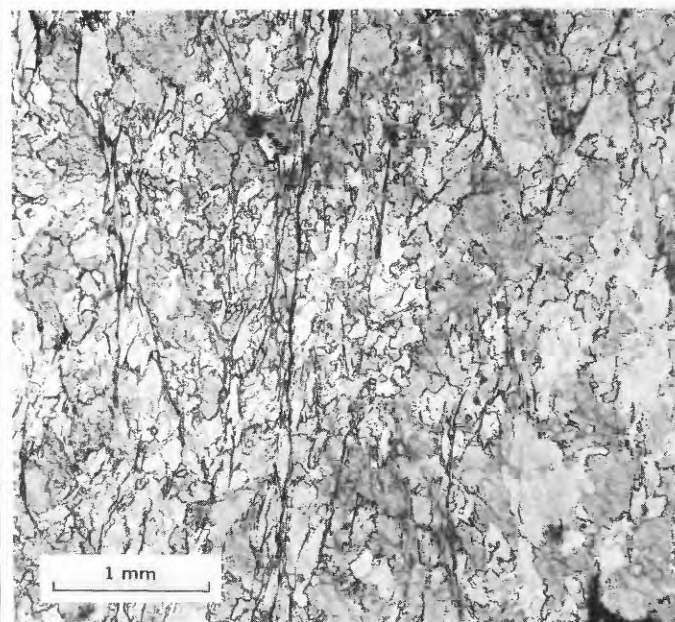


FIGURE 6.—Photomicrograph of deformed dolomite-blue amphibole-pyroxhlore carbonatite showing shear planes; pyroxhlore grain in lower right corner.

weathered outcrops. They are noticeably radioactive owing mostly to the abundance of pyroxhlore which contains as much as 0.3 percent thorium. Skeletal crystals and clusters of magnetite are irregularly disseminated.

This group of dikes also forms a coherent belt extending generally south from the Vermiculite mine and mostly west of the dolomite-pyroxhlore and dolomite-apatite groups of dikes on the east side of the complex.

The *dolomite-barite-monazite* dikes are generally composite bodies consisting of light-colored parts formed chiefly of dolomite and brownish-red fine-grained parts composed of dolomite, barite, monazite, apatite, ancylite, strontianite, and calcite. In some dikes the composite parts are arranged parallel to the dike walls.

In the brownish-red parts of the dikes, monazite and ancylite are intergrown as aggregates of minute grains and blade-shaped microlites which are dispersed chiefly in barite and to a lesser extent in dolomite and which impart turbidity and a reddish tint. The barite is granular and embays the coarse-textured dolomite.

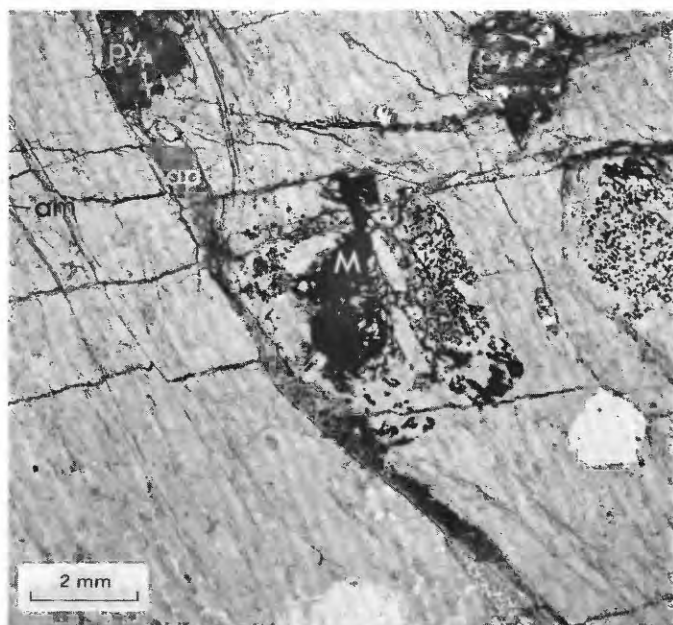


FIGURE 7.—Photomicrograph of deformed dolomite-blue amphibole-pyroxhlore carbonatite; lenticular medium-gray aggregates of apatite, *ap*, are parallel to shear planes in center and top center of photograph; dark-gray mottled grains are pyroxhlore, *py*; black skeletal grains are magnetite, *M*; blue amphibole, *am*, is concentrated along shear planes.

Some parts of the dolomite-barite-monzonite dikes consist of porous, cellular rock composed of dolomite, barite, ancyrite, and calcite with limonite coating surfaces and partly filling open spaces. Many dikes of this type are bordered and cut by limonite-stained shear zones. Commonly these dikes have thin zones of vermiculite along one or both walls.

Most of the dolomite-barite-monzonite dikes are 10–30 times more radioactive than the enclosing gabbro or pyroxenite, and are the most radioactive carbonatite dikes in the complex. They are concentrated mostly in a large cluster at and north of the Niles mine, and in a smaller group southeast of the Vermiculite mine.

CARBONATITE IN ROCKS THAT ENCLOSE THE COMPLEX

Several conspicuous carbonatite dikes intrude the Precambrian rocks that enclose the Gem Park Complex. These include a dike at the north end of the complex at the old Gem mine, which cuts the pyroxenite and extends into the granitic gneiss on Gem Mountain; a cluster of short dikes on Democratic Mountain on the east side of the complex; and a small composite carbonatite mass and associated fenite aureole approximately 1 mile southeast of the complex along Pine Creek (location shown in fig. 1). Other small dikes occur around the periphery of the complex but the carbonatites above are described as general examples.

All three of these carbonatites are rare-earth-bearing

in part and thus resemble the dolomite-barite-monzonite carbonatites that form a large group within the complex. However, in other respects they are different. Dikes that cut the gneissic granite are bordered by fenitized rocks—conspicuous because of the presence of green aegirine, blue sodic amphibole, and altered feldspar and the virtual absence of quartz. Sulfide minerals are commonly present in minor amounts, but vermiculite is rare.

The carbonatite at the north edge of the intrusive mass, explored by workings of the old Gem mine, contains an unusual assemblage of minerals and has some features not found in other carbonatites of the complex. In the mining area the carbonatite ranges from 1 to 5 feet in thickness for 500 feet along strike in pyroxenite and also extends several hundred feet into the gneissic granite.

The dike is composed mostly of dolomite and calcite. Medium-grained granular dolomite is replaced and veined by coarse-textured pink to gray calcite. The dolomite encloses breccia fragments of granite that exhibit various stages of replacement. Exceptionally clear idiomorphic quartz fills cavities in the dolomite, and in some places the quartz is rimmed by specular hematite. Chalcopyrite, pyrite, bornite, and sphalerite are disseminated in the carbonate minerals. Magnetite also occurs as irregular masses and small crystals. Gneissic granite wallrocks and wedges within the dike are locally replaced by albite.

The Gem mine produced a small tonnage of ore containing niccolite, annabergite, and native silver in the latter part of the 19th century (Eckel, 1961, p. 242). Neither niccolite nor native silver was identified in the present investigation; however, silver, nickel, and arsenic are conspicuous components in some of the carbonate dump materials as determined by X-ray fluorescence spectrography, and annabergite, a nickel-cobalt arsenate, was found coating some carbonate fragments from the dump.

Dikes on Democratic Mountain are 1–2 feet wide, generally fine grained, and banded parallel to the walls. Fenite wall zones containing green aegirine are well developed. These dikes and their wallrocks are strongly radioactive owing chiefly to thorium in rare-earth minerals.

The carbonatites along Pine Gulch are conspicuous because of the abundance of blue sodic amphibole in them. These carbonatites cut gneissic granite and pegmatoid granitic rocks and include a kidney-shaped carbonate mass about 100 feet long, several small carbonate masses, and several radiating carbonatite dikes. A shallow shaft at the south end of the largest carbonatite exposes granitic rocks which have been broken by a series of closely spaced fractures and which have been extensively replaced by sodic amphibole, dolomite, and albite.

The carbonatites along Pine Gulch are mostly dolo-

mite that is fine grained and granular, and they contain disseminated galena, apatite, pyrochlore, and monazite. Anomalous radioactivity was noted at the deposits. Spectrographic analyses of these rocks are given in table 11, columns 15, 23, and 24.

FENITE

Fenite is a rock produced by metasomatism of pre-existing rocks at borders of carbonatite and alkalic intrusions (Brögger, 1921; Verwoerd, 1966a, p. 122). Most occurrences of fenite throughout the world are products of metasomatism of country rocks that are unrelated to the alkalic rocks or carbonatites that intrude them. In a few occurrences, however, such as at Nemegosenda, Ontario (Parsons, 1961) and Meach Lake, Quebec (Hogarth, 1966), the term "fenite" has been applied to questionably genetically related but older rocks metasomatized at the borders of carbonatites. Garson (1966, p. 69), in his discussion of the origin of alnoitic rocks and carbonatite, also applied the term to related but older rocks and postulated that "carbonatite originates as a concentration of CaO, MgO, FeO, and volatiles in the upper portions of highly differentiated kimberlitic fractions above a parental mica peridotite," and that "alnoitic rocks are formed by desilication of deep-seated peridotitic material due to processes of fenitization * * *". In the Gem Park Complex local masses of gabbro and pyroxenite that have been metasomatized to the composition of fenite are termed fenite, along with fenitized Precambrian rocks, even though the gabbro and pyroxenite are considered to be related to the carbonatites that intrude and alter them.

Fenite is recognized at Gem Park in gabbro and pyroxenite of the Gem Park Complex which have been metasomatized over a large area in the vicinity of the old Vermiculite mine, in gabbro and pyroxenite of the complex along the borders of some carbonatite dikes, in surrounding gneissic granite enclosing carbonatite dikes and bodies, in quartzite inclusions contained in gabbro and pyroxenite, and in gneissic granite at the border of the complex.

The most extensive fenite in the Gem Park Complex is in pyroxenite and gabbro underlying an oval-shaped area about 1,500 feet long in the north-central part of the complex. These altered rocks are exposed in the cuts and pits of the Vermiculite mine and other scattered prospects in the outlined area (pl. 2). The amount of alteration varies from place to place from completely reconstituted rocks to isolated masses of virtually unaltered pyroxenite or gabbro. In general the pyroxenite and gabbro have been metasomatized to a variably distributed assemblage of fibrous blue sodic amphibole, aegirine, tremolite-actinolite, augite, phlogopite, vermiculite, dolomite, calcite, barite, apatite, and magnetite.

