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GEOLOGY OF THE LOOKOUT MOUNTAIN AREA, FREMONT COUNTY, COLORADO.

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Mineralogy

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GEOLOGY OF THE
LOOKOUT MOUNTAIN AREA,
FREMONT COUNTY, COLORADO

by
David Harrison Dahlem

A dissertation submitted in partial fulfillment
of the requirements for the degree of
Doctor of Philosophy in the
University of Michigan
1965

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TABLE OF CONTENTS

	PAGE
INTRODUCTION	1
Statement of problem	1
Location	2
Methods of investigation	2
Previous investigations	4
Acknowledgments	5
GENERAL GEOLOGY	7
Regional geologic setting	7
Petrologic units	12
IDAHO SPRINGS FORMATION	14
Field relationships	14
Microscopic petrography	19
Micaceous gneiss	19
Sillimanite-biotite gneiss	24
Sillimanite-muscovite schist	26
Cordierite-muscovite schist	27
Hornblende gneiss	29
Amphibolite	31
Cummingtonite amphibolite	32
Lime-silicate gneiss	33
Origin	37
Pelitic-quartz-feldspar assemblages	37
Summary of field relationships	37
Bulk mineral composition	39
Mineralogy	39
Ca-Mg assemblages	41
Summary of field relationships	41
Mineral composition	42
Parentage	45
Metamorphism	50
Post-metamorphic effects	56
PRECAMBRIAN IGNEOUS ROCKS	58
Pre-granite units	58
Diorite	58
Hornblende leucodiorite	59
Pegmatites	62
Age relationships	63
Precambrian granitic rocks	64
Boulder Creek granitoids	65

PAGE

Precambrian granitic rocks (cont'd.) . . . . . .
Pikes Peak granite 69
Pegmatitic granite and pegmatites . . . 72
Silver Plume "type" granite 73
Red granite 75
Origin 77
Migmatite 80
Diabase and other mafic dike rocks 83
Alkalic rocks 88
McClure Mountain complex 91
Dike rocks 94
Olivine gabbro-lherzolite dikes 96
Nepheline syenite 99
Lamprophyre 99
Augite dike 106
Ovoid lamprophyre 108
Trachyte 111
Breccia pipe 113
Carbonatites 120
Relationship of carbonatite and lamprophyre dikes to the McClure Mountain complex . . . 139

TERTIARY VOLCANICS. 142

QUATERNARY ROCKS. 147

Travertine and carbonate-cemented conglomerates. . 147
Alluvium 148

STRUCTURAL GEOLOGY. 150

General. 150
Metamorphic structural features. 150
Primary igneous structural features. 151
Folds 151
Faults 152

ECONOMIC GEOLOGY. 157

Iron Mountain mine 157
Rare-earth pegmatites. 158
Jim 3 mine 158
Horsepasture pegmatites 165
Miscellaneous rare-earth pegmatites 168
Mica and feldspar pegmatites 171
Thorium prospects 172
Miscellaneous deposits 173

PAGE

Miscellaneous deposits (cont'd.) . . . . . .
Leeks lode. 173
Green Dove. 178

GEOLOGIC HISTORY AND SUMMARY. 180

REFERENCES. 185

LIST OF TABLES

TABLE		PAGE
1	Petrologic units of the Lookout Mountain area. .	13
2	Modes of Idaho Springs rocks	21
3	Range in mineralogical composition of the major pelitic rock types	39
4	Range in mineralogical composition of the Ca-Mg-rich rock types.	43
5	Calculated oxide analyses of Idaho Springs members and comparison analyses.	47
6	Comparison of recast Idaho Springs analyses with Belt Series arkosic quartzite	48
7	Metamorphic mineral assemblages.	54
8	Proposed sequence of Precambrian granitoids. . .	65
9	Modal analyses of Wet Mountain granitic rocks. .	67
10	Summary of granitoids of the Lookout Mountain area	79
11	Details of northern Wet Mountain alkalic province.	90
12	Mineralogic summary of plutonic and hypabyssal dike rocks, northern Wet Mountain alkalic province	92
13	Proposed dike-rock age relationships	95
14	Textural varieties of lamprophyre dike rocks . .	103

LIST OF PLATES

PLATE		
1	Geologic map of the Lookout Mountain area	Pocket
2	Geologic map of the Klondike prospect	Pocket

LIST OF FIGURES

FIGURE		PAGE
1	Index map.	3
2	Regional setting of the Lookout Mountain area. .	8
3	Photomicrograph of cordierite-muscovite schist .	28
4	Photomicrograph of cummingtonite-hornblende amphibolite.	34
5	Photomicrograph of calc-silicate gneiss.	34
6	Photomicrograph of hornblende leucodiorite . . .	61
7	Granite migmatite.	70
8	Contorted biotite migmatite.	82
9	Breccia migmatite	82
10	Bifurcate diabase dike	85
11	Sketch of lamprophyre sill cutting offset basic dike	87
12	Photomicrograph of basic dike in Figure 11 . . .	89
13	Cross-faulted fracture controlling lamprophyre .	97
14	Photomicrograph of zoned augite phenocryst in spessartite.	101
15	Photomicrograph of barkevikite, augite, and magnetite phenocrysts in spessartite lamprophyre. . .	101
16	Chilled contact at margin of augite breccia dike	107

FIGURE		PAGE
17	Breccia center of augite breccia dike of Figure 16.	107
18	Photomicrograph of concentric bands around ovoid in ovoid lamprophyre	109
19	Photomicrograph of color-flow-banding in ovoid lamprophyre.	109
20	Photomicrograph of spherulitic trachyte.	112
21	Geologic map of the Pinon Peak breccia pipes . .	115
22	Pinon pipe breccia	117
23	Photomicrograph of crocidolite and aegirine in Pinon Pipe breccia	117
24	Basic dike intrusive breccia with granite gneiss	119
25	Geologic map of the Cabin Group carbonatites . .	123
26	Geologic map of the Dreamers Hope carbonatite. .	125
27	Geologic map of the Goldie carbonatite	127
28	Geologic map of the Theobold carbonatite	129
29	Chilled margin of a carbonatite near Goldie dike	130
30	Geologic map of the June RE-Th dike.	134
31	Photomicrograph illustrating clear carbonate intruding earlier hematitic carbonate.	137
32	Photomicrograph of brecciated sphalerite, quartz, and barite in a hematitic siliceous matrix . . .	137
33	Photomicrograph of euhedral bastnäsite in carbonatite.	140
34	Photomicrograph of welded vitric tuff.	146
35	Exhumed, terraced travertine deposits.	146
36	Geologic map of the Jim 3 pegmatite.	161
37	Mine map of the Jim 3 pegmatite.	163

FIGURE		PAGE
38	Geologic map of the Horsepasture pegmatites. . .	167
39	Geologic cross-section of the southwest Horsepasture pegmatite.	170
40	Geologic map of Leeks Lode copper prospect . . .	175
41	Mine map of Leeks Lode copper prospect	177

INTRODUCTION

STATEMENT OF PROBLEM

The Lookout Mountain-Five Point Gulch area is underlain by a thick assemblage of metasediments and intruding granites which have been correlated with Precambrian units defined in the central Colorado Front Range. The metasediments, correlated with the Idaho Springs Formation, consist of interlayered biotite and hornblende gneisses and schists with local calc-silicate and para-amphibolite lenses, and rare mafic ortho-gneisses, all metamorphosed to the almandine-amphibolite facies. A considerable time after metamorphism a series of four separate granites were emplaced giving rise to widespread migmatization and at least two generations of pegmatites, of which one contains rare-earth minerals.

Precambrian alkalic rocks that crop out in the southeastern part of the area belong to the McClure Mountain-Iron Mountain complex--a part of the Wet Mountain alkalic province which also includes the Gem Park stock and Democrat Creek complex further south. The McClure Mountain complex consists of a plutonic and late radial dike swarm intruded in the following order: gabbro, syenite, ijolite, nepheline syenite, lamprophyre, and carbonatite (lamprophyre and carbonatite dikes are the only units abundant in the Lookout Mountain area). Late lamprophyre and carbonatite dikes with associated fenitization transect the gneissic and granitic country-rock for ten miles though are

markedly concentrated in the southeast within three miles of the plutonic margin.

The Lookout Mountain-Five Point Gulch area is of particular geologic interest for two reasons. First, a description of the metamorphic and igneous assemblages and associated mineral deposits extends knowledge of the Front Range Precambrian core further south. Second, this area offers a complete assemblage resulting from alkalic igneous activity including plutonic intrusions, marginal dikes, and an explosion-breccia pipe.

LOCATION

The Lookout Mountain-Five Point Gulch area lies approximately 15 miles west of Canon City in Fremont County, Colorado (Figure 1). It is bounded on the north by the Arkansas River; on the east by Baker, Smith, and Copper Gulches; on the south by Turkey Creek; and on the west by Texas Creek. It includes 65 square miles centered approximately at 105°30'00" W. longitude and 38°22'30" N. latitude. Prominent peaks in the area are Lookout Mountain toward the south and Pinon Peak toward the east.

METHODS OF INVESTIGATION

This paper is based on field and laboratory studies developed during 1963, 1964, and 1965. Field geology was plotted on U. S. Geological Survey aerial photographs (series VDB, 1954) enlarged to a scale of 1:9,000 and transferred to a base map made from U. S. Geological Survey Royal Gorge and Cotopaxi quadrangle sheets

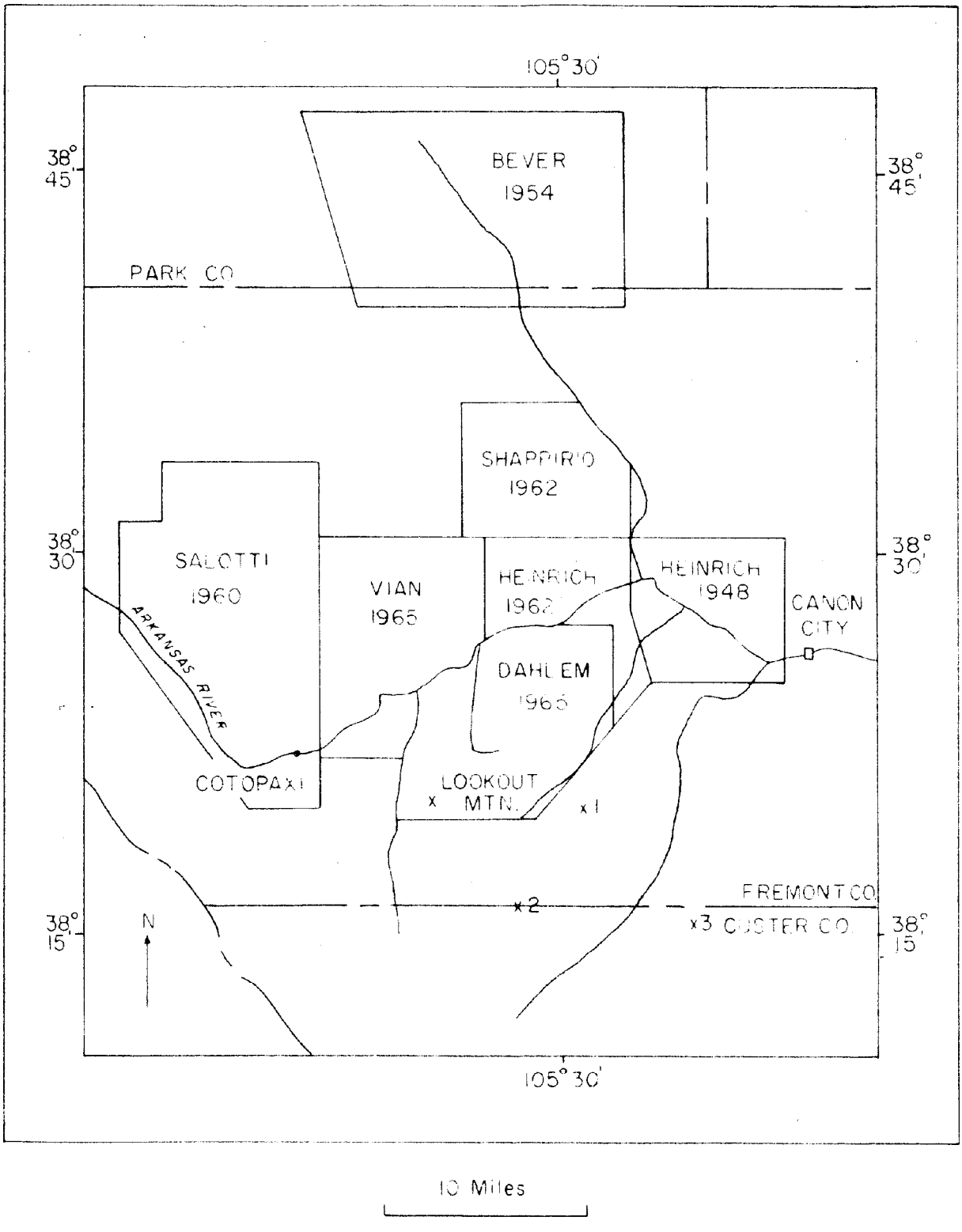


Figure 1. Index map of the Lookout Mountain area, Fremont Co., Colorado. 1, Iron Mountain - McClure Mountain complex; 2, Gem Park complex; 3, Democrat Creek complex.

at a scale of 1:31,250. Standard mineralogic and petrographic techniques were employed in the laboratory study.

PREVIOUS INVESTIGATIONS

There has been no previous geologic mapping in the Lookout Mountain area. The earliest report on the geology of the northern Wet Mountains was by Endlich (1874) for the Haydon Survey. This paper and one by Cross (1893) describe schists and gneisses of the Salida-Canon City area as among the oldest of the state.

Mathews (1894, 1900), Ball (1906), Spurr et al. (1908), and Lovering (1935) have named and described the major Precambrian units of the Colorado Front Range as a result of work in the Georgetown-Central City area. Over the next 30 years the correlation of Precambrian granites and gneisses was extended further south by Heinrich (1948) and Stark et al. (1949). Lovering and Goddard (1950) integrated all previous work with their investigations between Cripple Creek and Georgetown and extended regional Precambrian correlation to the vicinity of Texas Creek Junction. Under the direction of E. Wm. Heinrich, University of Michigan, five detailed geologic studies have extended correlation of the Precambrian units from the Guffey area to the Arkansas River as follows:

Heinrich (1948) Eight-Mile Park Area

Bever (1954) Guffey Area

Salotti (1960) Cotopaxi-Howard Area

Shappirio (1962) Tallahassee Creek Area

Gross (1962) Mount Rosa Area

Vian (1965) Devil's Hole Area

Recent detailed work by the U. S. Geological Survey on the stratigraphy and structure of the Colorado Precambrian near Central City was reported by Moench et al. (1962).

U. S. Geological Survey investigations of thorium deposits in the Wet Mountains have been summarized by Christman et al. (1953), Singewald et al. (1955), Singewald and Brock (1956), and Christman et al. (1959). Singewald (1913) and Becker et al. (1961) have described titano-magnetite deposits near Iron Mountain but neither recognized the alkalic nature of the assemblages. Parker et al. (1962) and Parker and Hildebrand (1963) have described the alkalic rocks and associated mineral deposits near Gem Park and McClure Mountain and have continued their investigations up to the present time (Nolan, 1964).