Some masses are composed almost entirely of coarse vermiculite with subordinate clots of fibrous amphiboles and other minerals and may have been 40-50 feet across as judged from the size of mining excavations. Some masses as much as several feet across, however, consist of fibrous sodic amphibole set in a matrix of fine fibrous actinolite, vermiculite, and chalky dolomite or calcite containing abundant small magnetite crystals. Some of these masses range in color from bluish black to blue to green. The change in color to green denotes the addition of aegirine to the assemblage. In the Vermiculite mine area the vermiculite masses are commonly bordered by or intergrown with rock containing fibrous sodic amphibole, vermiculite, and porcelainous pink to white natrolite and its chalky weathering products.

Narrow black dikelets of serpentine cut through this metasomatized area. They are conspicuous in the less altered parts but are mostly obscured in the highly metasomatized masses. The dikelets are 1-2 inches thick and occur as sets trending north to northwest and dipping southwest at moderate angles. The dikelets exhibit a consistent planar structure parallel to their walls. Some have narrow but well-developed vermiculite wall zones; others are sharply in contact with the granular gabbro or pyroxenite. Thin carbonatite veinlets follow along some of the black dikelets and in places occupy their centers, lie along their walls, or show crosscutting relations with them.

The dikelets of serpentine probably are altered fault gouge. The serpentine is dark brown to black with waxy luster and contains fine inclusions of a cream-colored component. Fine yellow to greenish-yellow fibers of a chrysotilelike mineral are contained in the waxy matrix. Small pods of calcite or dolomite and flakes of barite occur along with minute veinlets and cavity fillings of the carbonate minerals.

The dikelets and their vermiculite wall zones contain the rare niobium minerals, lueshite, fersmite, and natroniobite, along with pyrochlore, columbite, thorianite, natrolite, and monazite. Radioactive elements occur in some of the minerals, and the black dikelets account for the generally high radioactivity of most of the area of alteration.

The development of serpentine dikelets along small fractures and faults represents the initial phase of alteration in the fenite zone. Further alteration by fluids channeled along the dikelet zones converted the wallrocks, which were largely clinopyroxene, to an assemblage including phlogopite, amphibole, and magnetite. Lueshite, pyrochlore, and thorianite were deposited in the dikelets and wall zones.

As alteration progressed, large volumes of rock were converted to phlogopite, sodic amphibole, aegirine, mag-

netite, and carbonate minerals, and the earlier formed lueshite and pyrochlore were in part altered to fersmite, natroniobite, and columbite. Ramifying veinlets of carbonatite and rare-earth-bearing apatite were introduced, and in a later stage much phlogopite was converted to vermiculite.

Chemical analyses of the fenites in Gem Park are not available for computing precisely the amount of elements exchanged during fenitization, but qualitative appraisal can be made from the semiquantitative spectrographic analyses (table 12) and from the mineral assemblages present in the various rock types. The development of the serpentine dikelets and their altered border zones necessitated the addition of magnesium, alkalis (probably chiefly potassium), and carbonate ion, and the removal or redistribution of iron, aluminum, and calcium. The alkalis and some of the replaced iron and aluminum probably were taken up in phlogopite or biotite (which later became vermiculite), and at least some of the calcium and magnesium combined with the carbonate ion to form dolomite. Niobium, rare earths, strontium, and thorium undoubtedly were introduced. More pervasive alteration that changed large masses of pyroxenite and gabbro to fenite must have required the addition of considerable sodium (sodic amphibole, natrolite), magnesium (vermiculite, dolomite), barium and sulfur (barite), phosphorus (apatite), and water (amphiboles and vermiculite). Aluminum and part of the sodium and calcium may have been added or redistributed from plagioclase of the gabbro, and potassium must have been removed (phlogopite-vermiculite).

The fenitization of mafic rocks at Gem Park in some respects resembles that at Goudini, Transvaal (Verwoerd, 1966b, p. 301), where, in an early stage of fenitization of norite, pyroxene is altered to sodic amphibole and dolomite. A more advanced stage of fenitization at Goudini, due to closer proximity to the volcanic center, produced mostly aegirine from the original pyroxene instead of sodic amphibole, and cancrinite from the original plagioclase, a result probably of a lower partial pressure of water and higher temperature.

Vermiculite zones ranging from a few inches to more than a foot thick are formed along some carbonatite dikes in gabbro and pyroxenite. Some dikes have vermiculite formed along one wall, or commonly one wall zone is more extensively developed than the other. These altered zones are composed of coarse- to medium-textured masses of brown (occasionally green) vermiculite flakes and micaceous crystal books, which are as much as 1½ inches across, randomly packed in a tight, tough, interlocking mat with chalky fillings of calcite and dolomite. Magnetite in small amounts is enclosed in the books. It seems clear that the vermiculite is pseudomorphous

after phlogopite, and phlogopite appears to have been the sole potassic phase of these zones. The margin zones apparently formed contemporaneously with the carbonatite dikes at times of maximum temperatures and high CO₂ and H₂O partial pressures. Later alteration involving removal of potassium has converted phlogopite to vermiculite.

The fenite related to carbonatite dikes and bodies in the gneissic granite outside the Gem Park Complex is similar to that found in other granitic areas and described in the literature (Brögger, 1921; Verwoerd, 1966a). Fractures and cracks in the gneissic granite wallrocks of the carbonatites are filled with aegirine or aegirine-augite, and in the rocks adjacent to the cracks, quartz is removed and the potash feldspar is altered to a turbid perthite commonly highly colored by hematite. Some rocks are porous and when broken give off a fetid odor which probably is like that described by Heinrich and Anderson (1965, p. 1916) as a gas consisting of C₅ and C₆ hydrocarbons, and fluorine in the form of F₂, HF, and F₂O. The fenite associated with the carbonatite body in the Pine Creek drainage about a mile southeast of Gem Park differs from the above in the strong development of crocidolite instead of aegirine in the fenite aureole.

Fenite is developed also in the gneissic granite in an aureole surrounding the Gem Park Complex. The granite near the border of the complex is altered in a manner similar to that near carbonatite bodies, though to a lesser degree. The fenite is characterized chiefly by thin intersecting aegirine veinlets that have replaced material along fractures in the granite.

A few inclusions of quartzite in the gabbro and pyroxenite of the Gem Park Complex have been partly fenitized. Aegirine is in fractures and joints and partly replaces some quartz grains along grain boundaries. Most of the quartz grains of the quartzite are relatively unaltered, although some, especially near aegirine veinlets, are milky. No quartzite has been found in the Precambrian rocks surrounding the complex; hence the inclusions presumably were brought up from some depth by upwelling gabbro magma.

Whether fenite occurs in gabbro near the nepheline syenite body northwest of the Vermiculite mine cannot be determined because of the absence of exposures. The nepheline syenite itself, however, has undergone minor sodium metasomatism with the incipient replacement of nepheline by sodalite and analcite and the filling of voids by natrolite. It seems likely that this alteration is related to that described for the nearby Vermiculite mine area.

MINERALOGY CARBONATITES

Minerals found in the carbonatites are arranged in table 3 in groups to represent the various types of dikes.

TABLE 3.—Minerals in carbonatites from the Gem Park Complex

[M, major constituent; C, common accessory; R, rare accessory]

Mineral	Chemical formula	Type of carbonatite			
		Dolomite-pyroxhlore	Dolomite-apatite	Dolomite-blue amphibole-pyroxhlore	Dolomite-barite-monazite
Aegirine	$\text{NaFe}^{3+}(\text{SiO}_3)_2$				R
Albite	$\text{NaAlSi}_3\text{O}_8$				R
Anatase	TiO_2				R
Ancylite	$\text{Ce}_4\text{Sr}_3(\text{CO}_3)_7(\text{OH})_4 \cdot 3\text{H}_2\text{O}$				C
Apatite	$\text{Ca}_4(\text{PO}_4)_3\text{F}$	R	C	C	C
Barite	BaSO_4	C	C		C
Calcite	CaCO_3	C	R	R	C
Columbite	$(\text{Fe}, \text{Mn})(\text{Nb}, \text{Ta})_2\text{O}_6$			R	R
Dolomite	$\text{CaMg}(\text{CO}_3)_2$	M	M	M	M
Fluorite	CaF_2				R
Galena	PbS				R
Ilmenite	FeTiO_3	R	R	C	R
Magnetite	$\text{Fe}^{2+}\text{Fe}^{3+}_2\text{O}_4$	C	C	C	C
Monazite	CePO_4				C
Natrolite	$\text{Na}_2\text{Al}_2\text{Si}_8\text{O}_{10} \cdot 2\text{H}_2\text{O}$				R
Phlogopite	$\text{KMg}_3\text{AlSi}_3\text{O}_{10}(\text{OH})_2$	R	R	C	R
Pyrite	FeS_2			R	R
Pyroxhlore	$\text{NaCaNb}_2\text{O}_6\text{F}$	C	R	C	R
Pyrrhotite	Fe_{1-x}S			R	
Quartz	SiO_2				R
Sodic amphibole (crocidolite)	$\text{Na}_2\text{Fe}^{2+}_3\text{Fe}^{3+}_2(\text{Si}_8\text{O}_{22})(\text{OH}, \text{F})_2$			C	R
Sphalerite	ZnS			R	R
Strontianite	SrCO_3	R			C
Thorianite	$(\text{Th}, \text{U})\text{O}_2$				R
Vermiculite	$(\text{Mg}, \text{Fe}^{2+}, \text{Fe}^{3+}, \text{Al})_6(\text{Si}, \text{Al})_8\text{O}_{20}(\text{OH})_4 \cdot 8\text{H}_2\text{O}$	C	C	C	C

Dolomite, the dominant mineral in all the carbonatites at Gem Park, is mostly coarse textured and weathers light brown. The unweathered mineral is opaque white to creamy. The N_o index of refraction ranges from 1.686 to 1.688, in the range of magnesiodolomite (Verwoerd, 1966a, p. 173), indicating that the rock can be classed as beforosite. Most of the unweathered dolomite is clear in thin section; however, dolomite in rare-earth-rich dikes is generally turbid with microlites, presumably some variety of rare-earth carbonate.

Calcite and *strontianite* are found mostly as secondary minerals in the dolomite-barite-monazite carbonatite dikes. Both minerals occur in fine-grained clusters in these dikes and are associated with barite, monazite, and ancylite. Strontianite is not conspicuous in hand specimen, even in rocks that contain as much as 10 percent strontium. Strontianite, as fine-grained aggregates, is also found in the coarsely crystalline dolomite parts of these dikes.

Apatite is present in nearly all carbonatite dike rocks, and three varieties are conspicuous: tiny colorless grains, light-green to blue granular clots, and brownish-red crystals. The tiny colorless grains seem to be disseminated throughout the carbonatite rocks. The light-green to blue massive clots, which are as much as several inches across, occur in some coarse-textured carbonatite. These clots are composed of small interlocking prismatic crystals which are alined along shear planes in the carbonatite

and which exhibit fluxion structure (fig. 8). A spectrographic analysis of this green apatite shows it to contain 3-4 percent total rare earths (table 4). The brownish-

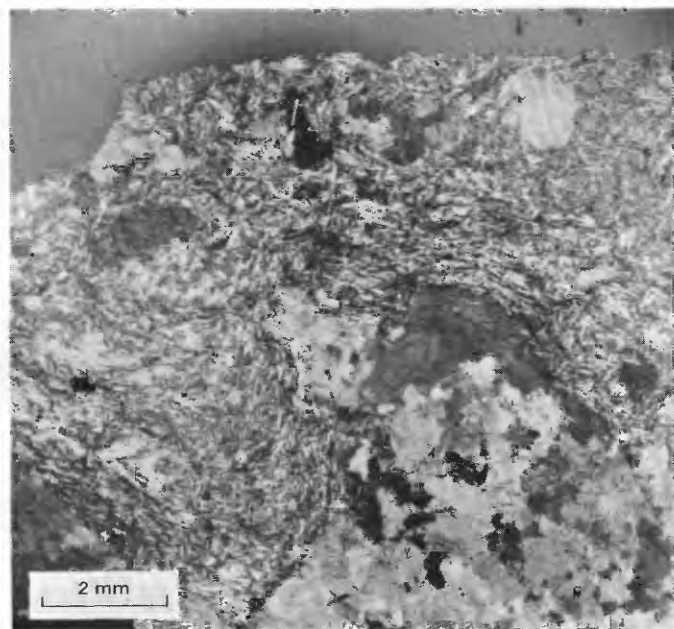


FIGURE 8.—Photomicrograph of finely crystalline apatite clot in carbonatite. Note alinement of apatite crystals giving fluxion structure.

TABLE 4.—*Semiquantitative spectrographic analysis of green rare-earth apatite from the Gem Park Complex*

[Harriet Neiman, analyst. Laboratory No. D130116]

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

red crystals, which are long and prismatic, commonly occur in dolomite-barite-monazite dikes. These crystals are mostly turbid with clouds of extremely fine grained rare-earth minerals, chiefly monazite and ancyllite.

Monazite and *ancylite*, rare-earth minerals, generally occur together in the dolomite-barite-monazite dikes. Ancyllite predominates in some zones within those dikes that are rich in strontianite. In the dolomite-blue amphibole-pyroxhlore dikes, however, ancyllite unaccompanied by strontianite is found as small disseminated pink clusters, 1–2 mm across. In the dolomite-barite-monazite dikes, ancyllite occurs both as discrete prismatic dark-reddish-brown crystals and as pink to white bladed crystals pervading porous friable rock consisting of barite, strontianite, calcite, and monazite. One dike at the Letha Lee prospect (pl. 1) contains ancyllite of opaque cream to pink color and pseudo-octahedral form. Monazite

commonly is the dominant accessory mineral in the dark-reddish-brown zones within the dolomite-barite-monazite dikes and occurs as wispy streaks composed of extremely finely bladed clusters. Much of this finely divided monazite is mixed with ancyllite, and together the minerals form a conspicuous turbid mass in the dolomite or barite host. More coarsely crystalline monazite occurs as rosettes of bladed crystals several millimeters across set in the dolomite groundmass (fig. 9). Some crystals of monazite have diamond-shaped cross sections. Most of these rare-earth-rich rocks are more highly radioactive than the pyroxenite or gabbro host. The radioactivity is believed to be due to thorium in the monazite because neither thorianite nor thorite has been found in these rocks.

Pyroxhlore occurs in the Gem Park Complex in a large number of dikes belonging to the dolomite-pyroxhlore and dolomite-blue amphibole-pyroxhlore types, as previously outlined. The pyroxhlore is most abundant in the blue amphibole-bearing type. Commonly the pyroxhlore is present as small turbid yellow to amber anhedral grains, a fraction of a millimeter to 6 mm across. Some pyroxhlore, however, forms octahedrons that may be translucent to nearly opaque in thin section and partly to completely metamict.

The chemical composition of the light-amber pyroxhlore is given in table 5. According to G. A. Desborough of the U.S. Geological Survey, the crystals examined are homogeneous in composition except that some darker cores are slightly richer in tantalum than the material surrounding the cores.

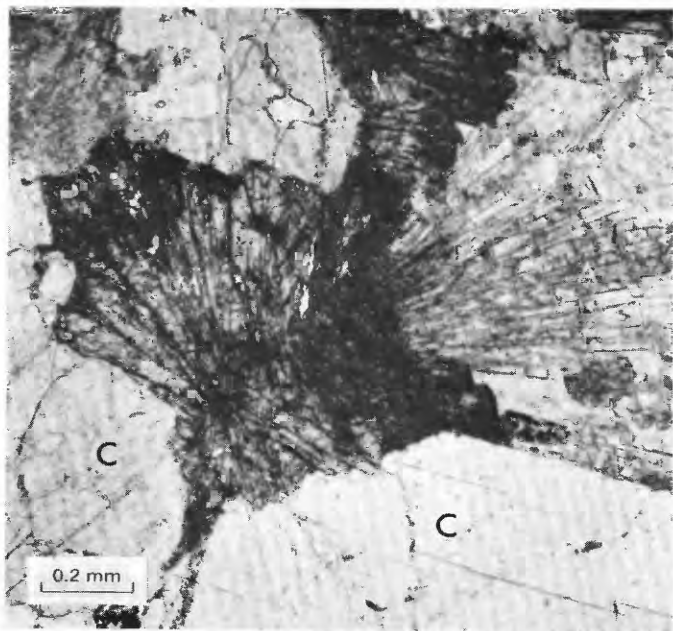


FIGURE 9.—Photomicrograph of monazite (M) rosette in carbonatite (C) with apatite (A).

TABLE 5.—*Chemical composition of light-amber pyroxhlore from the Gem Park Complex*

Constituent	Content (percent)	Constituent	Content (percent)
Na ₂ O	¹ 7.6–8.4	SrO	² 1.2
CaO	¹ 14.3–17.1	ThO ₂	² .3
MnO	² .1	Fe ₂ O ₃	¹ .1–.9
MgO	¹ <.2	TiO ₂	¹ 1.8–3.5
Ce ₂ O ₃	² 1.2	Nb ₂ O ₅	¹ 56.5–61.5
La ₂ O ₃	² .2	Ta ₂ O ₅	¹ .1–1.1
Pr ₂ O ₃	² .1	F	³ 5.

¹ Microprobe analysis of several different pyroxhlore crystals. Analyst, G. A. Desborough.

² Semiquantitative spectrographic analysis of a handpicked sample of pyroxhlore. Analyst, Harriet Neiman.

³ Estimated.

Columbite in the Gem Park carbonatites has been found only in a dolomite-blue amphibole-pyroxhlore dike at one place, and in a carbonatite body outside the complex. In the blue amphibole-rich carbonatite, magnetite and pyroxhlore are particularly enriched, a feature that may account for the presence of the iron-rich niobate, columbite. The columbite occurs in irregular masses and is localized along sinuous shear zones cutting the car-

bonatite. The carbonate in these zones is turbid with blue amphibole and clusters of small pyrochlore flakes and wisps. This rock is noticeably radioactive, and the radioactivity doubtless is due to minor thorium and uranium in the columbite. X-ray fluorescence analysis shows both thorium and uranium to be present, but at levels below detection by spectrographic methods used for table 6. The columbite is in large highly lustrous black grains that are nearly opaque in thin section.

Columbite occurs in parts of the carbonatite body in the Pine Creek drainage about a mile southeast of Gem Park. Here small, well-formed, dark-reddish-brown crystals of columbite are disseminated in fine-grained dolomite, which also contains quartz, galena, and sphalerite.

Sphalerite, *pyrite*, and *anatase* are not common but are present locally as widely scattered grains in dark streaks along the borders of the carbonatites.

TABLE 6.—*Semiquantitative spectrographic analysis of columbite from the Gem Park Complex*

[Harriet Neiman, analyst. Laboratory No. D132297]

Element	Content (percent)	Element	Content (percent)
Nb	> 10	Cr	.007
Fe	5	La	.05
Mg	3	Ce	.5
Ca	3	Sm	.02
Ti	2	Sr	.15
Al	.02	Zr	.5
Mn	.15	Sc	.05
Ba	.003		

FENITES

Many of the minerals found in the carbonatites are also common in the fenitized gabbro and pyroxenite in the area of the old Vermiculite mine (table 7); however, a few rare mineral species in the fenite are not found in the carbonatites.

TABLE 7.—*Minerals in fenitized gabbro and pyroxenite from the Gem Park Complex in the area of the old Vermiculite mine*

[M, major constituent; C, common accessory; R, rare accessory]