Landes (1935) described a feldspar pegmatite near Sheep Basin. Heinrich (1948) and Hanley et al. (1950) describe pegmatites in adjoining areas of the type found near Lookout Mountain.

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The writer also wishes to thank the ranchers and prospectors of the area for assistance and information. In particular, G. C. Addey of Canon City spent several days in the field familiarizing the writer with his mineral deposits. And without the help, companionship, and continued encouragement of my wife, Joan L. Dahlem, this project would surely have been more difficult.

GENERAL GEOLOGY

REGIONAL GEOLOGIC SETTING

In Colorado, the Rocky Mountain Front is dominated 1) by the north-south trending Front Range from Wyoming to Canon City, 2) by a southern-tip of the Front Range called the Wet Mountains, and 3) by the Sangre de Cristo Range which continues south into New Mexico. The Lookout Mountain area is on the northwestern flank of the Wet Mountains.

According to Eardley (1962, p. 394), the Front Range and Wet Mountains were closely associated during both the late Paleozoic and Laramide orogenic events. Structural and petrologic detail suggest that the association goes back into Precambrian time. Both are characterized by Precambrian metamorphic and igneous cores flanked on the east by steeply-dipping and, in places, overturned and thrust sediments. The western Front Range margin is marked by an east-dipping thrust extending north from South Park and also south toward the Canon City Embayment (Figure 2).

The Wet Mountain-Wet Mountain Valley tectonic unit is offset approximately 30 miles west of the southern Front Range. It consists of an eastern range and parallel western valley which extends 50 miles south-southeast from the Arkansas River. The overall structure of the unit south of Westcliffe is that of a simple anticline and syncline faulted on the west and plunging south (Burbank and Goddard, 1937). North of Westcliffe, the

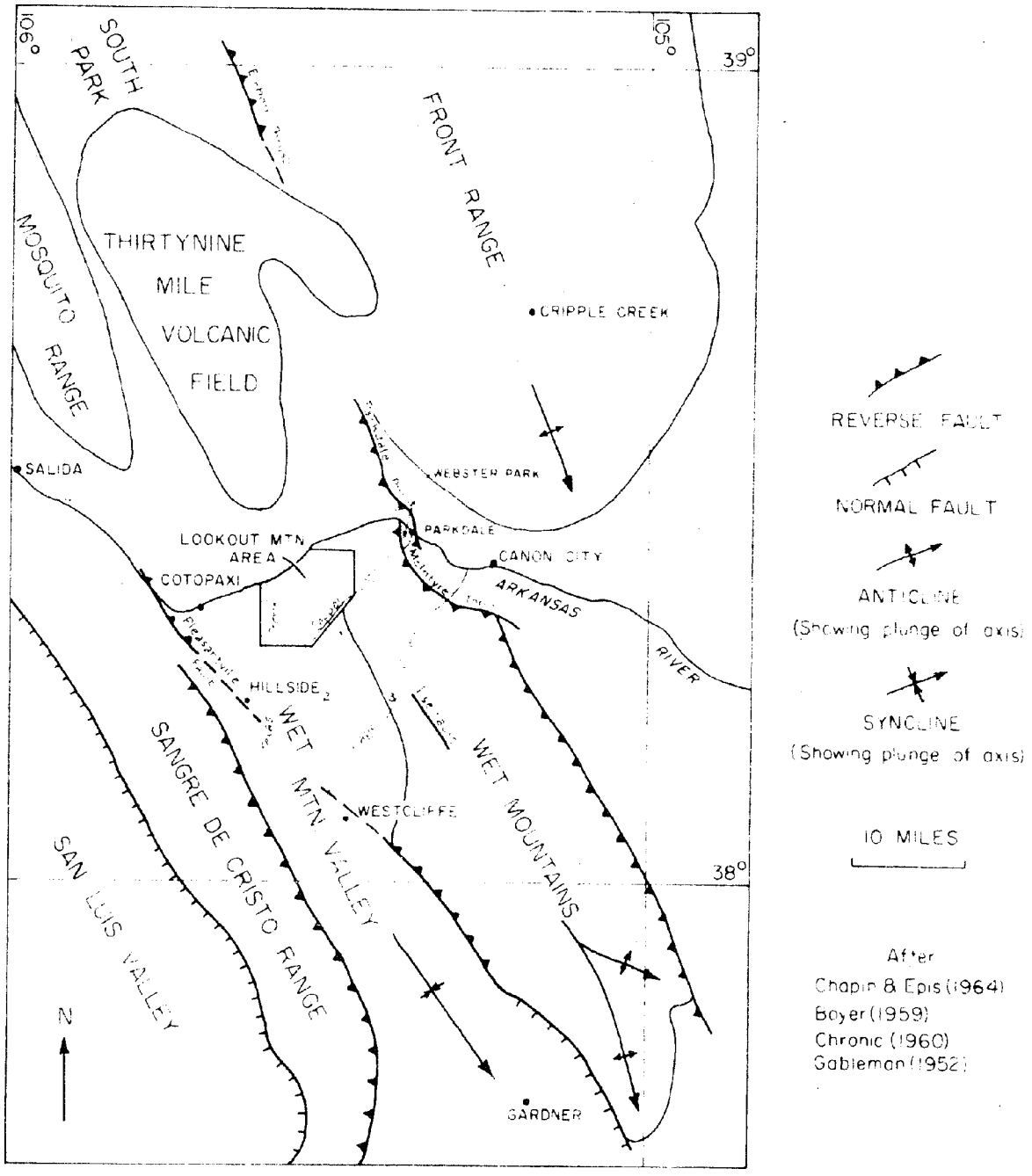


Figure 2. Regional setting of the Lookout Mountain area, Fremont Co., Colorado. 1, McClure Mountain complex, 2, Gem Park complex, 3, Democrat Creek complex

valley (syncline) narrows between the Pleasantville fault and the marginal faults of the Sangre de Cristo Range and the low-lying hills east of Hillside are not structually related to either southern fold.

The belt of Precambrian rocks exposed in the Front Range and Wet Mountain core outcrops as far south as the Greenhorn Peaks near Gardner, but along with exposures in the range proper the metamorphics also outcrop or underlie shallow Tertiary sediments and volcanics from the eastern Wet Mountain "range" approximately ten miles west. This area of low-lying Precambrian rocks west of the Wet Mountains is bounded on the east by the Ilse fault and its northward projection, and approximated on the west by a line drawn from the Arkansas River four miles west of Cotopaxi to Hillside and Westcliffe. This line also coincides with the Pleasantville fault (Gabelman, 1952; Salotti, 1960) and is the approximate eastern limit of sediments in the Wet Mountain Valley. An apparent arm of the Wet Mountain Valley extending north of Westcliffe toward McClure Mountain contains little sediment and is cut almost directly on bedrock.

A geologic section from Canon City across the northern Wet Mountains into the Wet Mountain Valley would exhibit the following: steep east-dipping Paleozoic and Mesozoic sediments of the Canon City Embayment, folded and thrust along N-S trending faults between Eight-Mile and Webster Parks; Precambrian rocks thrust east over synclinally-folded Cretaceous sediments at the west margin of Webster Park (Campbell, 1922; Chronic, 1960).

From Canon City to Webster Park, Precambrian rocks are exposed in Eight-Mile Park and in two fault blocks near Parkdale. Further west, Precambrian rocks crop out continuously as far as Hillside. The poorly defined Wet Mountain axis projects to the Arkansas River between Webster Park and Five Point Gulch, and from the latter to Cotopaxi (or Hillside) the metamorphics belong to the region of low-lying hills defined above. Major north-south faults transect the metamorphic assemblage at Five Point Gulch, Texas Creek, Sandy Gulch, and south of Bernard Creek at Cotopaxi.

In most respects, the metamorphic assemblage of the northern Wet Mountains and Lookout Mountain area is similar to that described in the Front Range to the north. It consists of a thick assemblage of metasediments called the Idaho Springs formation, probably intruded prior to metamorphism by mafic dikes and sills and intruded both during and after metamorphism by batholithic masses varying from granite to tonalite in composition. The largest of these is the Pikes Peak batholith which is exposed in the southern Front Range 15 miles northeast of the Lookout Mountain area. Two distinct periods of granite emplacement have been recognized in the Front Range on the basis of structural and textural criteria and both have been recognized in the Lookout Mountain area. The earlier catazone (Buddington, 1959) plutons are represented by the Kenosha, Boulder Creek, and Pikes Peak batholiths of the Front Range emplaced in that order (Badgley, 1960). The younger plutons have been grouped as Silver

Plume type by Lovering and Goddard (1950) and exhibit mesozone characteristics consistent with their emplacement under less deep-seated conditions. Included in this group are the Cripple Creek and Silver Plume batholiths, a number of isolated plutons of the Front Range, and the Red Aplitic Granite of the Tallahassee Creek area (Heinrich, oral communication). Pegmatites related to the earlier catazone intrusives are very common but few related to the Silver Plume type of intrusive have been found.

The Wet Mountain alkalic province consists of three separate complexes in southeastern Fremont and Custer Counties, Colorado. The McClure Mountain complex, approximately four miles southeast of Lookout Mountain is the largest and most varied of the three, and the numerous alkalic, lamprophyric, and carbonatitic dikes described in this report are believed related to it.

Thus the Precambrian rocks of the Lookout Mountain area fall into three groups as follows: (1) the pre-granite metasediments of the Idaho Springs formation, (2) the two major stages of plutonic granite emplacement, and (3) the post-granite alkalic complex.

Tertiary pyroclastics found both north (Vian, 1965) and south (Cross, 1896) are only sparingly represented near Lookout Mountain. Here they occur on a truncated Precambrian terrane with no evidence as to their relationship to contemporaneous sediments. Aside from recent alluvial and colluvial material,

no post-Cambrian sediments have been preserved in the Lookout Mountain area.

PETROLOGIC UNITS

Table 1 lists the petrologic units recognized in the Lookout Mountain area.

Table 1. Petrologic units of the Lookout Mountain area.

Period	Name	Characteristics
Quaternary		Alluvial and colluvial material Travertine and cemented fluvial deposits
Tertiary		Pyroclastics and ash
Precambrian		Diabase dikes
	McClure Mountain Alkalic Rocks	Alkalic dike rocks and carbonatites Hornblende Syenite Nepheline Syenite Gabbro
	Granites Red Aplitic Silver Plume (?) type Pegmatitic Pikes Peak Boulder Creek Tonalite	
	Migmatites	
Map symbols Plate I	M 1	Granite migmatite
	M 2	Contorted biotite gneiss with minor feldspathic injection
		Hornblende gabbro-diorite
	Idaho Springs formation	
	IS 1	Feldspathic gneiss
	IS 2	Foliated biotite gneiss with phacoidal and nodular sillimanite
Map symbols Plate I	IS 3	Massive biotite gneiss
	IS 4	Foliated hornblende gneiss
	IS 5	Amphibolite
	IS 6	Muscovite schist with local cordierite or sillimanite nodules

IDAHO SPRINGS FORMATION

Gneisses and schists correlated with the Idaho Springs formation underlie the northern half of the Lookout Mountain area. They consist of banded biotite gneiss with less abundant intercalated hornblende gneiss and mica schist units. Introduction of feldspathic material is widespread resulting in both injection gneiss and metasomatized assemblages. Six units have been mapped (Table 1) based on field criteria such as mineralogical composition and rock structure.

FIELD RELATIONSHIPS

Banded biotite gneiss (IS 2) is the most abundant unit of the Idaho Springs formation and is characteristically developed southeast of Texas Creek Junction. It is a medium gray, medium- to fine-grained rock with well-developed mineralogical banding and poor cleavage. Biotite, the most common mafic mineral, is always oriented in the plane of foliation but is rarely concentrated in wholly mafic bands alternating with bands of plagioclase, microcline, and quartz. Banding varies from 1 mm to 3 cm with layers of 1 cm thickness most common. Alternating layers of hornblende-rich and biotite-hornblende gneiss are important near Texas Creek Junction.

Biotite gneiss east of Five Point Gulch differs from that to the west by being more coarsely banded, containing more pegmatitic material and abundant high-grade metamorphic minerals

such as sillimanite and garnet. Fewer hornblende-rich layers occur to the east although small discordant amphibolite bodies are more common.

Two compositionally extreme types crop out in Five Point Gulch. One-half mile above the Arkansas River confluence, coarse-grained biotite schist containing hornblende porphyroblasts up to 1 cm diameter is locally abundant. The foliation of the schist parallels that of the surrounding gneiss. Approximately one mile south of the Arkansas River, biotite gneiss is locally quartzitic. It is coarse grained, light gray, contains very little biotite, and lacks the small scale layering of the typical biotite gneiss.

Sillimanite is a common constituent of biotite gneiss east of Five Point Gulch and occurs in two stratigraphic units in the Texas Creek Anticline. It most commonly occurs as white felted phacoids from ¼ inch to 2½ inches across, oriented in the plane of foliation and scattered through an interval of from 100 to 500 feet. In the Texas Creek Anticline, a 500-foot-thick assemblage of phacoidal sillimanite-biotite gneiss can be traced discontinuously for two miles around the nose of the fold. An irregular unit of nodular sillimanite gneiss appears in Sec. 15, T.19S., R.73W. Here spheroidal nodules, up to 2½ inches across, consist of a cream-colored, felted sillimanite core with a hematite-stained muscovite rim in a matrix of granitized biotite gneiss.

Muscovite schist is the only well-defined marker bed in the Idaho Springs formation near Lookout Mountain. It is found as a 450-foot-thick unit extending between the Arkansas River and Five Point Gulch and as a thicker unit (650-700 feet) outlining the Washtub Gulch Syncline (Secs. 5 and 6, T.19S., R.72W., and Secs. 31 and 32, T.18S., R.72W., Plate 1). It is light gray, coarse grained, consisting predominantly of muscovite and quartz, with variable amounts of sillimanite, garnet, tourmaline, and magnetite.

Cordierite occurs as spectacular poikiloblastic aggregates in the Five Point Gulch mica schist. It varies from rectangular aggregates as large as 6 inches by 18 inches to ovoids less than ¼ inch across. Cordierite constitutes 15-30% of this schist which has been traced from the Five Point Gulch fault system northwest to Highway 50 and two miles further north by Vian (1965). It, too, serves as an excellent structural "marker" bed.

Massive biotite gneiss is a local non-foliate variant of the banded biotite gneiss of sufficient abundance to constitute a mappable unit. It is a coarse-grained, dark gray to black granoblastic rock lacking both conspicuous foliation and banding. It is most typically exposed at the mouth of Sawmill Gulch and along the east fork of Five Point Gulch. Biotite, quartz, and plagioclase are the only megascopic minerals, but microcline metacrysts near granite contacts are common. Massive biotite gneiss grades into banded gneiss and the contacts with migmatite have been drawn where granitic material constitutes

more than 50% of the rock. In Sec. 34, T.19S., R.73W., massive biotite gneiss xenoliths attenuated and strongly injected can be found in most granite outcrops and the enveloping granite is generally enriched in biotite.