Mineral	Chemical formula	Relative abundance
Aegirine	$\text{NaFe}^{3+}\text{Si}_2\text{O}_6$	M
Analcime	$\text{NaAlSi}_3\text{O}_8 \cdot \text{H}_2\text{O}$	R
Anatase	TiO_2	R
Ancylite	$\text{Ce}_4\text{Sr}_2(\text{CO}_3)_7(\text{OH})_4 \cdot 3\text{H}_2\text{O}$	R
Apatite	$\text{Ca}_5(\text{PO}_4)_3\text{F}$	C
Augite (clinopyroxene)	$\text{Ca}(\text{Mg}, \text{Fe}, \text{Al})(\text{Si}, \text{Al})_2\text{O}_6$	M
Barite	BaSO_4	C
Brookite	TiO_2	R
Calcite	CaCO_3	C
Columbite	$(\text{Fe}, \text{Mn})(\text{Nb}, \text{Ta})_2\text{O}_6$	C
Crocidolite (blue amphibole)	$\text{Na}_2\text{Fe}^{2+}_3\text{Fe}^{3+}_2(\text{OH})_2\text{Si}_8\text{O}_{22}$	M
Dolomite	$\text{CaMg}(\text{CO}_3)_2$	M
Fersmite	CaNb_2O_6	R
Fluorite	CaF_2	R
Hydropyrochlore	hydrated pyrochlore	C
Ilmenite	FeTiO_3	C
Lueshite	NaNbO_3	C
Magnetite	$\text{Fe}^{2+}\text{Fe}^{3+}_2\text{O}_4$	M
Manganese oxides	(Mn, O)	C
Monazite	CePO_4	R
Natrolite	$\text{Na}_2\text{Al}_2\text{Si}_3\text{O}_{10} \cdot 2\text{H}_2\text{O}$	C
Natroniobite	$\text{NaNb}_2\text{O}_6\text{OH}$	R
Perovskite (var. irenite)	$(\text{Na}, \text{Ce}, \text{Ca})(\text{Ti}, \text{Nb})\text{O}_3$	R
Phlogopite	$\text{KMg}_3\text{AlSi}_3\text{O}_{10}(\text{OH})_2$	R
Pyrite	FeS_2	R
Pyrochlore	$\text{NaCaNb}_2\text{O}_6\text{F}$	C
Quartz	SiO_2	R
Rutile	TiO_2	R
Serpentine	$\text{Mg}_3\text{Si}_2\text{O}_5(\text{OH})_4$	C
Sodalite	$\text{Na}_4\text{Al}_3\text{Si}_3\text{O}_{12}\text{Cl}$	R
Strontianite	SrCO_3	C
Thorianite	$(\text{Th}, \text{U})\text{O}_2$	R
Tremolite-actinolite	$\text{Ca}_2(\text{Mg}, \text{Fe})_5(\text{OH})_2\text{Si}_8\text{O}_{22}$	C
Vermiculite	$(\text{Mg}, \text{Fe}^{2+}, \text{Fe}^{3+}, \text{Al})_6(\text{Si}, \text{Al})_8\text{O}_{20}(\text{OH})_4 \cdot 8\text{H}_2\text{O}$	M

Lueshite, a rare niobate, NaNbO_3 , was first reported from the Vermiculite mine area in Gem Park by Parker, Adams, and Hildebrand (1962) as occurring in altered mafic rocks composed predominantly of vermiculite and fibrous actinolite-tremolite. More detailed work in the area has disclosed that the conspicuous black cubes of lueshite are in narrow black serpentine dikelets and in discontinuous vermiculite wall zones of these dikelets in altered gabbro and pyroxenite. Lueshite was one of the earliest minerals formed during fenitization of the pyroxenite and gabbro. Associated minerals include pyrochlore, ilmenite, thorianite, and rarely perovskite (var. irenite). Lueshite is sparsely and randomly distributed as individual cubes or clusters in the black dikelets, and in some places it is closely associated with subhedral octahedrons of pyrochlore. In vermiculite wall zones lueshite is enclosed in vermiculite books, forming clusters with ilmenite, pyrochlore, and thorianite. Lueshite also occurs in fine fibrous amphibole-carbonate material interstitial to larger vermiculite books. Lueshite crystals are a fraction of a millimeter to 3 mm across. The small cubes are lavender gray and barely translucent; the larger cubes are black and lustrous (see figs. 10 and 11). The mineral contains significant amounts of thorium and uranium, which, along with associated thorianite, account for the high radioactivity in parts of the fenite zone (table 8).

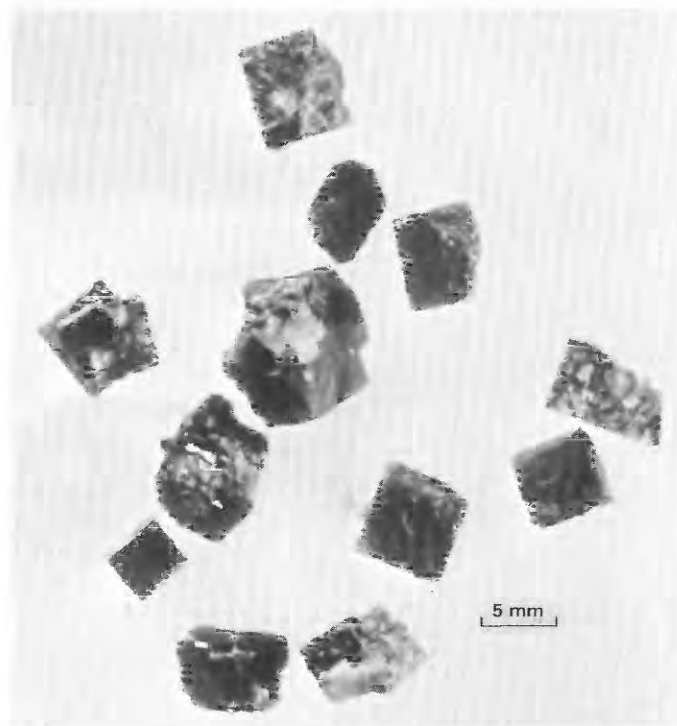


FIGURE 10.—Black lustrous lueshite crystals.

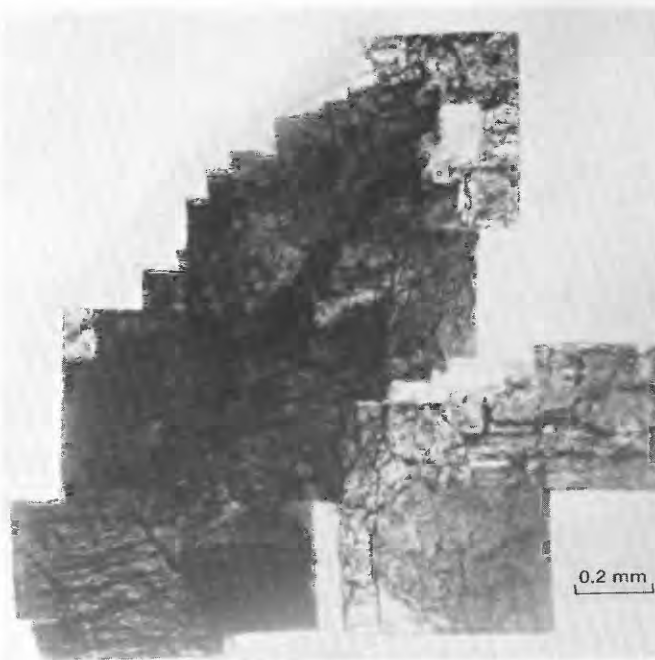


FIGURE 11.—Cut section of lavender-gray lueshite twin cluster.

Fersmite occurs in the fenite in masses of coarse vermiculite. Fersmite cubes and intergrown clusters of cubes and short complex prisms border small yellow claylike dolomite pods and veinlets in the vermiculite. Relict features indicate that the fersmite is a secondary product after an original lueshite-pyrochlore aggregate (fig. 12).

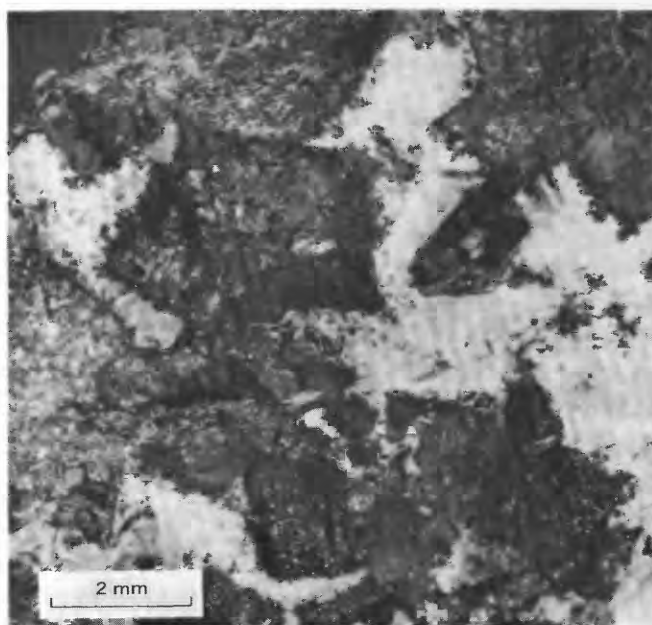


FIGURE 12.—Fersmite (gray) after lueshite in dolomite (white).

TABLE 8.—*Semiquantitative spectrographic analysis of lueshite from the Gem Park Complex*

[Nancy M. Conklin, analyst. Laboratory No. D298323]

Element	Content (percent)	Element	Content (percent)
Nb-----	>10	La-----	1
Na-----	>10	Ce-----	2
Ti-----	7	Nd-----	.7
Th-----	5	Pr-----	.1
Ca-----	1.5	Sm-----	<.1
Si-----	≈.5	Sr-----	.5
Fe-----	.7	Zr-----	<.1
Mg-----	.5	Y-----	<.01
Al-----	<.1	Ba-----	.015
Mn-----	.05	Pb-----	.15

The fersmite is dark brown and dull to moderately vitreous, and in most occurrences it is predominantly pseudomorphous after cubes of lueshite as much as 7 mm across. Fersmite fragments are nearly opaque and are composed of thin radiating blades with submetallic luster. As seen in thin section (fig. 13), orangish-brown blades of fersmite radiate from numerous centers within

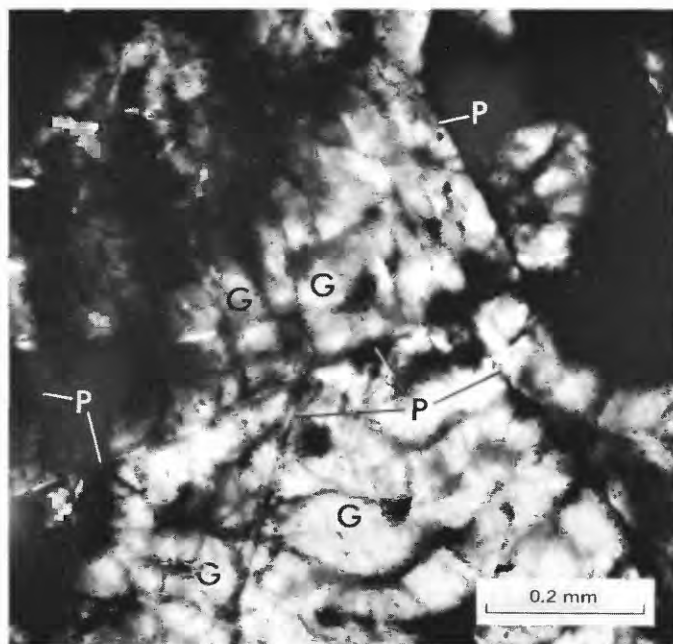


FIGURE 13.—Fersmite, orangish brown, in thin section. Note multiple growth centers (G) and phantom cube boundaries (P).

relict lueshite crystals, suggesting replacement of the original lueshite. Sparse blebs of black, opaque, vitreous lueshite remain within the fersmite as relict material.