Feldspathic gneiss is a medium-grained, orange to gray, poorly foliated gneiss typically exposed around the park west of Indian Spring. Its foliation is due to minor biotite which occurs in discontinuous bands from 1 mm to 1 cm thick. Potash feldspar, quartz, and plagioclase are the other megascopic constituents. Potash feldspar is rudely concentrated in bands. Upon weathering, iron in the potash feldspar is oxidized causing a red streaked effect on the outcrop adding to the apparent foliation of the rock. Although feldspathic gneiss crops out over a large area near Indian Spring, it is also a minor constituent in banded gneiss (Sec. 5, T.19S., R.72W.; and Secs. 8 and 9, T.19S., R.73W., Plate 1) interlaminated with biotite and hornblende gneiss. In the latter occurrence, biotite is generally more abundant than in rocks near Indian Spring. Feldspathic gneiss grades into a granite that resembles Pikes Peak granite along strike (eg. Sec. 19, T.19S., R.72W.).

Both hornblende gneiss and amphibolite occur in the Idaho Springs sequence near Lookout Mountain. Hornblende gneiss is widespread but constitutes a mappable unit only locally. It occurs most commonly as thin discontinuous layers intercalated with banded biotite gneiss in both the Texas Creek Anticline and Washtub Gulch Syncline. The most persistent unit is that

between upper Stacy and Rito Gulches which can be traced southeast discontinuously in T.19 and 20S., R.73W. to the south of Lookout Mountain (Plate 1). A thick conformable unit can be seen just west of Sheep Basin on Highway 50 and is similar to the one mapped at the mouth of Baker Gulch. In both occurrences the units can be traced for about one mile before being truncated by cross-faults.

Amphibolite is widespread in the Lookout Mountain area but not abundant. A 300-foot sill north of Pinon Peak (Sec. 18, T.19S., R.72W.) is the only unit large enough to be mapped. One-half mile east of Five Point Gulch, several small discordant bodies crop out in the Highway 50 road cut, and a number of other irregular and lensoid units are particularly numerous in the Texas Creek Anticline. Amphibolite is only weakly granitized. It is not resistant to erosion and as a result, much float is found but outcrops are sparse.

A cummingtonite-hornblende amphibolite was found in the massive biotite gneiss zone about one-quarter mile north of the mouth of Sawmill Gulch (Sec. 20, T.19S., R.73W., Plate 1). It is a medium-grained, non-foliated greenish-brown rock locally containing introduced feldspathic material.

Previous estimates of the thickness of the Idaho Springs formation vary from several thousand feet (Salotti, 1960) to 25,000 feet (Lovering, 1929). In the Lookout Mountain area, the maximum possible thickness is approximately 8,000 feet. This is based on sections folded in the Texas Creek Anticline

and Washtub Gulch Syncline assuming the mica schist units that occur in each are correlative. Such a composite section would include the following:

2,500'	Feldspathic gneiss--biotite gneiss
500-700'	Mica schist
2,000'	Biotite gneiss with phacoidal sillimanite
3,000'	Banded biotite gneiss with abundant hornblende gneiss and pegmatitic material
8,000-8,200'	

The mappable units described above can be organized as follows to facilitate their petrographic description:

Pelitic quartz-feldspar assemblages
Micaceous gneisses, undifferentiated biotite-rich with some hornblende
Sillimanite-biotite gneiss
Muscovite schist, ±sillimanite and biotite
Cordierite-muscovite schist

Ca-Mg assemblages
Hornblende gneiss
Amphibolite
Cummingtonite amphibolite
Lime-silicate gneiss

MICROSCOPIC PETROGRAPHY

MICACEOUS GNEISS

Micaceous gneiss consists predominantly of quartz-biotite-feldspar gneiss and some mafic-poor variants. It includes units mapped as banded biotite gneiss, massive biotite gneiss, and feldspathic gneiss. All varieties contain essential quartz and plagioclase with microcline and biotite ranging from several percent to over 25%. The accessory mineral suite includes myrmekite, muscovite, magnetite, sphene, apatite, zircon, allanite, garnet, tourmaline, epidote, and sillimanite. The most

common alteration products are sericite, chlorite, kaolinite, hematite, limonite, and calcite.

Two basic textural variations are present in the micaceous gneisses--one, a mosaic intergrowth of quartz and feldspar with subparallel orientation of biotite, and the other a moderately cataclastic schistose texture. These textures correspond to massive- and finely-banded, biotite gneiss and schist, respectively (Modes 4 and 6, Table 2). In the typical gneiss, subhedral plagioclase (Ab_{65-73}), and anhedral quartz $\pm$microcline occur in a medium-grain (0.5-0.7 avg.) granoblastic texture. Plagioclase grains are rarely zoned with sericitized cores rimmed with albite. Microcline is usually perthitic. The abundance of myrmekite is directly related to the amount of microcline present and commonly occurs along microcline grain boundaries. Subhedral, ragged biotite individuals up to 1 mm long show greater preferred orientation with increased abundance. The biotite content varies from 5 to 50%, and averages about 15%. In most specimens the accessory minerals are concentrated along trains and clusters of biotite. Allanite and zircon commonly produce pleochroic halos in biotite, and sphene develops as clusters of subhedral grains or along biotite cleavage traces. Minor muscovite is oriented parallel to the foliation in aggregates with biotite as the latest primary mineral.

Biotite schist consists of 50% well-oriented biotite flakes as long as 1.5 mm, in a matrix of finer-grained quartz and andesine (Ab_{53}). Hornblende prophyroblasts with peripheral fine-

Table 2. Modes of Idaho Springs rocks.

Sample	1	2	3	4	5	6
Quartz	40.6%	41.4%	24.7%	41.8%	49.4%	17.4%
Microcline			36.7	31.2	tr	tr
Orthoclase	28.5	41.3				
Plagioclase	22.0	10.6	29.8	13.0	18.6	16.6
Biotite			8.4	13.4	28.1	54.7
Hornblende						5.4
Sillimanite						
Myrmekite	6.0	4.0				
Muscovite						
Accessories	3.0	2.7	.5	.6	4.0	6.1
Ab-content	73	71	65	73	70	75
Qtz/Feld	.80	.80	.37	.95	2.6	1.04
K-Feld/Plag	1.3	3.9	1.2	2.4	tr	tr
Felsic/Mafic	29	36	12	6	2	.5

Sample	7	8	9	10	11	12
Quartz	65.0%	49.4%	50.3%	60.8%	47.4%	56.3%
Microcline		31.3	27.8		32.5	10.4
Plagioclase		10.1	11.6			10.6
Biotite	13.0	7.7	8.6		5.9	11.1
Hornblende	19.6					
Sillimanite				39.1		4.8
Muscovite		1.6	1.4		14.1	6.7
Accessories	2.3	tr	tr		tr	tr
Ab-content		75	75			51
Qtz/Feld		1.19	1.28		1.47	2.7
K-Feld/Plag		3.1	2.4			.98
Felsic/Mafic	2	12	11		16	5

Sample	13	14	15
Quartz	10.4%		
Plagioclase	28.6	5.2%	20.8%
Biotite			28.6
Hornblende	60.2	94.8	16.2
Cummingtonite			29.4
Accessories			5.2
Ab-Content	56	41	65-75
Qtz/Feld	.36		
Felsic/Mafic	.6	.05	.3

Table 2 (cont'd.)

1. Feldspathic gneiss, Lookout Mountain area, Sec. 30, T.19S., R.72W.
2. Feldspathic gneiss, Lookout Mountain area, Sec. 24, T.19S., R.73W.
3. Biotite gneiss, Sec. 16, T.19S., R.73W.
4. Biotite gneiss, Sec. 15, T.19S., R.73W.
5. Garnet-biotite gneiss, Sec. 20, T.19S., R.72W., on Copper Gulch south of Spring Gulch.
6. Hornblende-biotite schist, mouth of Five Point Gulch.
7. Hornblende-biotite gneiss, Sec. 9, T.19S., R.73W., intercalated hornblende-rich Idaho Springs layer.
8. Sillimanite-biotite gneiss, 200 yards east of Five Point Gulch mouth on Highway 50.
9. Matrix of nodular sillimanite-biotite gneiss, Sec. 15, T.19S., R.73W.
10. Sillimanite-quartz nodule.
11. Phacoidal sillimanite-biotite gneiss, Sec. 34, T.18S., R.73W.
12. Sillimanite-biotite gneiss, Sec. 10, T.19S., R.73W.
13. Hornblende gneiss, Sec. 31, T.19S., R.73W.
14. Amphibolite, Sec. 18, T.19S., R.72W.
15. Cummingtonite amphibolite, Sec. 27, T.19S., R.73W.

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grained magnetite, and quartz augen as large as 1 cm across are molded by biotite. Garnet poikiloblasts up to 2 cm in diameter have developed across the gneissic fabric and may exhibit biotite and sutured-quartz rims with no feldspar. Common inclusions are quartz, biotite, and allanite.

Feldspathic gneiss is essentially a biotite-poor gneiss. It consists of a sutured intergrowth of quartz and orthoclase-perthite with subordinate oligoclase. Biotite is minor, randomly distributed and commonly part of interstitial mafic aggregates that also contain magnetite, garnet, and apatite. The accessory suite of Modes 1 and 2, Table 2, consists of 90% biotite. Finely divided, randomly distributed hematite accounts for the reddish hue developed upon weathering.

Massive biotite gneiss from Sawmill Gulch consists of a coarse intergrowth of oligoclase (Ab_{75}), biotite, and quartz with abundant sphene and apatite. The rock is characterized by its lack of biotite orientation and by an abundant accessory suite (10-15%). Subhedral oligoclase (50%) commonly exhibits albitic rimming. Quartz (10%) and microcline (1-5%) are anhedral, interstitial though microcline also occurs in a second generation as porphyroblasts up to 2-3 cm across. Biotite (25%) is subhedral, commonly poikilitic and randomly distributed. Sphene (5%), magnetite (4%), and apatite (2%) are commonly clustered with biotite and rarely strewn along the foliation. Oligoclase cores are selectively sericitized; biotite has been altered to chlorite and locally epidote. Oligoclase rims are commonly dotted with quartz inclusions.

Textural evidence suggests that at the point of highest regional metamorphic grade, the equilibrium assemblage was quartz-plagioclase(Ab_{65-73})-microcline-biotite $\pm$garnet. The substitution of orthoclase perthite for microcline in feldspathic gneiss without the breakdown of biotite to sillimanite and a spinel mineral is anomalous and suggests a non-equilibrium condition.

Post regional metamorphic effects listed in decreasing order of age are:

1. Sericitization of plagioclase
2. Chloritization of biotite
3. Albite rim and myrmekite development

The only variations due to granitization or to proximity to a granite contact are the development of poikilitic microcline metacrysts and anhedral quartz replacing all other components of the parent gneiss. In some samples microcline and quartz have replaced 75% of the original assemblage.

SILLIMANITE-BIOTITE GNEISS

Sillimanite-biotite gneiss is the sillimanite component of biotite gneiss, feldspathic gneiss, and some gneissic portions of granite migmatite. Sillimanite most commonly occurs as fine rods, phacoids, and spheroidal augen oriented in the plane of foliation. Where sillimanite is more abundant, it occurs with subordinate quartz in bands interlaminated with bands of quartz-microcline $\pm$plagioclase.

Sillimanite-biotite gneiss is essentially a medium-grained, poorly banded biotite gneiss with sillimanite substitutions for biotite (Modes 8, 9, 11, 12, Table 2). The most common assemblage is quartz-microcline, sillimanite $\pm$plagioclase $\pm$biotite $\pm$muscovite along with accessory zircon, apatite, allanite, magnetite, tourmaline, garnet, and sphene. Two textural varieties are common. One has the mosaic texture common to the biotite gneiss; the other is characterized by recrystallization and elongation of felsic constituents parallel to the foliation. Anhedral quartz and equant perthitic microcline occur in an interlocking to mosaic aggregate with subhedral plagioclase (Ab_{51-75}). The amount of myrmekite is directly related to the

abundance of microcline. Scattered biotite, up to 1.5 mm in length, is generally oriented and commonly intergrown with accessories and minor primary muscovite.

Sillimanite constitutes up to 40% of some rocks. It occurs as individual needles randomly distributed in the matrix and fibrolitic masses replacing biotite, quartz, and feldspars. Intermediate textures have been observed between these two textures as follows: (1) individual needles replacing biotite, paralleling the foliation, (2) bundles of needles in biotite, paralleling the foliation, (3) curved and swirling sillimanite needles in biotite, and (4) masses of swirling fibrolitic sillimanite with no biotite associated. Primary muscovite intergrown with biotite is replaced along with the biotite but to a lesser extent. The most common type of phacoid consists of fibrolitic sillimanite and minor quartz. Nodular sillimanite (Mode 10, Table 2), in contrast, consists of randomly oriented brown fibrolitic sillimanite bundles in a matrix of recrystallized, sutured and interlocking quartz surrounded by a muscovite-quartz $\pm$feldspar rim.

Muscovite occurs in two generations. The earlier is contemporaneous with the biotite or regional metamorphism; the later generation is post-sillimanite and is clearly not related to the regional metamorphic assemblage. This retrograde metasomatic muscovite occurs as very coarse poikilitic plates up to 2 cm across, randomly oriented across the preexisting foliation. Common inclusions are quartz and sillimanite

with fibrolitic sillimanite commonly occupying the cores of large individuals. All stages of muscovite development can be seen from 1) fibrolitic masses with marginal rims of ragged muscovite, 2) to poikilitic muscovite flakes with internal quartz and random acicular sillimanite.

Petrographic evidence suggests that the equilibrium assemblage of sillimanite-biotite gneiss was the same as that of biotite gneiss during regional metamorphism as follows: quartz-plagioclase(Ab_{51-75}) $\pm$microcline $\pm$biotite $\pm$garnet. Subsequently the assemblage was modified to quartz-sillimanite $\pm$microcline $\pm$plagioclase $\pm$garnet, or quartz-sillimanite $\pm$garnet.

SILLIMANITE-MUSCOVITE SCHIST

Sillimanite-muscovite schist, a local variant of sillimanite-biotite gneiss, consists of essential quartz, sillimanite, and muscovite with variable biotite, microcline, and plagioclase (Ab_{72}) and accessory tourmaline, magnetite, garnet, and zircon. It differs from the gneiss by being coarser grained (1-3 mm avg.) and consisting predominantly of muscovite and sillimanite in a matrix of coarse-grained interlocking quartz $\pm$microcline. Microcline is interstitial to poikilitic porphyroblastic. As in the sillimanite gneiss, sillimanite is most commonly fibrolitic and muscovite is retrograde after sillimanite, the remaining partly-replaced biotite, and microcline.

CORDIERITE-MUSCOVITE SCHIST

Cordierite-muscovite schist is a coarse-grained schistose rock composed of essential muscovite, quartz, sillimanite, cordierite, and plagioclase. It occurs as a 450-foot-thick bed that has been traced approximately four and one-half miles northwest from Five Point Gulch into the Devils' Hole area (Travis, 1956; Vian, 1965). This unit is similar to muscovite schists described above but in addition contains cordierite aggregates up to 18 inches across. Common accessory minerals are magnetite, microcline, tourmaline, garnet, and biotite.

The rock usually exhibits banding on a microscopic scale with muscovite-sillimanite-biotite layers alternating with layers of quartz and feldspars. The micaceous bands consist of fibrolitic sillimanite that have almost completely replaced biotite, subsequently being replaced by muscovite, in a matrix of quartz and plagioclase. Discontinuous trains of fine-grained equant magnetite commonly outline the foliation. Plagioclase (Ab_{69}), locally abundant, contains numerous inclusions of quartz and magnetite, and is elongate parallel to the foliation. A few plagioclase porphyroblasts reach a diameter of 1.5 mm.

Cordierite occurs as poikiloblastic aggregates (Figure 3) principally in micaceous layers where it has replaced all pre-existing species except muscovite and sillimanite. One- to two-millimeter individuals are choked with inclusions rarely exhibiting inclusion-free rims. Larger individuals are commonly surrounded by a quartz-muscovite rim. The most abundant inclusions are

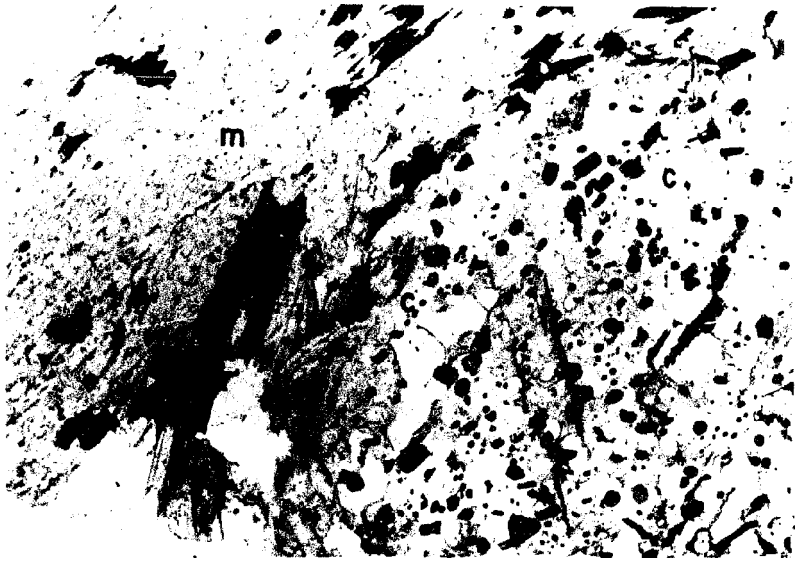


Figure 3. Photomicrograph of cordierite-muscovite schist. Muscovite (m) surrounding cordierite (c) porphyroblast. Note trains of magnetite in cordierite paralleling schistocity (upward to right), Sec. 4, T.19S., R.73W. Plane polarized light, x35.

quartz, magnetite, schorl, muscovite, altered biotite, and sillimanite. Where a large biotite flake abuts cordierite it is not deformed, but continues into the cordierite as either a string of altered fragments or as a limonite-stained zone. This evidence along with magnetite trains not being deflected around the cordierite suggests the cordierite grew in situ by replacement, not by thrusting aside layers of the micaceous host. Pinitization is widespread in coarser grains and may demonstrate a preferential marginal alteration of the cordierite.

The quartz-plagioclase-cordierite-biotite-garnet combination was the equilibrium assemblage during regional metamorphism. This was later modified to a quartz-cordierite-sillimanite-garnet-plagioclase non-equilibrium assemblage as indicated by incomplete reaction. The subsequent retrograde assemblage consists of quartz-plagioclase-cordierite-biotite-sillimanite-muscovite-garnet.

HORNBLENDE GNEISS

The occurrence west of Sheep Basin is typical of hornblende gneiss in the Lookout Mountain area. It is black, medium grained ($\pm$1 mm), foliated, with mineralogical banding from 1 mm to 3 cm wide and a major rock cleavage at 1 to 12 inch intervals. Biotite gneiss layers are intercalated as in the Texas Creek Junction area and a local microscopic alternation of biotite and hornblende-rich units is also common. At the Baker Gulch

occurrence, little admixed biotite is present, but quartz and calcite pods and layers may be seen.

The hornblende gneiss of Rito Gulch is gray-green and medium to coarse grained. It is banded on a scale of 2 mm to 3 cm with poor rock cleavage. The rock consists of alternating feldspathic and amphibole layers with rare porphyroblasts of amphibole and garnet. Epidote is an abundant constituent megascopically.

The essential constituents are hornblende and plagioclase (Ab_{55-72}), with quartz, diopside, and biotite abundant in some specimens. Textures vary from subhedral-granular to porphyroblastic with hornblende, plagioclase, quartz, and magnetite porphyroblasts. In granoblastic aggregates equant hornblende (0.5 to 1.5 mm) may be concentrated either in bands or randomly distributed in a mosaic of plagioclase $\pm$quartz. Secondary overgrowths of actinolitic hornblende commonly result in poikiloblastic intergrowths with inclusions of quartz, plagioclase, and magnetite. Plagioclase (Ab_{55-72}) is commonly zoned with rare examples of Na-core zoning. Rare augen consist of mosaic plagioclase or quartz up to 1 cm across. The most common accessory minerals, sphene and magnetite, are scattered throughout. Epidote occurs as discrete euhedra in all other constituents, as a product of saussuritization and in veinlets. Biotite is commonly found as an inclusion in poikiloblastic hornblende. Other accessory species are garnet, zircon, and apatite.

The most common alteration reactions are 1) plagioclase to sericite $\pm$epidote $\pm$calcite, 2) hornblende to biotite, 3)

hornblende to chlorite, epidote, and fine-grained magnetite, and 4) magnetite to hematite or limonite. Rare quartz veinlets have altered their wall rocks with the introduction of microcline into the surrounding gneiss.

The assemblages hornblende $\pm$plagioclase(Ab_{55-72}) $\pm$quartz $\pm$biotite were all at equilibrium during regional metamorphism. Subsequent retrograde phenomena have altered this assemblage as follows:

1. Hornblende overgrowths
2. Biotite alteration of hornblende
3. Saussuritization of plagioclase
4. Quartz veins, microcline introduction

AMPHIBOLITE

Amphibolite is a black to green-black coarse-grained rock commonly having no rock cleavage or banding. Units are both concordant and discordant to the enclosing biotite gneiss and rarely persist for more than several hundred feet along strike. Randomly distributed felsic augen consisting of a mosaic aggregate of plagioclase up to 1 cm across account for the only common megascopic textural variant.

Under the microscope the rock is seen to consist of essential hornblende with accessory plagioclase and minor clinozoisite, biotite, zircon, magnetite, sphene, apatite, and quartz. Two textures are common--porphyroblastic and anhedral granular. In the anhedral granular rock, medium- to coarse-grained hornblende (1 mm to 5 mm), commonly twinned, predominates with interstitial plagioclase. In the porphyroblastic

rock equant to elongate hornblende up to 1 cm is surrounded by a medium-grained mosaic or hornblende and interstitial plagioclase (Ab_{41-51}) from 0.5 to 1.0 mm in size which has been sericitized and saussuritized. Clinozoisite, the next most abundant accessory, replaces both plagioclase and hornblende and develops as poikiloblastic euhedra up to 0.7 mm. Rarely, actinolitic overgrowths extend hornblende grains as poikiloblastic individuals into interstitial felsic masses. Biotite is a common alteration of hornblende.

CUMMINGTONITE AMPHIBOLITE

In thin-section, cummingtonite, green hornblende, brown biotite, and plagioclase constitute the essential suite of cummingtonite amphibolite with apatite, magnetite, quartz, rutile, and anthophyllite as accessories. A decussate arrangement of characteristically twinned cummingtonite laths from 0.5 to 2.0 mm is the dominant textural feature with interstitial plagioclase and minor quartz. Laths are commonly fractured or broken. Some are poikiloblastic with inclusions of biotite, quartz, and magnetite.

Pale green hornblende appears most commonly replacing cummingtonite (Figure 4) and may be poikiloblastic containing cummingtonite inclusions in optical continuity. Further evidence of the replacement lies in the fracture-localization of many hornblende replacement individuals. The only feature difficult

to explain is the rare intergrowth consisting of an euhedral hornblende core in optical continuity with a cummingtonite rim.

Biotite occurs in two generations with differing habit and color. Early biotite is pleochroic dark-brown to tan with magnetite dust included along cleavage traces. Individuals of this generation are relatively stubby, broken, and an integral part of the decussate cummingtonite fabric. The second generation replaces cummingtonite, hornblende, and may grow over clusters of the earlier biotite. It is generally a lighter brown and anhedral. Plagioclase individuals are equant and interstitial, strongly zoned, but poorly twinned. Cores are generally sericitized. Both rutile and apatite occur in trains of individuals cutting all other species. Magnetite is scattered through the rock as fine grains, rarely as coarse.

LIME-SILICATE GNEISS

Lime-silicate gneiss, which is poorly exposed and not abundant, does not constitute a mappable unit but is included in banded biotite gneiss, massive biotite gneiss, and hornblende gneiss. Calcium-rich assemblages containing calcite, diopside, epidote, hornblende, $\pm$magnetite, and $\pm$garnet are characteristic occurring as thin concordant lenses and layers rarely larger than 1 foot thick and 15 feet long.

An occurrence one-half mile west of the Klondike prospect (Sec. 22, T.19S., R.73W.) is the only exception and consists of numerous layers over a ½-mile-square area of granite migmatite.

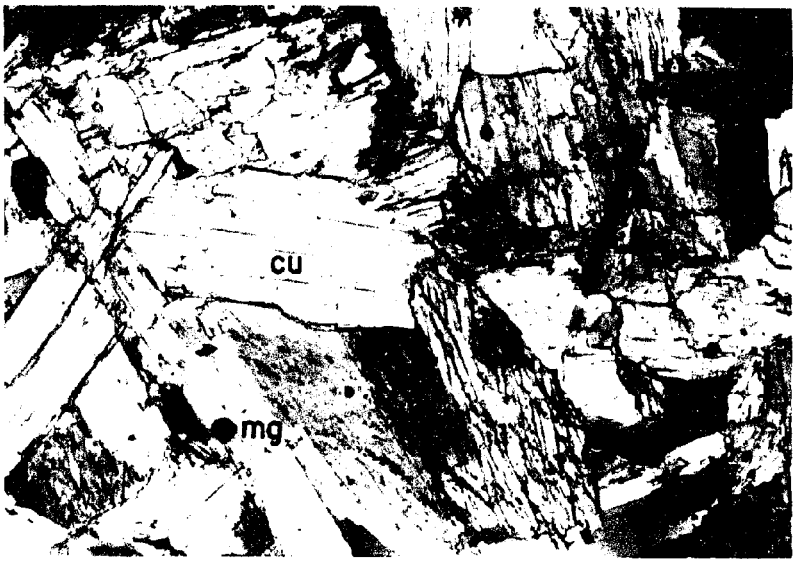


Figure 4. Photomicrograph of cummingtonite-hornblende amphibolite, Sec. 27, T.19S., R.73W. Cummingtonite (cu) partly altered to hornblende (h). Magnetite (mg). Plane polarized light, x35.

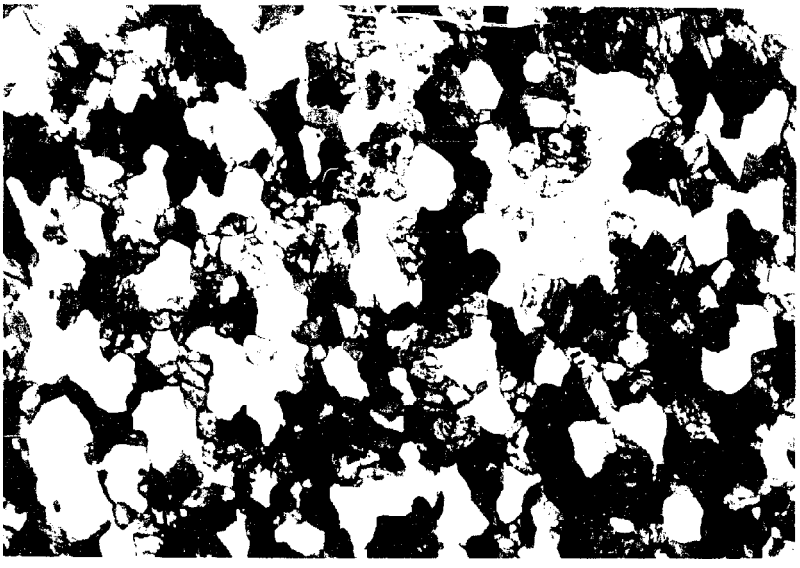


Figure 5. Photomicrograph of calc-silicate gneiss, Sec. 29, T.18S., R.72W. Granoblastic diopside (light gray) and hornblende (dark gray) in a matrix of plagioclase and carbonate. Plane polarized light, x35.

The rock is medium grained, mottled with green to brown streaks and pods in a white granoblastic matrix. Though commonly non-foliate, any traces of foliation are strongly contorted and strong recrystallization may obliterate the foliation altogether. Microscopically the rock is seen to consist of a xenomorphic aggregate of quartz, and microcline averaging 0.2 mm. Accessory minerals are granular, commonly arranged in a rude banding of scapolite, diopside, epidote, clinozoisite, and sphene. Scapolite is rarely poikilitic with grains as large as 0.5 mm. Alteration is minor with diopside altering to hornblende and scapolite to sericite.

The June No. 2 (Sec. 34, T.19S., R.73W.) occurrence consists of a 15-foot-long, 1-foot-wide, biotite-free lens in biotite gneiss. Along the center of the lens is a line of discontinuous boudin up to 2 inches wide containing a quartz core and marginal hornblende, epidote, and garnet. Nodules of magnetite up to 4 inches across are commonly found in the nearby float.

A third occurrence of lime-silicate rock is found in hornblende and biotite gneiss on upper Baker Gulch. Here calcite and quartz lenses in hornblende gneiss are bordered by coarse-grained diopside, epidote, and hornblende (Figure 5). The lenses are concordant, up to 6 inches thick and 10 feet long, and consist of granular calcite (2 mm) or quartz. Rarely a lens contains contiguous quartz and calcite layers.

Lime-silicate-bearing hornblende gneiss is commonly banded. Mafic layers consist of essential granular hornblende and diopside with interstitial quartz, plagioclase (Ab_{61}), and calcite. Felsic bands consist of twinned subhedral to anhedral andesine and anhedral quartz with granular clinozoisite, hornblende, diopside, and calcite with scattered epidote. Calcite is both granular and interstitial in mafic bands. Where calcite abuts plagioclase, granular epidote commonly separates the two. All minerals are coarser near felsic bands, particularly diopside and epidote. Common replacement phenomena are calcite after plagioclase and actinolitic hornblende after epidote and diopside. Sphene is common and tourmaline is a rare felsic-layer constituent.