The fersmite from Gem Park is partly metamict, as shown by the fact that X-ray diffraction reflections are sharpened by heating. X-ray diffraction patterns agree well with published data (Wambeke, 1965; Hess and Trumpour, 1959; Vlasov, 1964). A semiquantitative spectrographic analysis of fersmite is given in table 9.

TABLE 9.—*Semiquantitative spectrographic analysis of fersmite from the Gem Park Complex*

[Harriet Neiman, analyst. Laboratory No. D132295]

Element	Content (percent)	Element	Content (percent)
Nb-----	>10	La-----	.5
Fe-----	1.5	Ce-----	1.5
Mg-----	.1	Pr-----	.1
Ca-----	7	Nd-----	.3
Ti-----	3	Th-----	.5
Al-----	.015	Sr-----	.15
Mn-----	.5	Zr-----	.05
Ba-----	.2	Pb-----	.015
Cr-----	.007		

Natroniobite, a rare form of sodium niobate, $\text{NaNb}_2\text{O}_5\text{OH}$, previously reported only from the Lesnaya Veraka and Salanlatvin massifs, U.S.S.R. (Kukhareenko and others, 1965, p. 362-368), is found in Gem Park as an alteration product of lueshite, pyrochlore, and possibly fersmite. It occurs in vermiculite-rich fenite at the Vermiculite mine, where it is intergrown with fine granular columbite, fersmite, pyrochlore, and rarely, monazite (fig. 14). Some small cubic pseudomorphs after lueshite are

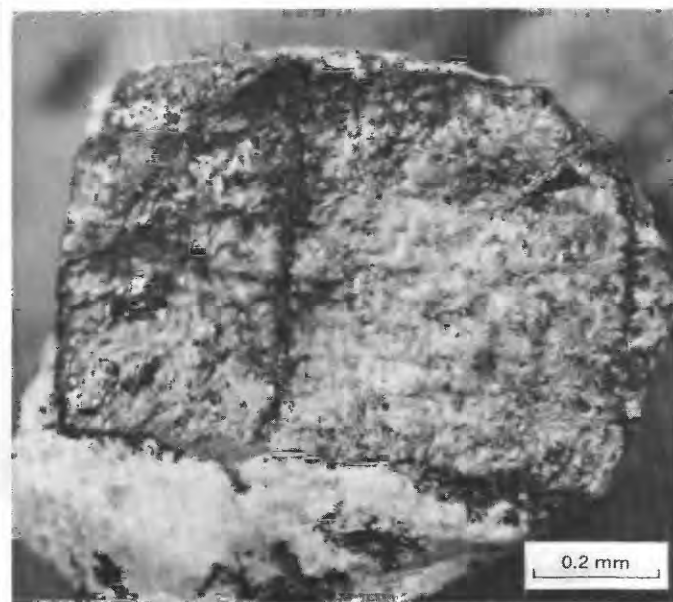


FIGURE 14.—Natroniobite in radiating clusters and columbite (black) replacing lueshite cube.

composed entirely of natroniobite. The mineral is yellow to brownish yellow with waxy to silky luster derived from the strongly fibrous habit. Commonly the mineral occurs in radiating aggregates of fibrous crystals (fig. 15).

X-ray diffraction data of the Gem Park natroniobite compare well with those from Lesnaya Veraka, U.S.S.R. (Kukhareenko and others, 1965, p. 366), as shown in table 10.

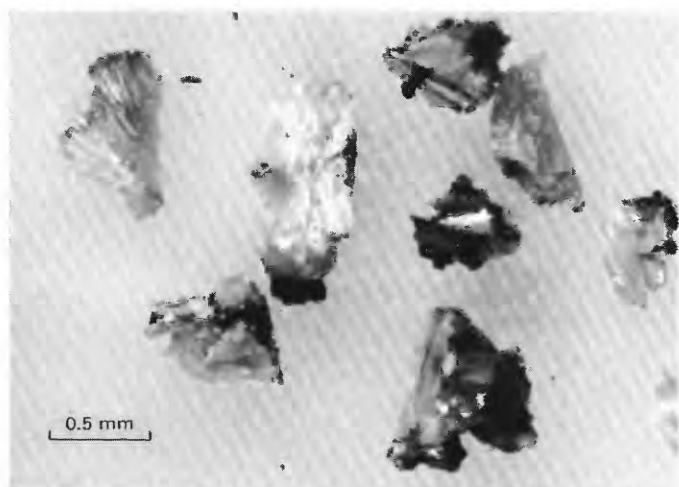


FIGURE 15.—Fragments of fibrous natroniobite; black grains are columbite.

Because it is finely intergrown with columbite and pyrochlore, natroniobite of sufficient purity for chemical analysis has not been separated.

TABLE 10.—X-ray diffraction data for natroniobite

[Dash leaders indicate lines not found in corresponding positions. *I* is intensity of line relative to intensity of strongest line, which is defined to be 10; *d* is spacing of atomic planes in angstrom units]

Gem Park Complex, Colo.		Massif Lesnaya Varaka, U.S.S.R. (Kukhareenko and others, 1965)	
<i>d</i>	<i>I</i>	<i>d</i>	<i>I</i>
4.81	7	4.8	2
3.84	1	3.79	4
3.77	2	3.36	2
		3.29	3
3.05	10	3.06	9
2.97	4	2.97	10
2.77	2	2.79	2
2.68	5	2.69	3
		2.60	1
2.46	1	2.47	1
2.37	1	2.39	3
2.38	1	2.30	1
2.23	1	2.25	2
		2.04	1
1.93	2	1.99	1
1.89	1	1.93	3
		1.89	5
1.72	3	1.87	1
1.61	3	1.76	2
		1.72	6
1.545	1	1.60	8
1.52	2	1.59	4
		1.544	4
		1.523	4

Monazite and *ancylite* are very rare in the fenites of Gem Park and appear to be limited largely to late-stage carbonate veinlets that ramify through some of the massive vermiculite-blue amphibole rocks at the Vermiculite mine. *Ancylite* in well-formed pale-pink opaque octahedral crystals, 1–2 mm across, is common in at least one veinlet.

Monazite occurs with *ancylite* in turbid wisps and radiating clusters in the carbonate veinlets. *Monazite* also is found in relict cube casts of original lueshite, admixed with columbite and natroniobite. Possibly the *monazite* was formed in the alteration of fersmite, an intermediate stage in the alteration of the original lueshite. This *monazite* is of an unusual, long, narrow rodlike habit and is present in small radiating clusters or clots of randomly oriented crystals (fig. 16) that are typically chalky white

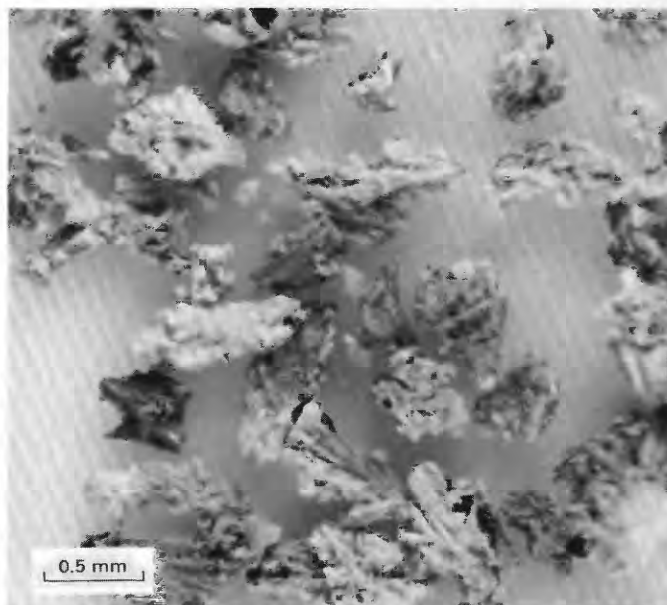


FIGURE 16.—Chalky white grains of fibrous monazite.

to cream-colored, but in some places are reddish brown. Identification was by X-ray diffraction.

Thorianite is associated with lueshite predominantly in the black serpentine dikelets and associated vermiculite border zones in the less intensely fenitized gabbro and pyroxenite. A large part of the radioactivity associated with these deposits is no doubt due to this mineral. Within the more intensively altered vermiculite-blue amphibole rocks where assemblages of fersmite and natroniobite occur, *thorianite* seems to be absent.

The *thorianite* invariably occurs as well-formed equidimensional dodecahedral crystals, $\frac{1}{8}$ to $\frac{1}{4}$ mm across (fig. 17). The crystals are light orange and translucent and have a dull luster. The identification was by X-ray diffraction.

Vermiculite is one of the most abundant and conspicuous minerals in the fenitized gabbro and pyroxenite at the Vermiculite mine. Some large bodies of compact vermiculite rock have been mined in open pits to a depth of approximately 40 feet. The vermiculite is light brown and probably is pseudomorphous after phlogopite. It occurs in the form of soft and pliable crystalline plates or books

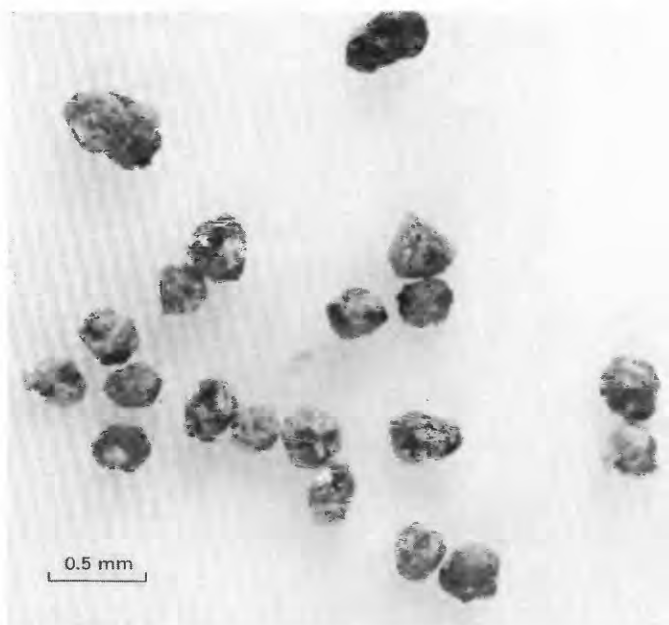


FIGURE 17.—Light-orange thorianite crystals.

as much as $1\frac{1}{2}$ inches across. At places many plates show pseudo-hexagonal outlines and enclose hexagonal phantom crystals. Along the wall zones of the black dikelets normally light-brown vermiculite locally contains pale-green areas. Where the vermiculite is associated with the black dikelets and niobium minerals, barite, magnetite, and ilmenite are common inclusions along with minor rutile, brookite, perovskite, pyrochlore, and lueshite.