In the vicinity of calc-silicate lenses, hornblende gneiss is banded by an alternation of coarse (0.15 mm) and fine (0.07 mm) layers of equivalent mineralogy. Where biotite gneiss is interlaminated with hornblende gneiss, calc-silicate layers consist of trains of granular clinozoisite and hornblende with minor biotite, diopside, muscovite, and accessory sphene, zircon, magnetite, and garnet. Common late metamorphic reactions involve the changes typical in both pelitic and calcareous rocks as follows: 1) biotite → sillimanite → muscovite, 2) biotite → chlorite, and 3) actinolitic hornblende replacing both hornblende and muscovite.

The fourth occurrence is in Sec. 32, T.19S., R.73W., on upper Rogers Gulch. The regional metamorphics consist of

injected hornblende gneisses included within the granite migmatite and the calcium-rich units are coarse-grained, green pyroxene-bearing zones. The rock is massive, consisting of coarse granoblastic pyroxene with a carbonate-rich matrix. Though exposures are poor, the unit appears to conform roughly to the regional foliation. A similar occurrence can be seen in Sec. 3, T.19S., R.73W., on the east of Five Point Gulch.

ORIGIN

In order to determine from what parent materials the Idaho Springs metamorphic rocks were derived, the pertinent field relationships and mineralogical data will be summarized in the following paragraphs. After the type of source material is established, its metamorphism and post-metamorphic effects will be considered.

PELITIC-QUARTZ-FELDSPAR ASSEMBLAGES

SUMMARY OF FIELD RELATIONSHIPS

The Idaho Springs formation consists of a thick series (8,000'+) of banded biotite gneiss with local intercalated hornblende, sillimanite, and feldspathic units and a medial mica schist marker bed. On the basis of equivalent mica schist and subjacent sillimanite biotite gneiss, a correlation of sections in the Texas Creek Anticline and Washtub Gulch Syncline has been suggested and the composite column listed on p. 19.

The following features are important:

1. Lowest member is a banded biotite gneiss and hornblende gneiss assemblage. Estimate 20% hornblende gneiss.
2. Unit 1 is overlain by a phacoidal sillimanite, poorly banded, biotite gneiss assemblage. Estimate 50% contains some sillimanite.
3. Mica schist unit.
4. Unit 3 is overlain by biotite-poor biotite gneiss and feldspathic gneiss.

The most characteristic feature of the assemblage is the lack of mineral segregation and lack of clastic and chemical sedimentary end-members. Banded biotite gneiss commonly contains 15-30% biotite. Light and dark alternating bands differ little except in biotite content. Quartzitic units found near the mouth of Five Point Gulch are feldspathic and contain about 5% biotite. Hornblende layers in the lower part of the section alternate with biotite on a scale of 1 mm up to tens of feet, and rarely are adjacent layers free of the other mafic. In addition, the average grain size range of all units is the same (exclusive of metasomatized units) and between 0.5 and 1.0 mm. Contacts between light and dark layers are sharp but the change of mineralogy across a contact is slight. Contacts between major units such as between the sillimanitic and hornblende-rich biotite gneisses are gradational and arbitrary. Along the trend of the units the thickness of individual layers does not vary notably locally. With the lack of marker horizons no

correlation is possible from outcrop to outcrop. On a regional scale, units such as hornblende gneiss, sillimanite gneiss and biotite schist can be traced for several miles but with a noticeable change in thickness. To what degree faulting or plastic flow contributes to this variation has not been estimated.

BULK MINERAL COMPOSITION

The pelitic-quartz-feldspar members of the Idaho Springs formation consist of (Table 3) essential quartz, microcline or orthoclase, oligoclase-andesine, biotite, with variable amounts

Table 3. The range in mineralogical composition of the major pelitic rock types.

	Qtz	K-Feld	Plag	Bio	Musc	Sill	Cord
Micaceous gneiss	25-65	0-40	10-30	5-50			
Sillimanite-biotite gneiss	45-55	10-30	10-12	5-10	tr-14	tr-40	
Muscovite schist	50-60	0-10	0-10	0-10	20-30	10-20	
Cordierite-muscovite schist	30-50	tr	10-20	tr-10	15-30	5-20	15-30

of sillimanite, and muscovite, and accessory hornblende, magnetite, sphene, garnet, apatite, and zircon.

MINERALOGY

Micaceous gneiss is a gray, banded, foliate rock consisting of essential quartz, oligoclase-andesine, and biotite, with variable microcline, and accessory muscovite, magnetite, garnet, hornblende, sphene, apatite, and zircon. The most common

texture consists of a mosaic of quartz, plagioclase, and microcline with biotite individuals, the most abundant mafic mineral, oriented and randomly distributed in the plane of foliation. Megascopic banding may be pronounced but is the result of a minor change in biotite content. Biotite content varies from an accessory amount to 50% in biotite schist.

Sillimanite-biotite gneiss consists of the same basic mineralogy as micaceous gneiss, but differs from it in two ways: 1) texture, and 2) abundance of sillimanite and muscovite. The texture is characterized by elongate felsic constituents oriented parallel to the foliation with randomly distributed lepidoblastic biotite. Sillimanite occurs as nematoblastic needles and elliptical fibrolitic masses intergrown with biotite and muscovite. Muscovite is a minor late prograde metamorphic mineral but more commonly replaces fibrolitic sillimanite and microcline as coarse-grained poikiloblastic randomly oriented flakes.

Muscovite schist is a poorly banded rock consisting of felsic bands of elongate quartz, plagioclase, and microcline alternating with bands of lepidoblastic biotite. Sillimanite commonly replaces biotite, and lepidoblastic muscovite replaces sillimanite. Tourmaline, magnetite, garnet, apatite, and zircon are common accessories.

Cordierite is an essential constituent of the Five Point Gulch muscovite schist. It occurs as poikiloblastic ovoids from 0.5 mm to more than 1.0 cm replacing all essential constituents

except muscovite and sillimanite. Trains of magnetite presumably relic after original bedding are not deformed by cordierite though muscovite locally is molded.

CA-MG ASSEMBLAGES

SUMMARY OF FIELD RELATIONSHIPS

Hornblende gneiss is a dark green to black, poorly banded rock consisting of medium-grained hornblende and plagioclase with rare augen of plagioclase. It varies from units 500 feet thick (mouth of Baker Gulch) to bands less than 1 foot thick interlaminated with biotite gneiss. Banding of the hornblende rock parallels that of the associated biotite gneiss. Quartz and calcite lenses 10-15 feet long are common and always parallel the foliation.

Lime-silicate units are closely associated with hornblende gneiss. They are lensoid, commonly 10-20 feet long and are zoned with a quartz core and marginal epidote, hornblende, diopside, and garnet. Units have been found in biotite gneiss but are more common in hornblende gneiss.

Amphibolite is a black medium- to coarse-grained granoblastic rock megascopically, consisting only of hornblende. It occurs primarily as thick sills (500 feet), and also as dikes, and irregular units less than 20 feet across in biotite gneiss and granite migmatite. While it may appear generally concordant with foliation, local discordance is common.

Amphibolite and hornblende gneiss are separated only with difficulty in the field. For this reason, the majority of previous investigators have lumped the two rock types. In spite of this, previous descriptions show that hornblende-rich rocks are more abundant in the southern Front Range-Wet Mountain area than to the north. In the Lookout Mountain area hornblende gneiss is most abundant in the south and east. Descriptions of the Idaho Springs rock types by Shappirio (1962) near Parkdale emphasize this component and Christman et al. (1959) describe the Idaho Springs formation as consisting largely of hornblende or mafic gneisses. Boyer (1959) likewise emphasizes this trend in the southern Wet Mountains.

Cummingtonite-hornblende amphibolite is a coarse-grained, massive rock consisting of megascopic amphibole, biotite, and plagioclase. It is a minor constituent in a zone of highly injected massive biotite gneiss and not found elsewhere. A similar rock type was described in the Tallahassee Creek area (Shappirio, 1962) in an alternating hornblende-cummingtonite gneiss sequence.

MINERAL COMPOSITION

The Ca-Mg-rich members of the Idaho Springs formation consist of essential hornblende and andesine-labradorite; with variable cummingtonite, biotite, diopside, and epidote; and accessory microcline, sphene, magnetite, calcite, clinozoisite, sphene, apatite, quartz, rutile, and anthophyllite. Table 4

shows the range in mineralogical composition of each rock type described.

Table 4. Range in mineralogical composition of the Ca-Mg-rich rock types.

	Hnbd	Plag	Bio	Epid	Diop	Qtz	Cumm	Calc	Ab
Hornblende gneiss	60	25-35	0-10			5-10			56
Amphibolite	95	5							41
Cummingtonite amph't.	16	21	29				29		65-75
Lime-silicate gneiss	30	10-20		20	20	10-20		0-10	60-65

Hornblende gneiss is a medium-grained, foliated rock consisting of essential granular hornblende, plagioclase, and quartz. Felsic bands consist of plagioclase $\pm$quartz. Biotite, if abundant, occurs in mafic bands with hornblende and in wholly biotite bands. Where calcite is abundant it occurs both in and between mafic bands and is commonly accompanied by diopside. Where calcite and diopside form megascopic lenses, epidote, hornblende, diopside, and rarely garnet form coarse-grained granular borders along the lens.

Lime-silicate lenses in biotite gneiss consist of trains of granular clinozoisite, hornblende, and diopside paralleling the biotite foliation.

Amphibolite consists of 90+% hornblende in a subhedral granular texture with minor interstitial plagioclase and epidote. Plagioclase is more basic (Ab_{41}) than in hornblende gneiss (Ab_{56}) and intense alteration of plagioclase with replacement by late actinolitic hornblende overgrowths suggest the two are not in equilibrium.

Cummingtonite amphibolite consists of a decussate intergrowth of essential cummingtonite, hornblende, biotite, in a matrix of plagioclase (Ab_{65-75}) with abundant apatite and sphene. Hornblende individuals may be rimmed by cummingtonite which is, in turn, altered to hornblende. Similar cummingtonite-rich gneisses of the Tallahassee Creek area (Shappirio, 1962) are part of an amphibolite sequence consisting of alterating hornblende- and cummingtonite-rich bands.

From the foregoing, it is likely that hornblende gneiss, lime-silicate gneiss and cummingtonite amphibolite are related and probably developed from the same sedimentary sequence as did banded biotite gneiss. For amphibolite, the high hornblende content, low sodic component of plagioclase, and probable non-equilibrium relationship between hornblende and plagioclase suggest an origin different from that of hornblende gneiss--most probably meta-igneous.

Discussions in Lovering (1929) and Lovering and Goddard (1950) indicate that rocks similar to the amphibolites of the Lookout Mountain area are common in the Front Range (see also Bever, 1954, and Shappirio, 1962). These writers believe that these layers were originally sills (and a few minor dikes) of dioritic or gabbroic composition emplaced before the development of regional schistosity in the host sediments. Relict ellipsoidal structures indicate that some of the "sills" were actually flows.

In the Lookout Mountain area, amphibolite units are essentially concordant, but dikes do occur. No relict structures or textures have been found, and the foliation, where present, is poor with no banding such as characterizes the hornblende gneiss of metasedimentary origin. The high mafic mineral content, low albite component of plagioclase, and essential absence of quartz suggest that the amphibolites of the Lookout Mountain area originated as gabbroic sills and dikes in the Idaho Springs formation. They have been entirely recrystallized and their mineral assemblages agree in grade with those of the enclosing metasediments. Thus they were emplaced prior to the Idaho Springs metamorphism.

PARENTAGE

Parentage of the Idaho Springs formation has been, since the original description by Ball, ascribed to intercalated sandstones and shales with minor calcareous material that has been subjected to high grade regional metamorphism. These basic ideas have remained the same and have been reiterated in every account of the Front Range metasediments since then. Ball (1906) suggested that the metamorphism of sandstones produced quartz (biotite) gneisses; shales yielded biotite schist and biotite-sillimanite schist, and calcareous sandstones yielded lime-silicate rocks. This approach was given quantitative significance by Bever (1954), Salotti (1960), and Shappirio (1962). The general procedure consisted of averaging modes

from biotite-feldspar gneisses along the Front Range and comparing calculated oxide percentages with the composite chemical analysis of shale. That sillimanite is not an intrinsic or metamorphic constituent but a metasomatic product was suggested by this reasoning.

Several unusual features exhibited by the quartz-feldspar gneiss members of the Idaho Springs formation can be used to further clarify its origin. (1) The average grain size of the assemblage is about 0.5 mm, and a size in excess of 1.0 mm is rare. (2) Mafic constituents are rarely concentrated in layers but distributed through the rock with only sufficient concentration to define a rude banding. (3) Quartz is the most abundant constituent and the quartz/potash feldspar ratio is generally 1 or above. (4) The felsic/mafic mineral ratio is generally about 5. The conclusion to be drawn from these points is that the original rock was a poorly-sorted but banded, quartz-rich sediment.

In Table 5, oxide analyses calculated from average biotite gneiss and schist are compared with the analysis of an average shale. The quartz-rich character of the metasediments is apparent and augmenting the SiO_2 of analysis 3 and recalculating to 100% provides a satisfactory approximation to the biotite gneiss composition.

The constituents of biotite gneiss can be recast as minerals typical of low grade quartz-feldspar metasediments. Table 6 shows a comparison between such a mode and the mode of an arkosic

quartzite of the Belt Series (analysis 4, Tables 5 and 6). The two metasediments differ primarily in potash feldspar and sericite contents, the calculation of which depends on the K_2O/Al_2O_3 ratio of the analysis. A large value favors the

Table 5. Calculated oxide analyses of Idaho Springs members and comparison analyses.

	1	2	3	4	5	6
SiO_2	75.3%	75.0%	61.2%	74.8%	47.7%	38.0%
Al_2O_3	11.3	12.3	16.2	13.6	13.7	7.2
Fe_2O_3	.3	.5	4.2	.4	10.8	.4
FeO	.3	5.1	2.6	.4	14.3	.4
MgO			2.5	.8	5.4	.8
CaO	3.6	.9	3.3	2.0	6.1	27.9
Na_2O	1.8	2.3	1.4	1.5	1.7	.7
K_2O	5.7	2.7	3.4	3.9		2.1
H_2O	1.6	.6	5.3	1.5		1.0
CO_2						21.8
	100.0	99.4	100.0	100.3	99.8	100.3

1. Average biotite gneiss, Lookout Mountain area.
2. Average quartz-biotite schist, Salotti, 1960.
3. Average shale, Clarke in Pettijohn, 1960, p. 106.
4. Belt series arkosic quartzite, Harrison and Jobin, 1963.
5. Hornblende gneiss, Lookout Mountain area.
6. Belt series argillaceous carbonate rock, Harrison and Jobin, 1963.

abundance of feldspar over sericite because of the mole ratios of 1:1 and 1:3, respectively. Should K_2O have been added metasomatically so that the present rock contains more than the original sediment, the mode would consist of less microcline, more sericite, and quartz; even more closely approximating the Beltian argillite mode.

The calcic fraction of the metasediments has been considered derived from dolomitic or ankeritic shales. In Table 5, an oxide analysis of hornblende gneiss is compared with a Belt Series argillaceous carbonate rock. If the carbonate rock were to contain a larger argillaceous fraction the two analyses would

Table 6. Comparison of (1) the recast analysis 1, Table 5 with (4) the mode of a Belt Series arkosic quartzite.