Perovskite, possibly the thorium variety *irenite*, was separated from ground vermiculite collected at a radioactive fersmite-natroniobite occurrence in a large mass of vermiculite rock at the Vermiculite mine. The mineral is black, submetallic, and totally metamict. The heated mineral gives an X-ray diffraction pattern that matches that of *irenite* given by Vlasov (1964, p. 418). Accompanying minerals are ilmenite and pyrochlore.

Natrolite, *analcite*, and *sodalite*, sodium-rich minerals, are present in minor amounts in the Gem Park Complex. *Natrolite*, the most common of the group, occurs in fenite as conspicuous chalky white and vitreous pink clots as much as several inches across in some of the coarse-textured actinolite-sodic-amphibole-vermiculite rocks exposed in the Vermiculite mine walls.

Less strongly altered *natrolite*-bearing rocks at the fringe of the intensely metasomatized area are pods of former gabbro pegmatite. The plagioclase of the pegmatite has been altered to *natrolite* and the pyroxene converted partly to *aegirine-augite*. In the intensely altered zone the amphibole-vermiculite-*natrolite*-bearing rocks may represent more highly altered gabbro pegmatite pods. *Analcite*, *sodalite*, and *natrolite* all occur in the small

altered syenite pegmatite body a short distance northwest of the old Vermiculite mine. *Analcite* and *sodalite* replace *nepheline* and possibly *alkali feldspar*; *natrolite* fills the interstices between crystals of the pegmatite minerals.

GEOCHEMISTRY

The carbonatites and fenites at Gem Park contain concentrations of minor elements such as barium, strontium, niobium, rare-earth elements, and thorium that are typical of alkaline rocks and carbonatites in many alkaline complexes in the world (Pecora, 1956; Verwoerd, 1966a). They also contain copper and vanadium in concentrations much greater than are found in ordinary rocks. Semiquantitative spectrographic analyses of carbonatites and fenites from Gem Park are given in tables 11 and 12.

Barium and strontium are abnormally abundant in both carbonatites and fenites at Gem Park. Strontium is more abundant than barium in all but a few carbonatites that contain exceptionally high contents of *barite*. Barium content ranges from 0.007 to 7 percent and is highly variable among the carbonatites and even along the same dike. The strontium content ranges from 0.015 to 7 percent but is mostly high. Verwoerd (1966a) noted similar relations between barium and strontium in the South African carbonatites.

The barium and strontium contents of the fenite (table 12) reach values near 5 percent, the barium commonly exceeding strontium. Generally the calcium-rich rocks such as carbonatite, however, are rich in strontium which proxies for calcium in calcium minerals. Vermiculite-rich rocks are commonly enriched in barium, which is present as *barite* inclusions in the vermiculite.

Niobium content of 39 carbonatite samples from Gem Park (table 11) ranges from <0.001 to 0.7 percent and averages 0.07 percent. Most of the niobium is in *pyrochlore*, although some is in *ilmenite* and in sparsely distributed *columbite*.

The niobium content of the fenite samples (table 12) ranges from <0.002 to >1.0 percent and averages about 0.12 percent. The niobium is concentrated in *lueshite*, *fersmite*, *natroniobite*, *pyrochlore*, and *columbite*. Niobium in trace amounts also occurs in *vermiculite*, where it seems to be present both in the vermiculite lattice and in included minerals such as *ilmenite*, *rutile*, and *anatase*.

Rare-earth elements in the Gem Park Complex are largely concentrated in the dolomite-*barite*-*monazite* carbonatite dikes in *monazite*, *ancylite*, and *apatite*. In 15 samples of carbonatite dikes of this type, the total rare-earth-element content reaches 10 percent and averages 4 percent; in the other types of carbonatite it averages about 0.2 percent.

In the Gem Park Complex, as in many rare-earth-bearing carbonatite complexes throughout the world, the carbonatites and fenite contain dominantly the light rare-

[All are semiquantitative spectrographic analyses, by Harriet Neiman and J. L. Finley, except that fluorine was analyzed by distillation-colorimetric method, by Johnnie Gardner and W. D. Goss. Samples are located on pl. 1. N, not detected; L, detected but below limit of determination; —, not looked for. Results are reported in percent to the nearest number in the series 1, 0.7, 0.5, 0.3, 0.2, 0.15, 0.1, and so forth; these numbers represent approximate midpoints of group data on a geometric scale. The assigned group for semiquantitative results will include the quantitative value about 30 percent of the time. These data should not be quoted without stating these limitations]

	Dolomite-blue amphibole-pyroxhlore carbonatites										
Sample	1	2	3	4	5	6	7	8	9	10	11
Laboratory No. D-----	129150	129151	129152	129153	139124	130125	130127	131237	131240	131241	131242
Si-----	7	0.5	1	0.5	0.05	0.5	0.1	1.5	0.3	0.3	0.3
Ti-----	1.5	.03	.2	.05	.0005	.02	.002	.3	.007	.005	.03
Al-----	2	.15	.3	.1	.05	.1	.05	.7	.15	.05	.2
Fe-----	7	3	>10	3	2	3	2	3	3	3	7
Mg-----	10	10	3	7	10	10	10	7	10	>10	>10
Ca-----	7	10	10	10	>10	>10	>10	>10	>10	>10	>10
Na-----	.7	.3	.5	.3	.1	.5	.15	.3	.3	.3	.7
K-----	N	N	.7	N	N	N	N	N	N	N	N
P-----	N	.7	5	.7	N	2	.2	3	1.5	N	.5
Mn-----	.1	.15	.15	.2	.5	.5	.5	.5	.7	.7	.7
F-----	.22	.49	1.23	.56	.03	.03	.03	.29	.07	.11	.11
Ba-----	.01	.007	.05	.007	.007	.01	.01	.015	.015	.007	.015
Co-----	.003	.0007	.002	.0007	.001	.001	.0007	.0015	.001	.0007	.0007
Cr-----	.07	.0007	.001	.0005	.0002	.0007	.0005	.003	.0005	.0007	.0015
Cu-----	.07	.0001	.0002	---	.001	.001	---	.0002	.001	L	.0005
Ga-----	.002	N	.0001	N	N	N	N	.0007	N	N	N
Mo-----	N	N	N	N	N	N	N	N	N	N	N
Nb-----	N	.3	.7	.3	.0015	.1	.02	.15	.005	.03	.2
Ni-----	.03	N	N	N	N	.0005	N	.0005	N	N	.2
Pb-----	N	.001	.007	N	N	.001	N	.001	.001	L	L
Sc-----	.007	.003	.007	.003	.0007	.002	.001	.0015	.002	.003	.007
Sr-----	.015	1	1.5	1.5	1	1	1	1.5	1.5	1.5	2
Th-----	N	N	N	N	N	N	N	N	N	N	N
V-----	.03	.005	.03	.003	.0015	.0015	.0015	.005	.002	.003	.003
Y-----	.003	.007	.03	.01	.002	.01	.003	.03	.015	.003	.007
Zn-----	N	N	.03	N	N	N	N	N	N	N	N
Zr-----	.007	.002	.03	.003	N	.005	N	.003	N	.002	.007
La-----	N	.03	.15	.03	.015	.05	.02	.15	.03	.015	.03
Ce-----	N	.07	.5	.1	.02	.15	.05	.3	.15	.015	.07
Pr-----	---	N	<.002	<.002	---	---	---	N	N	N	N
Nd-----	---	.03	.15	.05	.007	.1	.02	.07	.07	.007	.003
Sm-----	---	.015	.03	.015	---	.01	---	N	N	N	N
Eu-----	N	N	N	N	N	N	N	N	N	N	N
Gd-----	---	---	.01	---	---	---	---	---	---	---	---
Tb-----	---	---	.07	---	---	---	---	---	---	---	---
Dy-----	---	---	.015	---	---	---	---	---	---	---	---
Ho-----	---	---	.005	---	---	---	---	---	---	---	---
Er-----	---	---	.01	---	---	---	---	---	---	---	---
Tm-----	---	---	.005	---	---	---	---	---	---	---	---
Yb-----	.0003	.0003	.001	.003	N	.0003	.0001	.0007	.0007	L	.0003
Lu-----	---	---	.007	---	---	N	N	N	N	N	N

[illegible]

Sample Laboratory No. D-----	Dolomite-barite-monzonite carbonatites—Continued						Dolomite-apatite carbonatite	
	23 130108	24 130109	25 130110	26 130111	27 130113	28 131251	29 130115	30 130117
Si-----	0.2	0.07	0.15	0.3	0.7	2	0.01	0.5
Ti-----	.015	N	.001	.003	.015	.15	L	.02
Al-----	.3	.1	.2	.3	.2	.07	.05	.15
Fe-----	3	5	2	5	5	5	2	2
Mg-----	10	5	2	2	7	7	10	7
Ca-----	>10	>10	>10	>10	>10	>10	>10	>10
Na-----	.2	N	.3	N	.2	.2	.15	.3
K-----	N	N	1.5	2	N	N	N	N
P-----	N	N	10	2	N	5	N	.7
Mn-----	.5	.7	.5	1	.7	.7	.5	.5
F-----	.04	.05	.03	.03	.04	---	.05	.03
Ba-----	.1	.15	.5	.5	1	.15	.01	.015
Co-----	.0015	.0015	.0007	.003	.0007	.003	.0007	.0015
Cr-----	.0002	.001	.0005	.0015	.001	.002	.0002	.0007
Cu-----	N	.0005	.003	.007	.0007	.001	.0001	.0007
Ga-----	N	N	N	N	N	N	N	N
Mo-----	N	.0015	N	.001	.0007	N	N	N
Nb-----	.015	.0010	.003	.003	.02	.02	N	.03
Ni-----	N	N	.002	.001	.001	.003	N	.0003
Pb-----	.0015	.002	.002	.005	.003	N	.001	.001
Se-----	.0005	N	.001	N	N	N	.0007	.0015
Sr-----	.7	.7	3	.5	7	.7	2	1.5
Th-----	N	N	N	.05	N	N	N	N
V-----	.0015	N	N	N	N	.002	N	.0015
Y-----	.002	.003	.03	.02	.005	.001	.002	.005
Zn-----	N	.3	---	N	N	N	N	.002
Zr-----	N	N	.005	N	N	N	N	N
La-----	.5	.3	---	1.5	.5	1.5	.05	.03
Ce-----	.7	.5	1.5	2	.7	1.5	.02	.07
Pr-----	---	---	---	---	---	.3	---	---
Nd-----	.2	.3	.7	.7	.3	.7	.015	.03
Sm-----	.02	.03	.07	.1	.03	L	N	N
Eu-----	N	N	.015	.01	N	N	N	N
Gd-----	---	---	.02	.015	---	N	---	---
Tb-----	---	---	N	N	---	N	---	---
Dy-----	---	---	.01	N	---	N	---	---
Ho-----	---	---	.002	.002	---	N	---	---
Er-----	---	---	N	N	---	N	---	---
Tm-----	---	---	N	N	---	N	---	---
Yb-----	N	N	.0015	.0003	N	.001	N	.0001
Lu-----	---	---	N	N	---	N	---	---

Sample Laboratory No. D-----	Dolomite-pyroxhlore carbonatite								
	31 131236	32 130121	33 130123	34 131238	35 131239	36 130114	37 131248	38 131249	39 131250
Si-----	1.5	0.15	0.5	0.05	0.15	0.15	0.15	0.3	0.3
Ti-----	.1	.003	.007	N	.003	L	.007	.01	.03
Al-----	.5	.7	.1	.07	.1	.1	.07	.07	.2
Fe-----	3	1.5	2	3	3	2	1.5	3	5
Mg-----	7	2	10	>10	7	7	1.5	10	3
Ca-----	>10	>10	>10	>10	>10	>10	>10	>10	>10
Na-----	.15	.7	.5	.15	.15	.15	.15	.3	.15
K-----	N	N	N	N	N	N	N	N	N
P-----	1	7	.5	N	N	5	N	N	.5
Mn-----	.5	.7	.5	.7	.7	.5	.7	.7	.7
F-----	.14	.03	.03	.04	.01	.09	.03	.03	.11
Ba-----	.03	.03	.007	.7	.03	.02	.2	.007	.07
Co-----	.0015	.0005	.0007	.0007	.0015	.001	.0003	.003	.003
Cr-----	.001	.0002	.0015	.0005	.0005	.0001	.001	.0002	.0007
Cu-----	.0007	.0007	.0001	N	.003	.0005	.0003	.0007	.007
Ga-----	.0007	N	N	N	N	N	N	N	N
Mo-----	N	N	N	N	N	N	N	N	N
Nb-----	.15	.005	.002	.003	.003	.002	N	.03	.003
Ni-----	.0007	.001	N	.0007	.0015	.001	N	N	N
Pb-----	.0015	.003	N	.015	.001	.001	.001	.002	.003
Se-----	.0015	.0005	.001	.0015	.002	.003	.003	.003	.003
Sr-----	1	1	1	1.5	2	1.5	2	.7	.7
Th-----	N	N	N	N	N	N	N	N	N
V-----	.015	N	.0015	.0007	.002	.0005	.001	.003	.003
Y-----	.01	.03	.005	.003	.003	.001	.03	.0015	.007
Zn-----	.003	.001	N	N	N	N	N	N	N
Zr-----	.003	.001	N	N	N	N	N	N	N
La-----	.07	.5	.02	.03	.015	.01	.15	.015	.03
Ce-----	.15	1	.05	.07	.05	.015	.15	.03	.07
Pr-----	N	---	---	N	N	---	N	N	N
Nd-----	.07	.3	.002	.015	.03	---	.07	.015	.03
Sm-----	N	.05	N	N	N	N	N	N	N
Eu-----	N	.01	N	N	N	N	N	N	N
Gd-----	N	.01	N	N	N	N	N	N	N
Tb-----	N	N	---	N	N	---	N	N	N
Dy-----	N	.002	---	N	N	---	N	N	N
Ho-----	N	---	---	N	N	---	N	N	N
Er-----	N	---	---	N	N	---	N	N	N
Tm-----	N	---	---	N	N	---	N	N	N
Yb-----	.0003	.001	.0001	N	.0001	N	.0007	N	.0003
Lu-----	N	---	---	N	N	---	N	N	N

TABLE 12.—Analyses, in percent, of rocks from fenite area, Gem Park Complex

[All are semiquantitative spectrographic analyses by Uteana Oda, except that Nb was analyzed by A. P. Marranzino, by X-ray fluorescence method. Samples are located on pl. 2, -----, not looked for. Results are reported in percent to the nearest number in the series 1, 0.7, 0.5, 0.3, 0.2, 0.15, 0.1, and so forth; these numbers represent approximate midpoints of group data on a geometric scale. The assigned group for semiquantitative results will include the quantitative value about 30 percent of the time. These data should not be quoted without stating these limitations]

Sample Field No. WM-63-----	40 700	41 701	42 702	43 703	44 704	45 705	46 706	47 707	48 708	49 709	50 710	51 711
Ti-----	0.5	1	0.7	0.7	0.7	0.1	1	1	0.7	0.7	1	>1
Fe-----	7	15	7	15	15	20	5	20	10	20	15	20
Mg-----	5	5	7	7	7	1.5	2	2	5	5	5	1.5
Ca-----	20	15	20	1.5	1.5	5	3	1	15	5	3	1.5
Mn-----	.2	.1	.15	.1	.1	>1	.1	.1	.15	1	.2	.2
Ba-----	.5	.07	.1	.02	.2	.3	.2	.2	.05	.2	.1	.05
Co-----	.007	.007	.007	.007	.007	.007	.005	.007	.007	.007	.007	.01
Cr-----	.1	.02	.07	.05	.05	.002	.2	.2	.1	.07	.07	.05
Cu-----	.01	.02	.05	.15	.0015	.007	.03	.03	.1	.05	.02	.01
Ga-----										.0007	.0015	.001
Mo-----	.0001	.0002	.0002	.0002	.0003	.001	.0005	.0007	.0002	.0005	.0003	.0007
Nb-----	.015	.002	.003	.02	.03	.02	.03	.05	.05	.2	.05	.1
Ni-----	.015	.02	.03	.05	.015	.01	.03	.03	.03	.03	.03	.02
Pb-----			.0005			.003			.001	.005	.0005	<.05
Sc-----	<.05	.007	.006	.007			.0015	.001	.003	.003	.007	
Sr-----	.1	.02	.07	.015	.05	.5	.15	.015	.1	.15	.1	.07
V-----	.01	.07	.03	.03	.03	.05	.03	.05	.03	.07	.05	.07
Y-----	.0005	.001	.0015			.005	.0005		.002	.003	.0005	.001
Zn-----	<.02											
Zr-----	.001	.005	.003	.01	<.1		.001	.001	.007	.01	.007	
La-----	.002	<.02	.005		.02	1	.02	.002	.015	1	.1	.1

Sample Field No. WM-63-----	52 712	53 713	54 714	55 715	56 716	57 717	58 718	59 719	60 720	61 721	62 722	63 723
Ti-----	1	0.5	0.7	0.7	0.7	0.7	0.5	0.7	0.7	0.1	>1	1
Fe-----	7	7	7	10	10	10	15	20	7	10	20	7
Mg-----	7	7	10	5	5	10	5	5	3	5	3	7
Ca-----	10	7	5	7	7	3	7	7	7	10	7	3
Mn-----	.1	.15	.2	.15	.5	.3	.2	.07	.3	>1	.07	.07
Ba-----	.03	.03	.15	.05	.03	.03	.5	.2	.1	.15	.15	.1
Co-----	.007	.007	.007	.005	.007	.007	.007	.005	.007	.0015	.007	.007
Cr-----	.1	.1	.007	.07	.1	.15	.1	.2	.007	.005	.2	.02
Cu-----	.02	.005	.015	.015	.005	.007	.0015	.007	.015	.007	.007	.0015
Ga-----	.001	.001	.0005	.001		.0007	.0005	.0015	.002		.002	.002
Mo-----	.0002	.0002		.0002	.0005	.0001	.0003	.0007	.0002	.0002	.0005	.0001
Nb-----	.003	.07	.2	.15	.15	.15	.015	.05	.15	.02	.05	.05
Ni-----	.03	.03	.03	.03	.02	.03	.015	.015	.015	.015	.02	.015
Pb-----	.0005	.0015	.005	.001	.002	.002				.0005		
Sc-----	.003	.0015	.0005	.007	.001	.0015	.001	.002	.005	.0005	.003	.005
Sr-----	.03	.15	.1	.07	.03	.05	.07	.05	.5	.5	.03	.07
V-----	.03	.015	.01	.015	.015	.01	.015	.03	.03	.005	.03	.015
Y-----	.001	.002	.002	.0005	.001	.001	.0005	.0005	.002	.005	.0005	
Zn-----			.02									
Zr-----	.005	.005	.005	.015	.001	.003	.005	.001	.007	.001	.003	.015
La-----	.002	.05	.015	.005	.01	.01	<.002	<.002	.015	.05		.002

Sample Field No. WM-63-----	64 724	65 725	66 726	67 727	68 728	69 729	70 730	71 731	72 732	73 733	74 734	75 735	76 736
Ti-----	1	0.7	1	1	1	1	0.2	1	0.5	0.02	>1	>1	0.7
Fe-----	7	5	7	20	3	5	2	15	7	3	10	15	10
Mg-----	5	1	5	5	5	5	5	5	1.5	10	7	5	5
Ca-----	1.5	2	10	3	2	15	15	7	2	15	10	10	1.5
Mn-----	.07	.1	.15	.15	.2	.07	.3	.15	.07	.7	.2	.15	.1
Ba-----	.1	.2	.07	.15	.2	.1	.015	.15	.3	.015	.15	.015	.15
Co-----	.007	.001	.007	.007	.003	.002	.001	.007	.001	.0005	.007	.007	.005
Cr-----	.01	.0005	.2	.2	.015	.02	.001	.01	.015		.01	.015	.02
Cu-----	.003	.007	.01	.01	.007	.003	.0005	.015	.0015	.003	.05	.02	.002
Ga-----	.0015	.002	.0015	.0015	.0015	.0015		.0015	.002		.001	.0015	.002
Mo-----	.0001	.0002	.0002	.0002		.0001		.0003	.0002		.0002	.0002	.0002
Nb-----	.05	.02	.002	.15	>1	.05	.01	.05	.015	.03	.5	<.002	.03
Ni-----	.01	.01	.015	.02	.007	.007	.002	.015	.005	.001	.03	.01	.02
Pb-----		.001	.0005		.003	.0005			.001				
Sc-----	.0015	.0005	.007	.007	.0005	.005	.002	.003	.0015	.0005	.003	.003	.07
Sr-----	.05	.05	.03	.15	.1	.2	.7	.2	.07	.3	.3	.03	.01
V-----	.015	.003	.03	.07	.003	.15	.002	.03	.007	.003	.02	.007	
Y-----		.0003	.0002		.0005	.0015	.0015	.002	.002		.001	.0015	
Zn-----				<.002									
Zr-----	.005	.05	.007	.01	.01	.007		.003	.02		.002	.002	
La-----		.02	.002	.015	.2	.01	.007	.015	.01	.01	.03		

40. Tremolite-calcite-magnetite rock.

41. Pyroxenite, moderately altered.

42. Altered pyroxenite, cut by carbonate stringers.

43. Actinolite rock bordering vermiculite body.

44. Vermiculite rock.

45. Actinolite-vermiculite breccia.

46. Vermiculite-blue amphibole rock.

47. Fibrous amphibole-vermiculite-magnetite rock.

48. Altered pyroxenite.

49. Amphibole-vermiculite rock and carbonatite.

50-51. Fibrous amphibole-vermiculite rock cut by carbonatite.