	1	4
Quartz	43%	52%
Potash Feldspar	31	6
Plagioclase (Ab_{90})	18	15
Chlorite	3	3
Sericite	5	24
	100	100

be similar. However, the high iron content of the gneiss is significant and cannot be explained as an ankeritic constituent.

The original deposit was probably a thick assemblage of fine-grain, argillaceous sediment containing abundant quartz and potash feldspar. The Pierre shale (Cretaceous) of southern Colorado was suggested by Shappirio (1962) as a similar unmetamorphosed sediment. The Belt Series (Precambrian) of Montana and Idaho more closely approximates the Idaho Springs formation. The latter is probably in excess of 10,000 feet and possibly 20,000 feet thick in some locales. The Belt Series consists of silt-size, quartz-feldspar-rich shales and argillites to over 40,000 feet in several areas. The series is predominantly clastic but also contains local carbonate

facies and abundant calcareous argillite. Whereas marble and quartzite are not abundant in the Idaho Springs formation, Snively (1948) describes marble, and Wells et al. (1964) described the Coal Creek quartzite both from the northern and central Front Range. In details of sedimentary texture and structure, and regional extent the Idaho Springs and Belt sequences are similar. The features of thickness, poor sorting, and banding are common to both.

The original Idaho Springs sediment was a fine-grained cyclic sediment deposited in a large basin or trough. The present fine-grained unsorted and banded features suggest deposition took place a sufficient distance from shore to eliminate coarse clastics, yet in water not too deep to destroy banding produced by seasonal erosional variation. The interbedded clastic and calcareous-clastic unit is characteristic of either basin or shelf environment, but the extreme thickness of the assemblage suggests geosynclinal deposition. The relative scarcity of possible volcanic units and presence of limy members suggests a miogeosynclinal assemblage. The surrounding terrane has been described as granitic (Lovering, 1929) from the igneous quartz (with bubble trains) and general granitic composition of the sediment. The surrounding land masses were probably of low relief and distant, to provide an adequate comminution.

METAMORPHISM

The metamorphic history of the Idaho Springs sediment can be divided into three parts as follows: 1) an early period of accumulation, intrusion of mafics, and regional metamorphism without significant deformation or granite intrusion, 2) a period of metamorphic quiescence with further sedimentation, and 3) a complex period of multiple granite batholith emplacement and deformation. That an interval of metamorphic quiescence separates the two metamorphically-active periods has been demonstrated by batholithic granite of the second stage intruding late, relatively unmetamorphosed sediments of the first stage.

After accumulation of a significant thickness of Idaho Springs sediment, recrystallization of mafic constituents produced a rude schistosity which aided the later intrusion of basic dikes and sills. With further regional metamorphism a rude foliation developed upon recrystallization of the dikes and sills and both sediment and intrusive were metamorphosed to the almandine-amphibolite facies.

The medium-grade regional metamorphic assemblages that characterize the Idaho Springs formation are relatively uniform throughout the Front Range and Wet Mountains. However, some variation does exist both regionally and locally. Significantly lower grade metasediments have been described from the Cache la Poudre River area (Braddock, 1964), near Coal Creek (Lovering and Goddard, 1950), near Cotopaxi (Salotti, 1960),

and northwest of Eight-Mile Park (Heinrich, oral communication). In all cases, regional metamorphism attained a grade of upper greenschist facies with non-equilibrium assemblages up to the sillimanite-almandine amphibolite level. An increase in regional metamorphic grade has also been mapped by Singewald (1963) in the Wet Mountains. Here charnokitic rocks have been found as a structural core in the Mt. Tyndall quadrangle. These variations can be explained in two ways. The low grade assemblages could represent sediments that were never deeply buried and at no time subjected to plutonic conditions. However, the occurrence of higher grade assemblages near structural cores and lower grade assemblages relatively near the flanks of the Precambrian belt suggests tectonic control was probably more important than load metamorphism.

On a local scale variations in metamorphic grade are restricted to the occurrence of sillimanite and the substitution of orthoclase perthite for perthitic microcline in some biotite-poor gneisses. Sillimanite occurs in two common parageneses--as individuals and fibrolitic masses replacing biotite, and as felted nodules and phacoids in biotite gneiss. To explain the former, Bever (1954) has suggested progressive metamorphism in the proximity of an intrusive. The common association of sillimanitic rocks in highly injected zones along with a calculated excess of Al_2O_3 in oxide percentages prompted Salotti (1960) to conclude that most of the Idaho Springs sillimanite is of metasomatic origin. In the Lookout Mountain area biotite gneiss

east of the Five Point Gulch fault zone is sillimanitic and contains abundant pegmatitic material. In the Texas Creek Anticline a 500-foot interval of biotite gneiss is sillimanitic with no symmetrical intrusive. This would suggest that at least some of the sillimanite is the result of local prograde effects.

The substitution of orthoclase perthite for microcline in biotite-poor gneisses (Sec. 19, T.19S., R.72W., Plate 1) is probably the result of a local increase of grade in biotite gneiss near a granite intrusive. The fact that biotite is not prograded to sillimanite in this process may be the result of excess K_2O since these rocks contain approximately 40% orthoclase (Turner and Verhoogen, 1960, p. 544).

The characteristic feature of Idaho Springs metamorphism is its relative uniformity and complete lack of systematic change in grade. For this reason the use of an isograd system is entirely unsatisfactory for regional mapping of the Idaho Springs formation.

Mineral assemblages commonly found in the Idaho Springs formation have been divided into two groups--pelitic-quartz-feldspar and Ca-rich (Table 7). Both groups are metasedimentary. They have been assigned a regional metamorphic grade of staurolite-almandine amphibolite by the following characteristics:

1. Assemblages of both calcareous and pelitic-quartz-feldspar rock groups substantially agree in the grade assignment.
2. Intimate association of calcareous and pelitic units.

3. Calcareous assemblages contain andesine-labradorite plagioclase characteristic of kyanite or staurolite level as contrasted with bytownite or anorthite expected in the sillimanite zone.
4. Pelitic-quartz-feldspar assemblages contain oligoclase-andesine characteristic of the staurolite-kyanite Barrovian zones but not albite as would be expected at lower grade.
5. Staurolite and kyanite have been reported from other areas in more pelitic zones of the Idaho Springs formation (assuming they are correlative units).

Quartz-biotite, quartz-oligoclase-biotite, and quartz-microcline-oligoclase-biotite are the most widespread mineral assemblages of the Lookout Mountain area. All three assemblages may, in addition, contain almandite, muscovite, and sillimanite. All are considered typical of the regional metamorphism of feldspathic sandstone or shale with minor admixed or interlayered carbonatic or dolomitic material (Harker, 1950, p. 246; Turner and Verhoogen, 1960, p. 544; Shappirio, 1962, p. 81). Explanation for the absence of pelitic index minerals lies in the abundance of potash feldspar, which, along with textural evidence indicates that most potash feldspar is pre-regional metamorphic and from the previous calculations, probably detrital. Where the rock contains little microcline, the absence is probably compositional. Since both staurolite and kyanite have been reported in rare occurrences of the Idaho Springs formation

Table 7. Metamorphic mineral assemblages.

Pelitic-Quartz-Feldspar Assemblages

quartz-plagioclase-biotite
$\pm$microcline
$\pm$almandite
$\pm$muscovite
$\pm$sillimanite
quartz-oligoclase andesine-orthoclase perthite-biotite-almandite
quartz-andesine-microcline-biotite-hornblende
quartz-biotite-hornblende

Ca-Rich Assemblages

diopside-plagioclase
diopside-plagioclase-zoisite-calcite
diopside-plagioclase-hornblende-epidote
hornblende-plagioclase
hornblende-plagioclase-quartz-epidote

Mg-Rich Assemblages

cummingtonite-anthophyllite-plagioclase-biotite-hornblende-quartz

Cordierite Assemblages

quartz-cordierite-garnet
$\pm$sillimanite
$\pm$muscovite
$\pm$biotite
quartz-sillimanite-garnet

(Salotti, 1960, p. 53) their absence here probably represents an original bulk compositional inadequacy, in the case of staurolite (Shappirio, 1962, p. 82), and the need for metasomatic Al_2O_3 in the case of the alumino-silicate.

The assemblage hornblende-andesine-epidote is characteristic of almost all amphibole-bearing gneisses and supports the suggestion of a lower almandine-amphibolite facies grade of regional metamorphism. According to Turner and Verhoogen (1960, p. 544)

if this assemblage had been raised to the sillimanite level the stable plagioclase would be more calcic, especially with the almost ubiquitous epidote. The presence of an average andesine plagioclase suggests a correlation with data from the feldspathic assemblages. The presence of diopside has been interpreted as the result of excess carbonate in the sedimentary sequence and its appearance in the diopside-epidote-calcite and diopside-epidote-hornblende assemblages is normal for this grade of metamorphism.

The occurrence of cummingtonite amphibolite represents the most magnesian assemblage of the metasediments. Mineralogical composition suggests regional metamorphism to the almandine amphibolite facies with andesine-labradorite plagioclase suggesting the lower part of the facies. The suggested origin for the Black Hills cummingtonite locality (Noble and Harder, 1948) is the regional metamorphism of magnesian siderite and chert. The Black Hills schists do not contain hornblende but Seager (1944) has described hornblende-bearing cummingtonite rocks at the Jardine-Crevasse Mountain district in south-central Montana.

The cordierite-muscovite schist of Five Point Gulch is similar to sillimanite-mica-quartz schists and gneisses described by a number of investigators (Buckwalter, 1950; Snively, 1948) in the northern Front Range--the only apparent difference being the high cordierite content. Travis (1956) described material taken from this unit where it outcrops on Highway 50 as being a

typical contact metamorphic quartz-mica schist. This is erroneous. The only nearby granites are the Pikes Peak at Texas Creek Junction and the Pegmatitic granite at the mouth of Five Point Gulch. No cordierite was found in or associated with either.

Cordierite-mica schist is a relatively uniform rock throughout its outcrop area. Cordierite content varies from 15-30% of the rock but there is no significant variation along strike. Contacts with the enclosing biotite gneiss, though covered, are sharp within 20 feet. Constant thickness of the cordierite-mica schist, abrupt and conformable contacts with surrounding gneiss, and the scattered occurrence of cordierite in biotite gneiss to the north (Vian, 1965), suggest that the cordierite of this unit is the result of an original magnesian sediment. Textural studies suggest its derivation might have been through a reaction such as the following (Francis, 1956):

musc + bio + qtz $\longrightarrow$ cord + potash feld + water.

POST-METAMORPHIC EFFECTS

Post regional metamorphic effects can be divided into 1) retrograde, an adjustment of regional metamorphic assemblages to lower grade conditions, 2) metasomatic, with the addition of extraneous material, and 3) pegmatitic.

After regional metamorphism high temperature assemblages were altered to an assemblage stable in the greenschist facies. In pelitic rocks calcic plagioclase was the first to be affected, altering to sericite, followed by chlorite replacing biotite.

In hornblende gneiss plagioclase was saussuritized, diopside was replaced by hornblende and subsequently replaced by biotite or chlorite. All of these reactions represent essentially isochemical changes with only local reorganization of constituents and the addition of water.

The metasomatic stage of development is characterized by the addition of Al and K in pelitic rocks and is correlated with granite emplacement during the batholithic cycle. The replacement of biotite by sillimanite along with the conversion of some original microcline to muscovite occurred at an early stage as shown by the alignment of most sillimanite with the gneissic foliation.

While some muscovite was produced during the Al metasomatism, the majority developed at a later time during a general K-metasomatic stage. At this time microcline porphyroblasts developed near granite contacts and muscovite replaced sillimanite over broad areas in the pelitic rocks. Stress was at a minimum during this stage resulting in random orientation of muscovite poikiloblasts which replace the gneissic fabric. The abundant tourmaline of some units may have developed at this time, but the concentration of individuals along the foliation suggests it was a detrital constituent.

The introduction of vein quartz and migmatitic effects will be discussed after the section on granite.

PRECAMBRIAN IGNEOUS ROCKS

PRE-GRANITE UNITS

Three occurrences of dioritic igneous rocks have been mapped in the Lookout Mountain area (Sec. 34, T.19S., R.73W.; Sec. 18, T.19S., R.72W.; and Sec. 25, T.18S., R.73W.; Plate 1). Smaller irregular units, predominately sills on the order of 10-30 feet wide and up to 100 feet long (unmapped) intrude the Idaho Springs formation on the northern flank of Lookout Mountain.

DIORITE

Two bodies of diorite crop out in the creek south of Sheep Basin. The unit one-half mile south of the Arkansas River is coarse grained, dark green and consists of megascopic hornblende up to 7-8 mm across with finer interstitial plagioclase and magnetite. Brown biotite is locally abundant as coarse unoriented tablets intergrown with hornblende. Local phases are porphyritic with equant hornblende aggregates over 1 cm across. The second unit, located two miles further south, consists of local lenses of biotitic-hornblende diorite intruding injected biotite gneiss. Contacts with the host gneiss foliation are generally concordant but locally discordant.

Diorite consists of a coarse-grained interlocking aggregate of poikilitic hornblende and biotite with an interstitial matrix of andesine and accessory orthoclase, sphene, magnetite, epidote,

clinozoisite, apatite, zircon, and calcite. Hornblende is arranged in aggregates as much as 1 cm across and constitutes 50-80% of the rock. Poorly twinned and zoned subhedral andesine (Ab_{56-66}) dominates the matrix and may be bent or broken. The biotite content ranges from 0-25%. The mica is coarse grained and occurs as decussate intergrowths crystallizing either simultaneously with or after hornblende. Where biotite is particularly abundant, plagioclase is more strongly zoned and interstitial aggregates consist of euhedral plagioclase and perthitic orthoclase with rare myrmekite.

Other common accessory minerals are apatite, sphene, zircon, and allanite. Apatite grains up to 0.4 mm are common in some varieties and sphene occurs as granular or irregular masses associated with mafic aggregates. Zircon and allanite, scattered through the mafics are surrounded by radioactive halos. Common alteration products are epidote and biotite from hornblende; clinozoisite, sericite, and kaolinite from plagioclase; and chlorite and magnetite from biotite. Masses of fine-grained hydromuscovite selectively replace plagioclase cores, alternate twin lamellae, and rarely entire individuals.

HORNBLENDE LEUCODIORITE

The hornblende leucodiorite stock occurring one mile east of Lookout Mountain consists of an irregular body intruded roughly parallel to foliation of the enclosing gneisses with a line of mafic pegmatites along the southern contact. Contact relationships

with the gneissic country rock cannot be observed because of local colluvial material but in most cases the contact is sharp within 10 feet.

The major rock type is a coarse-grained, foliate leucodiorite consisting of plagioclase and hornblende. Foliation is locally distinct and is the result of a hornblende concentration with only rare lineation. Two textural variations are apparent as follows: 1) grain size varies from in excess of 1 cm in the northwest to ±2 mm toward the south; 2) along with this variation, foliation is more pronounced toward the southern contact and almost imperceptible toward the north. On a weathered surface, basic feldspar is covered with white supergene $CaCO_3$ giving the rock a stark black and white effect. Several smaller, satellitic bodies were correlated by this characteristic in spite of major changes in texture and bulk mineralogy.