52. Altered pyroxenite.

53. Vermiculite rock, pale green.

54. Calcareous vein zone and altered pyroxenite.

55. Blue fibrous amphibole-vermiculite rock.

56. Brown and green vermiculite rock.

57. Serpentine dikes in amphibole-vermiculite rock.

58. Fibrous blue amphibole-vermiculite rock.

59. Coarse-textured blue amphibole-augite-vermiculite rock.

60. Calcareous dikes in fibrous amphibole-augite-vermiculite rock.

61. Carbonatite dike.

62. Vermiculite-blue fibrous amphibole rock.

63. Coarse-textured blue fibrous amphibole-natro-

lite-vermiculite rock.

64. Vermiculite-iron ore rock.

65. Calcareous dike and altered pyroxenite.

66. Altered pyroxenite.

67. Vermiculite-fibrous amphibole rock.

68. Coarse vermiculite rock.

69. Fibrous blue amphibole-natro-

lite-vermiculite rock.

70. Carbonatite dike.

71. Altered gabbro.

72. Lamprophyre dike.

73. Carbonatite.

74. Carbonatite and pyroxenite.

75. Pyroxenite.

76. Vermiculite-augite rock.

earth elements cerium, lanthanum, and neodymium. In the fenite, rare-earth elements are found chiefly in monazite and, in minor amounts, in such minerals as fersmite and lueshite.

Phosphorus occurs largely in apatite which is irregularly distributed in most carbonatites but which is most abundant in the dolomite-barite-monazite carbonatites. Phosphorus in some samples of carbonatites of this type makes up as much as 10 percent of the rock. Some phosphorus no doubt is in monazite as well as in apatite.

Thorium is localized chiefly in the fenite area in the vicinity of the Vermiculite mine and accounts for most of the radioactivity found there. The distribution of radioactivity in the mine area is shown by isorads on plate 2. The highest radioactivity occurs 300–400 feet west of the main pits of the mine and is believed to stem largely from a concentration of thorium-bearing serpentine dikelets. The thorium is in thorianite, irenite, monazite, and, to a minor extent, pyrochlore and other niobium-bearing minerals. Some carbonatite dikes are also locally radioactive owing to thorium in monazite and pyrochlore.

Copper and vanadium are enriched in the fenite at the Vermiculite mine. Samples from the fenite (table 12) in general contain <0.0015–0.15 percent copper and 0.002–0.15 percent vanadium. Copper and nickel are concentrated locally in the coarse pyroxenite at the periphery of the complex and in a few carbonatite dikes. The copper occurs in chalcopyrite, and the nickel occurs in pyrrhotite, niccolite (?), and annabergite. The mineral or minerals containing vanadium are not known.

SUMMARY AND CONCLUSIONS

The Gem Park Complex consists mostly of pyroxenite and gabbro with minor dikes and bodies of lamprophyre, syenite porphyry, and nepheline syenite pegmatite and abundant dikes and irregular bodies of carbonatite, all of Cambrian age. A mass of fenite lies near the center of the complex. The complex is funnel shaped and is a composite body composed of layers and discordant bodies of gabbro and pyroxenite. The whole complex lies discordantly in Precambrian gneissic terrane and is in turn unconformably overlain by Tertiary volcanic rocks. Large areas in the complex are covered by Quaternary alluvium and colluvium.

Conspicuous features of the Gem Park Complex are the shape and structure of the complex as a whole, the composition and structural arrangement of abundant dikes and irregular bodies of carbonatite, the presence of a strongly fenitized mass of rock near the center of the complex, and the relatively high content of niobium, rare-earth elements, and thorium in both the fenites and carbonatites. These features lead the writers to conclude that an unexposed massive carbonatite underlies, at unknown depth, the central part of the complex.

The funnel shape and concentric arrangement of rocks of the Gem Park Complex are common features of alkalic complexes of the world, many of which contain carbonatites. In some complexes the concentric bodies have been shown to be in the form of ring dikes and cone sheets, and in other complexes—for example, Okonjeje (Simpson, 1954) and Iron Mountain (Shaw and Parker, 1967)—some of the rocks are stratiform. All these structures appear concentric in plan, and where relief is slight and exposures are limited, such as at Gem Park, the character of the structure may not be recognizable.

The composition and structural arrangement of carbonatite dikes have been described in considerable detail in this report. Four types of dikes have been distinguished, each of which has a different distribution within the complex (pl. 1): (1) The dolomite-pyrochlore dikes, which are in a zone around the east side of the complex, (2) the dolomite-barite-monazite dikes, which are largely confined to the west side, (3) the dolomite-apatite dikes, which are scattered among the dolomite-pyrochlore dikes along the east side of the complex, and (4) the dolomite-blue amphibole-pyrochlore dikes, which also occur along the east side of the complex. All these types of dikes are present in both conspicuous radial and tangential dike sets (and some dikes have intermediate attitudes) which are confocal generally about an area in the central part of the complex. In detail there seem to be at least two centers of focus. The dolomite-barite-monazite dikes radiate from and are confocal with a point in the fenitized area surrounding the Vermiculite mine, and the other dikes seem to focus on a line or zone that extends from the Vermiculite mine to a point about 2,000 feet south of it.

The writers believe that these dikes radiate from and focus on their source, which is interpreted to be a massive carbonatite intrusion. The differences in composition of the dikes may result from their slightly different ages of intrusion and their injection from the main carbonatite at different stages in its ascent in the complex. Differences could also be a result of feeder dikes tapping the main carbonatite at different places. The latter explanation might also account for the general linear focus of the dikes along the east side of the complex, as a large feeder dike could lie at depth along this zone.

The fenite in the north-central part of the complex is also believed to have significance in pointing to underlying carbonatite. These altered rocks not only contain a high concentration of minor elements, such as niobium, rare-earth elements, and thorium, that are found in the carbonatite dikes, but also contain anastomosing carbonatite dikelets and disseminated carbonate minerals and other minerals typical of fenites produced by carbonatite intrusives in mafic rocks.

Verwoerd (1966a, p. 141), in his study of fenites and carbonatites, concluded that:

"The addition of CO_3^{2-} ions during fenitization may perhaps be used as a criterion to establish the source of fenitizing fluids. Thus, CO_3^{2-} reaches its peak in the examples studied at Goudini where fenitization is already associated with carbonatization phenomena, while feldspathoid intrusives are not known to be present. CO_3^{2-} is also an important constituent of fenites closely associated with carbonatite (Tweerivier, Chishanya). On the other hand CO_3^{2-} is absent in fenites where fenitization was not directly linked to the carbonatite phase of an alkaline complex (Spitskop, Dorowa, Phalaborwa)."

The shape and size of the area underlain by fenite in Gem Park and the nature of the fenitizing process described above lead the authors to conclude that the source of fenitizing fluids was a carbonatite mass which lies at moderate depth below this area. The exposed fenite, which contains sodic amphiboles, vermiculite, and minor aegirine, probably represents the outer part of the fenite aureole, and as the postulated carbonatite is approached in depth, aegirine and other nonhydrous and higher temperature minerals would be the principal metasomatic constituents. The abundance of niobium, thorium, and rare-earth elements in the fenite strengthens the case for a carbonatite source inasmuch as these elements characterize the carbonatite dikes found in the complex.

ECONOMIC GEOLOGY

Concentrations of niobium, thorium, rare-earth elements, and phosphorus and deposits of vermiculite occur in the Gem Park Complex. Small deposits of iron, copper, silver, and nickel also are found in the complex but have not been studied in detail or appraised in the present work.

Niobium in the Gem Park Complex is contained in many carbonatite dikes and in fenite rocks at the Vermiculite mine. The individual carbonatite dikes offer little possibility for commercial recovery of niobium because they are discontinuous, small, and variable in grade. Locally, however, these dikes have concentrations of pyrochlore near the grade of present-day operating mines (table 11), and ore bodies might be found where numerous dikes join or are closely spaced. The fenitized gabbro and pyroxenite at the Vermiculite mine offer little promise for the commercial recovery of niobium even though a wide variety of niobium minerals are present and locally the content of niobium is generally higher than that in the carbonatite dikes (table 12). The grade is variable, and high concentrations of niobium found in serpentine dikes and small concentrations in vermiculite are not characteristic of the whole fenite mass.

The greatest potential for niobium in the Gem Park Complex lies in the possibility of a concealed carbonatite body. Such a body is postulated to lie approximately be-

neath the fenitized mass at the Vermiculite mine and is considered to have been the source of the fenitizing and niobium-rare earth-thorium-bearing fluids at the Vermiculite mine, as well as the source of the many carbonatite dikes in the complex. Such a carbonatite mass, especially in its apex, likely would be rich in niobium and related elements.

Thorium, rare-earth elements, and phosphorus probably are not recoverable economically from the carbonatite dikes, or from fenite in which they are found in minor amounts, but might be concentrated in an inferred underlying carbonatite mass. These elements might be valuable byproducts of economic deposits of niobium if such deposits should be found.

Vermiculite occurs locally in the fenitized mafic rocks at the Vermiculite mine and along some of the carbonatite dikes in other parts of the complex, but no large available tonnages of this mineral are indicated from surface exposures.

Copper and nickel occur in the Gem Park Complex but present work has been insufficient to appraise their potential. Copper in the form of chalcopyrite occurs in the coarse pyroxenite at the periphery of the complex, in the fenite at the Vermiculite mine, and locally in a few carbonatite dikes. Copper is the chief metal recovered from the Palabora (Phalaborwa) Complex in South Africa. (Engineering and Mining Journal, 1967), an alkalic complex similar in many respects to the Gem Park Complex.

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