Hornblende leucodiorite is a coarse-grained igneous rock containing essential andesine (Ab_{59}) and hornblende with accessory sphene, apatite, epidote, calcite, hematite, magnetite, and pyrite. The texture most commonly consists of a mosaic of 1-2 mm subhedral andesine in which individuals and aggregates of subhedral hornblende are imbedded (Figure 6). Hornblende varies from accessory to 40%. Andesine, the most abundant constituent, is unaltered and poorly zoned with rims containing a 3-6% higher albitic content. Marginal mortaring is common. Any alteration effects are localized along fracture zones. The lack of core alteration is in contrast to plagioclase of all other hornblende rocks of the area.



Figure 6. Hornblende leucodiorite, Sec. 34, T.19S., R.73W. Blocky hornblende (h) in a matrix of andesine. Saussuritization of plagioclase; magnetite (black), X polars, x35.

Where hornblende is abundant it is euhedral to subhedral, rarely poikilitic with relatively minor alteration. It generally occurs in aggregates intergrown with sphene, magnetite, apatite, epidote, and actinolitic alteration products. Saussurite is locally abundant and is accompanied by epidote and actinolite replacing hornblende. Hornblende also alters to chlorite and radial books of chlorite are not uncommon. Calcite is locally coarse grained but always located near a saussuritized mass.

PEGMATITES

A number of small pegmatites located along both the southeastern and southwestern hornblende leucodiorite contacts appear cogenetic with the diorite. They are generally of more mafic character than pegmatites associated with migmatite or granite and are characterized by the same chalky weathering product as are all the leucodioritic rocks. The pegmatites are small (largest about 25 feet across) and roughly circular in plan. They occur wholly within diorite and along its margin with the country rock, migmatitic gneiss. In most cases, the pegmatite structure is simple, with no noticeable zoning. In several occurrences a graphic quartz intergrowth was seen and two occurrences contain relatively clean quartz cores.

The dominant constituent is andesine (Ab_{65}) (compared with Ab_{59} in leucodiorite) and no compositional change toward the wall rock is discernable. Where quartz constitutes a major

part of the pegmatite, the intergrown feldspar is more sodic (Ab_{80}), strongly altered and poorly twinned.

Along one pegmatite contact actinolite has developed inward from the dioritic wall rock. The amphibole is oriented perpendicular to the contact replacing plagioclase of the pegmatite. In another case, needles of actinolite up to 2 inches long together with coarse biotite were found in clear pegmatitic quartz float. The distribution of coarse, secondary actinolite is reminiscent of secondary replacement units in more acid complex pegmatites. Ilmenite occurs locally as an accessory.

AGE RELATIONSHIPS

The dioritic intrusives of Sheep Basin intrude the Idaho Springs metasediments. They are not metamorphosed nor visibly intruded by granite or pegmatitic material, but because of their local nature this latter feature may not be significant. Diorite was probably intruded after regional metamorphism and prior to Pikes Peak granite intrusion.

Field relationships suggest that leucodiorite is pre-granite and aplite. Its foliate character, though not uniform throughout the stock, possibly indicates the synkinematic intrusion of the stock during the original Idaho Springs metamorphism and therefore it developed much earlier than the diorite of Sheep Basin.

PRECAMBRIAN GRANITIC ROCKS

The granitoid rocks of the Wet Mountain-Front Range Precambrian area are particularly abundant and varied. The Lookout Mountain area is approximately 20 miles southwest of the southern end of the Front Range Pikes Peak batholith and contains several lithologically similar plutons. However, the granites here mapped are sufficiently different that correlation is uncertain.

The definition of Colorado Precambrian granitic rocks by Ball (1906), summarized by Lovering (1929), and brought up to date by Lovering and Goddard (1950) serves as a general guide for correlation. Most students of the Front Range Precambrian accept the existence of an early, coarse-grained, foliated, microcline granite and a late non-foliated discordant granite. The foliated granites are divided into an early phase called the Boulder Creek and the later, major phase called the Pikes Peak granite. Recent detailed mapping by the U. S. Geological Survey in the Central City area has shown that in addition to the main granite phase, the Boulder Creek part of the batholithic cycle was complex, with a number of more mafic phases. The Parkdale tonalite (Shappirio, 1962) described here under the name of Boulder Creek tonalite probably represents some intermediate phase. In the Lookout Mountain area, four separately mappable intrusive granites can be distinguished as outlined in Table 8, based primarily on field relationships.

Table 8. Proposed sequence of Precambrian granitoid bodies in the Lookout Mountain area.

Relative Age		Type of Granitoid
4		Red Aplitic granite
3		Silver Plume "type" granite
2	c.	Pegmatites of the Pikes Peak type
	b.	Pegmatitic granite
	a.	Pikes Peak granite
1	c.	Pegmatites of Boulder Creek affinity
	b.	Boulder Creek tonalite-granodiorite
	a.	Granitoid component of migmatite

BOULDER CREEK GRANITOIDS

The oldest granitic rock of the area is apparently the granitic component of migmatite found principally east of Five Point Gulch. It occurs as cross-cutting pods and dikes of pegmatite and aplite and in injection gneiss of the Idaho Springs formation (Sec. 8, T.19S., R.72W., Plate 1). Individual pegmatites range in size from ptygmatic units less than 5 feet across to a maximum of approximately 50 feet. The migmatitic granite is medium grained (1.5 mm) equigranular, white and mafic-poor. It consists of essential plagioclase and quartz, with subordinate microcline and accessory biotite and garnet. Pegmatitic units are unzoned and contain no secondary replacement units. The contacts with the surrounding gneisses are irregular, but sharp depending on the grain size of the rock and suggest a pre-tectonic to syntectonic injection with subsequent

metamorphism. Pegmatites of Pikes Peak affinity cut the ptygmatic units. Reasons for assigning a genetic connection between this material and the Boulder Creek tonalite-granodiorite are 1) the pre-Pikes Peak age, 2) the abundance of material in gneisses near the Boulder Creek contacts, and 3) the fact that pegmatites are particularly abundant near Boulder Creek intrusives in the Front Range.

Shappirio (1962) found, in the canyon of the Arkansas River, a marginal phase of the Pikes Peak pluton which he called the "Parkdale tonalite". Subsequent examination has indicated that this rock can be correlated with the Boulder Creek granite (E. N. Goddard and E. Wm. Heinrich, personal communication). The tonalitic-granodioritic rocks of the Lookout Mountain area (one mile east of Sheep Basin on Highway 50, Plate 1) strongly resemble the tonalite mapped by Shappirio and thus they also are here assigned to the Boulder Creek.

The Boulder Creek tonalite is a dark to medium gray, coarse-grained, biotite-rich rock containing essential quartz, andesine, and biotite with variable amounts of microcline. It has a poor to moderate foliation but parallelism of either foliation or contact with the structure of the enclosing metamorphics is difficult to demonstrate. The two units mapped are roughly circular, the northern one being elongate along the regional foliation.

In thin-section the rock is subhedral granular, slightly porphyritic, with local phenocrysts of plagioclase, microcline,

or quartz (Table 9). Any foliation is the result of biotite orientation around and between feldspar individuals. Plagioclase is the most abundant constituent and occurs as subhedral grains up to 1 cm across, with 1.5 mm average. Rare individuals are strongly zoned with untwinned cores and well-twinned andesine rims. Marginal granulation and bent or broken twin lamellae are common--some having been recrystallized. Biotite is locally chloritized and aggregates generally contain 90% of the accessory suite--magnetite, sphene, zircon, apatite, muscovite, and pyrite. Sphene may locally constitute 5% of the rock.

Table 9. Modal analyses of Wet Mountain Granitic rocks.

	1	2	3	4	5	6
Quartz	26.0%	33.2%	27.9%	29.0%	23.4%	25.8%
Microcline	4.9	36.4	33.6	43.0	30.0	38.6
Plagioclase	46.5	26.6	31.4	25.1	33.9	25.6
Biotite	18.5	.6	4.6	--	7.8	4.2
Myrmekite	--	1.9	2.0	2.5	3.9	3.6
Accessory	4.1	1.1	.7	.4	1.3	2.3
Ab-content	63	80	80	80	80	80

1. Boulder Creek tonalite, one mile east of Sheep Basin.
2. Pikes Peak granite east of Texas Creek Junction, fine aplitic border phase.
3. Pikes Peak granite east of Texas Creek Junction.
4. Aplite in Idaho Springs near Pikes Peak granite contact; (Sec. 5, T.19S., R.73W.).
5. Pikes Peak granite ¼ miles from mouth of Rogers Gulch.
6. Silver Plume "type" granite from Lookout Mountain.

Sericitization of the plagioclase is the only widespread alteration with local lacy patches of calcite accounting for the CaO content. Leucoxene after sphene and hematite after pyrite are the only other alteration products.

Microcline occurs as anhedral grains, elongate, commonly porphyritic. Myrmekite and rare micropegmatite are always localized near microcline and commonly embay or replace it. The occurrence of microcline in Boulder Creek tonalite is highly variable and is probably the key to either correlating it with the original Boulder Creek granite or considering it a different phase (Parkdale tonalite). In this area and that described by Shappirio (1962) the rocks are generally tonalitic in composition and have a coarse granitoid texture typical of the Boulder Creek granite. Occurrences to the north typically contain a greater abundance of microcline while only the unusual occurrence in the Texas Creek-Webster Park area is microcline-rich. The facts that 1) microcline-rich phases do occur and 2) the plutons are satellitic to the Pikes Peak batholith as originally defined (Lovering and Goddard, 1950, p. 27) further suggest the correlation.

The Boulder Creek granite has been considered an extremely fugitive-rich intrusive giving rise to abundant marginal metasomatic effects in the Front Range. The abundant ptygmatic pegmatites east of Five Point Gulch and south of Washtub Gulch were pointed out earlier. The fact that these are of a distinctly different character, and thought to be older than the Pikes Peak pegmatites suggests a possible correlation.

PIKES PEAK GRANITE

Pikes Peak granite, the most abundant igneous rock of the Lookout Mountain area is most typically exposed one-fourth mile east of Texas Creek Junction and near the mouth of Road Gulch about five miles south of Texas Creek (Plate 1). In addition, several smaller units have been correlated, primarily on the basis of field criteria and the abundant granite component of migmatite (Figure 7) to the south-west (Sec. 5, T.20S., R.73W.) is possibly from the same source.

Typical Pikes Peak granite is pink, coarse-grained porphyritic, with locally prominent foliation. It consists of elongate microcline phenocrysts up to 1½ cm across arranged in overlapping fashion, rarely as discrete feldspar bands, with thin discontinuous trains of biotite accentuating the foliation. Finer-grained equivalents tend to be saccharoidal with little mafic alignment or elongation of feldspars.

The essential minerals are microcline perthite, quartz, and oligoclase, with accessory biotite, hornblende, sphene, magnetite, zircon, apatite, and allanite. The most important textural features are 1) elongate microcline perthite crystals up to 1 cm across, 2) trains of brown biotite around feldspars forming a rude foliation, and 3) late albite replacing microcline and rimming and replacing sericitized oligoclase.

Microcline generally occurs as anhedral microperthitic individuals or aggregates up to 1½ cm across commonly including quartz and sericitized oligoclase. Oligoclase occurs as subhedral



Figure 7. Granite migmatite. Injected Idaho Springs biotite gneiss at Pikes Peak granite contact in migmatite, Sec. 33, T.19S., R.73W. Note foliation control of contact and injection.

grains from 0.5 to 1.5 mm across intergrown with microcline and albite forms late overgrowths replacing both microcline and oligoclase. Myrmekite is common but not abundant and is generally confined to microcline-oligoclase contacts. Quartz occurs as anhedral masses embaying all other constituents. Biotite, the most common mafic mineral is ragged to euhedral, and averages 0.7 to 1.0 mm in length. It is always oriented and tends to be molded around feldspars but trains are discontinuous. Mafic minerals, magnetite and sphene, are concentrated with biotite. Euhedral allanite occurs either as discrete individuals or intergrown with biotite.

A finer-grained phase has been recognized along some borders by Vian (1965) and Salotti (1960) and although what is thought to be an equivalent rock has been found in the Lookout Mountain area, it does not everywhere occur as a marginal phase. Table 9 (Modes 2 and 3) shows the difference between the finer- and coarser-grained rocks. The aplitic phase is medium grained, pink, with an average grain size of 1 mm. All essential and accessory minerals are the same but biotite is notably lacking. Myrmekite and late albitic overgrowths are more abundant in the finer phase. The mineralogical difference between the two types (more quartz and microcline in the aplite), if significant, indicates that the finer is a later differentiate; not a chilled border phase. Mode 4 (Table 9) was taken from an aplite dike in gneisses within 20 feet of the granite contact and represents the same trend. The occurrence of this finer phase as irregular,

ill-defined masses both in the granite and gneissic country-rock suggests it is nothing more than a local variant of the main magma.

Where the Pikes Peak granite contact can be seen, it is sharp or gradational within several feet. In Sec. 8, T.19S., R.73W. (Plate 1) a fault parallels the contact but further to the northeast it becomes typically intrusive. Contacts around both the southeast and southwest units are somewhat gradational. Near Lookout Mountain, Pikes Peak granite grades into migmatite with no definite contact, and, along with the increase of xenolithic material, the granite changes to a finer-grained rock which, at least megascopically, has been considered to be more suggestive of Silver Plume "type" granite.

PEGMATITIC GRANITE AND PEGMATITES

In contrast to the Boulder Creek type of pegmatites the Pikes Peak pegmatites are characterized by sharp, straight contacts, and variable mineralogy commonly containing tourmaline, magnetite, garnet, muscovite, and biotite along with essential quartz, microcline, and plagioclase. In addition the Pikes Peak pegmatites vary considerably in texture from granitic to giant pegmatitic and individual intrusives may be as large as one-fourth mile across. The larger units such as are mapped near the mouth of Five Point Gulch are of the latter type and have been called Pegmatitic granite. The smaller units are complex and consist of a more varied mineralogy.

Pegmatitic granite consists of microcline, plagioclase, quartz, and muscovite from less than 1 inch to more than 4 inches across. Accessory minerals are common near the walls and only in a few cases have secondary units of any importance been observed. Definitely relating the Pegmatitic granite to a specific granite is difficult. The fact that fine-grained internal phases resemble typical Pikes Peak granite along with the majority of the smaller units lying in proximity to the Pikes Peak intrusive suggest this correlation.

Several Pikes Peak pegmatites have been explored for rare-earth mineralization of which the Jim 3 and Horsepasture pegmatites are good examples (Secs. 28 and 21, T.19S., R.73W., respectively). They are commonly zoned, consisting of single or multiple quartz cores, surrounded by microcline and oligoclase intermediate zones. Secondary replacement units consisting of cleavelandite, muscovite, tourmaline, and rare-earth multiple oxides are generally found near core margins. A chilled contact consisting of aplite similar to Pikes Peak aplite dikes and sills surrounding the pegmatite is generally contaminated with xenoliths of the enclosing Idaho Springs metamorphics.

SILVER PLUME "TYPE" GRANITE

A number of small intrusives of the Front Range have been grouped as Silver Plume "type" granite (Lovering and Goddard, 1950, p. 28). These are non-foliate, discordant and more resistant to erosion than the older foliated granite. In the Lookout

Mountain area a number of small non-foliated bodies have been grouped as Silver Plume "type" of which those of Sec. 29, T.19S., R.73W., and of the summit of Lookout Mountain are characteristic.

In outcrop the Silver Plume granite is medium grained, pink and white, containing randomly oriented biotite, rarely grading to a coarse-grained non-porphyritic variety. It differs from the Pikes Peak granite principally in having no preferred orientation of biotite and a rude alignment of blocky feldspar individuals. A porphyritic unit two miles east of Sheep Basin has been included on the basis of general petrography and field characteristics.

Silver Plume granite consists of essential plagioclase and quartz with widely varying amounts of biotite and microcline (Mode 6, Table 9). The most important accessory mineral is epidote and along with sphene, apatite, magnetite, zircon, and hornblende may constitute as much as 10% of the rock. Oligoclase (avg. Ab_{80}) is generally blocky, subhedral, and varies from 1-1.5 mm diameter. It is commonly rimmed by albite, and embayed by anhedral quartz. The characteristic features of the rock are the granulation of feldspars, the marginal mortaring of large individuals and abundant epidote. Mafic minerals are, however, not strongly comminuted. Microcline anhedra up to 1-1.5 mm and as interstitial grains are common in units near Lookout Mountain. The porphyritic unit near Sheep Basin contains phenocrysts of microcline, generally as multigranular aggregates up to several centimeters across that grade to small internal

pegmatites. In spite of this difference, the Sheep Basin occurrence is included with the Silver Plume granites because of its similar accessory suite (epidote-bearing) and mortared characteristics.

Late effects of alteration are restricted to chlorite after biotite, sericite and kaolinite after plagioclase and hematite after magnetite.

RED GRANITE

Red granite is the least abundant granite of the Lookout Mountain area, but occurrences here represent only intrusions satellitic to a large Red granite pluton one mile southwest of Texas Creek Junction. Red granite is most typically exposed 200 yards south of Texas Creek Junction as two cupolas, east and west of Highway 69. One-half mile west of Texas Creek the granitic component of injection gneiss is Red granite which grades south into a massive Red granite pluton (Vian, 1965). Injection gneiss two miles south of Highway 50, Sec. 18, T.19S., R.73W., contains both Pikes Peak and Red granites but further south the Red granite component disappears.

Contacts of Red granite with Idaho Springs gneisses are generally sharp; only along upper Texas Creek can any assimilation be observed. In a railway cut on the eastern Red granite cupola injected hornblende-biotite gneisses are silicified where in contact with granite.

Red granite is a red medium-grained rock containing blocky, Carlsbad-twinned phenocrysts up to 1 cm long. It is generally not foliated but blocky microcline may be locally oriented resulting in an apparent foliation. The essential minerals are microcline, quartz, and oligoclase with accessory biotite, epidote, magnetite, apatite, zircon, and hematite. Common alteration products are chlorite, hematite, sericite, and epidote.

Microcline, the most abundant species (45%), occurs as phenocrysts and as blocky individuals in the matrix, rarely less than 1 cm across. Characteristic features of the Red granite are the marginal mortaring of microcline and system of through-going fractures. Microcline individuals are rudely aligned with the fracture zones which contain a matrix of fine-grained sutured quartz and sericitized oligoclase. Some microcline is poikilitic containing quartz, oligoclase, muscovite, and mafic inclusions. Dark brown, uncommonly chloritized biotite is the most abundant accessory mineral (5%). It occurs as fine ragged laths (up to 1.5 mm) molded around oligoclase, and generally oriented roughly parallel to the microcline orientation. Other mafic minerals such as epidote, magnetite, apatite, and muscovite are commonly associated with biotite in interstitial aggregates. The red color characteristic of the rock is the result of finely divided hematite in oligoclase. The abundant myrmekite is directly proportional to the available comminuted material and along most microcline individuals the mortared margin has been replaced by myrmekite.

Because of its distinctive and uniform red color and definite outcrop area, Red granite has been distinguished from Silver Plume "type" granites. Both types of granite are characterized by protoclastic textures, and abundant epidote. The contact relationships are similar--both being concordant and discordant with relatively sharp contacts and no migmatitizing relationships. However, Red granite is considered younger than the other Silver Plume "types" because red aplitic-granitic dikes transect all other granitic rocks of the area. Thin sections of red aplite dikes disclose the same protoclastic texture and hematitic pigmentation that characterize the Red granite (Vian, 1965).

ORIGIN

Granitic rocks of the Lookout Mountain area differ not only in bulk compositional (Table 10) and textural aspects but also in their effect on the country-rock--type and extent of migmatization and types of pegmatites. Buddington (1959) has summarized the characteristics of granitic plutons emplaced at different levels in the crust. Using this depth-zone classification, the Boulder Creek tonalite and Pikes Peak granite would both be included as transitional catazone-mesozone intrusives. However, there are several significant differences. The Boulder Creek granite is characterized by abundant metasomatic effects (sillimanite east of Five Point Gulch), abundant aplite dikes (Boos and Boos, 1957), and irregular, ptygmatic pegmatites. The Pikes Peak

granite, in contrast, has relatively sharp contacts, has not metasomatized its wall rocks, and is associated with massive, undeformed pegmatites. In addition, the Boulder Creek pegmatites contain a simple mineralogy. Pikes Peak pegmatites, commonly zoned, are noted for their complex mineralogy.

Silver Plume "type" and Red granites are both typically mesozonal. Both are predominately discordant, non-foliate, with local porphyritic phases, and uncommon migmatitization. Protoclastic texture exhibited by both types suggests deformation in the late stages of consolidation. Red aplite dikes transect all other granites of the Lookout Mountain area and because they are correlated with the Red granite, it is considered the youngest granite of the series.

Potassium-argon age dating (Heinrich, oral communication) indicates the granites of the Lookout Mountain area were emplaced in two different stages. Within the sensitivity of the method Pikes Peak granite and Boulder Creek granite (correlated with tonalite) were intruded at about the same time (1350-1370 m.y.). The fact that irregular pegmatites found along the margin of the tonalitic mass are cut by a regular, massive Pikes Peak type pegmatite (Secs. 7 and 9, T.19S., R.72W., Plate 1) suggests that the Boulder Creek period of intrusion predated the Pikes Peak period of intrusion. A date on Red granite at Texas Creek (1320 m.y.) corroborates the younger age of the Red granite as suggested by field evidence.

In summary, the Boulder Creek granite, and probably the tonalitic unit, were intruded under shallow catazone conditions either before or during deformation. The Pikes Peak granite

Table 10. Summary of granitoids of the Lookout Mountain area.

	Main Species	Plagioclase	Alk-Feld/Plag	Acc Min
Boulder Creek	tonalite	Ab_{63}	.1	Microcline Magnetite Sphene
Pikes Peak	granite-granodiorite	Ab_{80}	0.9-1.3	Biotite Myrmekite Sphene Hornblende
Silver Plume	granite	Ab_{80}	1.5	Biotite Sphene, magnetite, epidote, allanite
Red Granite	granite	Ab_{80}	1.5	Biotite, epidote, magnetite, apatite

	Texture	Pegmatites	Migmatite	Rel Age
Boulder Creek	Subhedral-sericite-porphyritic, foliated	Abundant, irregular, contorted, simple	Common Pervasive & pegm. injection	1
Pikes Peak	Anhedral granular to porphyritic, foliated	Abundant, discordant & concordant, zoned, secondary units common	Common Pervasive Injection gneiss marginal, regional	2
Silver Plume	Anhedral granular to porphyritic	Rare	Local injection gneiss	3
Red Granite	Porphyritic	Rare Late aplite dikes	Injection gneiss, silicification	4

possibly represents the main batholithic phase, but was intruded no earlier than late tectonic. The Silver Plume and Red granites were emplaced at a slightly shallower depth, 50 million years later, and at the end of a complex batholithic cycle.

MIGMATITE

Migmatites of the Lookout Mountain area consist predominantly of lit-par-lit gneisses with minor breccia migmatite, and examples of injection gneiss can be seen along the contacts of all major granite intrusives except the Boulder Creek tonalite. In each case, the granitic component of the migmatite resembles the nearby plutonic rock. The fact that migmatites of this type form partial halos around the Pikes Peak, Silver Plume, and Red granite plutons attest to their close temporal relationship.

Though little injection gneiss has developed along the Boulder Creek contact the general abundance of aplite and pegmatite east of the Five Point Gulch fault zone is considered the result of a pervasive migmatitization genetically related to the Boulder Creek tonalite-granodiorite. The fact that marginal ptygmatic pegmatite and aplite dikes are related to Boulder Creek intrusives in the Front Range was noted earlier, and these were, in the Lookout Mountain area, dated as pre-Pikes Peak pegmatites on the basis of cross-cutting relationships.

Rocks designated as migmatite underlie approximately 25% of the Lookout Mountain area (Plate 1) and for the purpose of mapping have been divided into two types based on the nature

and amount of intruding granitic material. Biotite gneiss migmatite (Mig 2, Plate 1) is the lesser injected of the two types and consists of finely banded lit-par-lit gneiss containing metacrysts of microcline, pods and layers of quartz, microcline, and oligoclase with scattered garnet and magnetite. This unit crops out south of the Washtub Syncline (Secs. 8, 9, 16, 17, T.19S., R.72W.) and extends east of Copper Gulch. It is highly contorted (Figure 8) and characterized by a lack of coarse-grained granitic material either as pegmatites or major intrusive masses.

In contrast, granite migmatite (Mig 1, Plate 1) contains a greater abundance of granitic material. It consists of biotite and hornblende injection gneiss with numerous large (10-50 feet diameter) pegmatites and irregular granitic intrusives. It crops out in the southern part of the mapped area where its close spatial relationship with the Pikes Peak and Silver Plume granites suggests a common origin.

Migmatites of the Lookout Mountain area consist predominantly of lit-par-lit gneisses in which the granitic component may range from 50-70% of the rock. The control exerted by the host biotite gneisses on granite intrusion is particularly evident in Sec. 32, T.19S., R.73W. where foliation of the Idaho Springs formation can be traced into migmatite. Whereas biotite gneiss is relatively easily injected and assimilated by the invading granitic material, hornblende gneiss is not as readily attacked. Hornblende gneiss at Rito Gulch can be traced southeast through the migmatite and



Figure 8. Contorted biotite migmatite. Pervasive quartzofeldspathic introduction with relatively little pegmatitic injection. Upper Spring Creek, Sec. 17, T.19S., R.72W.



Figure 9. Breccia migmatite. Hornblende and biotite gneiss fragments in aplitic granite matrix, Sec. 5, T.20S., R.73W.

although it is locally converted to a banded epidote-microcline-quartz rock, it does not lose its continuity or identity.

Breccia migmatite, as described by Salotti (1960), is extremely rare, having been found in only two outcrops (Secs. 3 and 5, T.20S., R.73W., Plate 1). In both cases fragments of hornblende gneiss from 6 to 18 inches across are imbedded in a matrix of granite (Figure 9). Trains of pyrogenic biotite in the granite outline flow-lines around the gneissic fragments.

The development of migmatite in the Lookout Mountain area was a complex multistage process. A stage of pervasive quartz-feldspar introduction with related aplite and pegmatite intrusion accompanied emplacement of the Boulder Creek tonalite. This stage was either pre- or syn-tectonic as evidenced by deformation of pegmatites of this period of intrusion. Much later and accompanying Pikes Peak, Silver Plume, and Red granite intrusion, peripheral injection gneisses developed, the most extensive of which accompanied Pikes Peak intrusion. The mere existence of breccia migmatite suggests an intrusive period at much shallower depths than has been inferred for emplacement of either the Pikes Peak or Boulder Creek plutons--therefore suggesting the granite matrix is the Silver Plume granite.

DIABASE AND OTHER MAFIC DIKE ROCKS

Diabase and other mafic dike rocks, common in adjacent areas (Heinrich, 1948; Shappirio, 1962; Salotti, 1960) are sparingly represented in the Lookout Mountain area. They are

dark green to black, medium to fine grained and commonly porphyritic. Dikes range in thickness from 1 to 7 feet with thicker units commonly showing bifurcation (Figure 10). Because they are poorly resistant to erosion, mafic dikes crop out only where protected by resistant host rocks and can be traced either by topographic depressions or by linear zones of strongly decomposed rubble. Diabase transects Pikes Peak granite (Sec. 31, T.19S., R.73W.) and related pegmatites (Sec. 12, T.19S., R.72W.). A mafic, but not diabasic dike near the mouth of Baker Gulch (Sec. 29, T.18S., R.72W., Figure 11) is offset and cut by a lamprophyre sill. The most probable age for most of these dikes is Precambrian although for some, a Tertiary age cannot be ruled out.

Diabase consists of essential plagioclase and diopsidic-augite with variable olivine and accessory magnetite and apatite. Talc, chlorite, magnetite pseudomorphs after olivine occur both as phenocrysts and in the matrix. Diopsidic-augite occurs in the matrix interstitial to plagioclase. Labradorite (Ab_{39-42}) occurs both as phenocrysts and in a sub-ophitic texture. Labradorite phenocrysts are euhedral and commonly contain irregular patches of matrix material consisting of skeletal magnetite in fine-grained pyroxene locally altered to chlorite. Diabase is commonly non-porphyritic. Porphyritic varieties are of two types containing phenocrysts of plagioclase or olivine replaced by carbonate.

The textures of mafic dike rocks are highly varied even though their mineralogy is restricted. In general they are

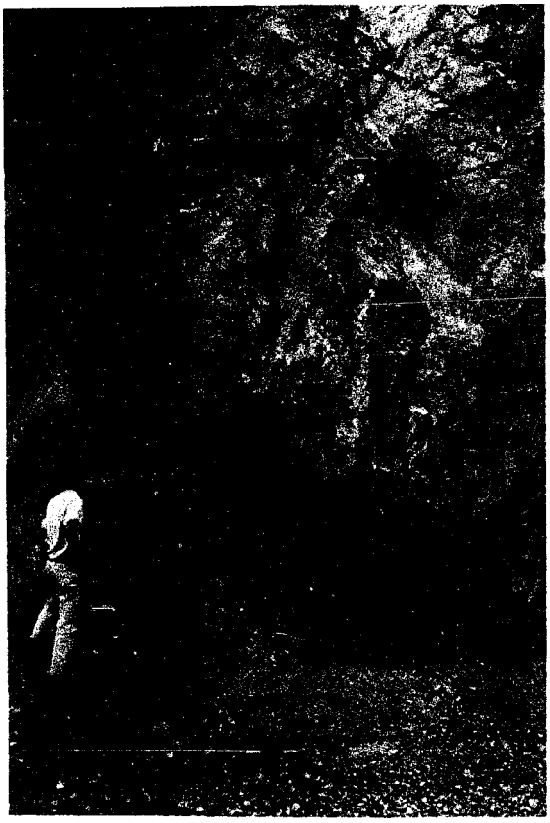
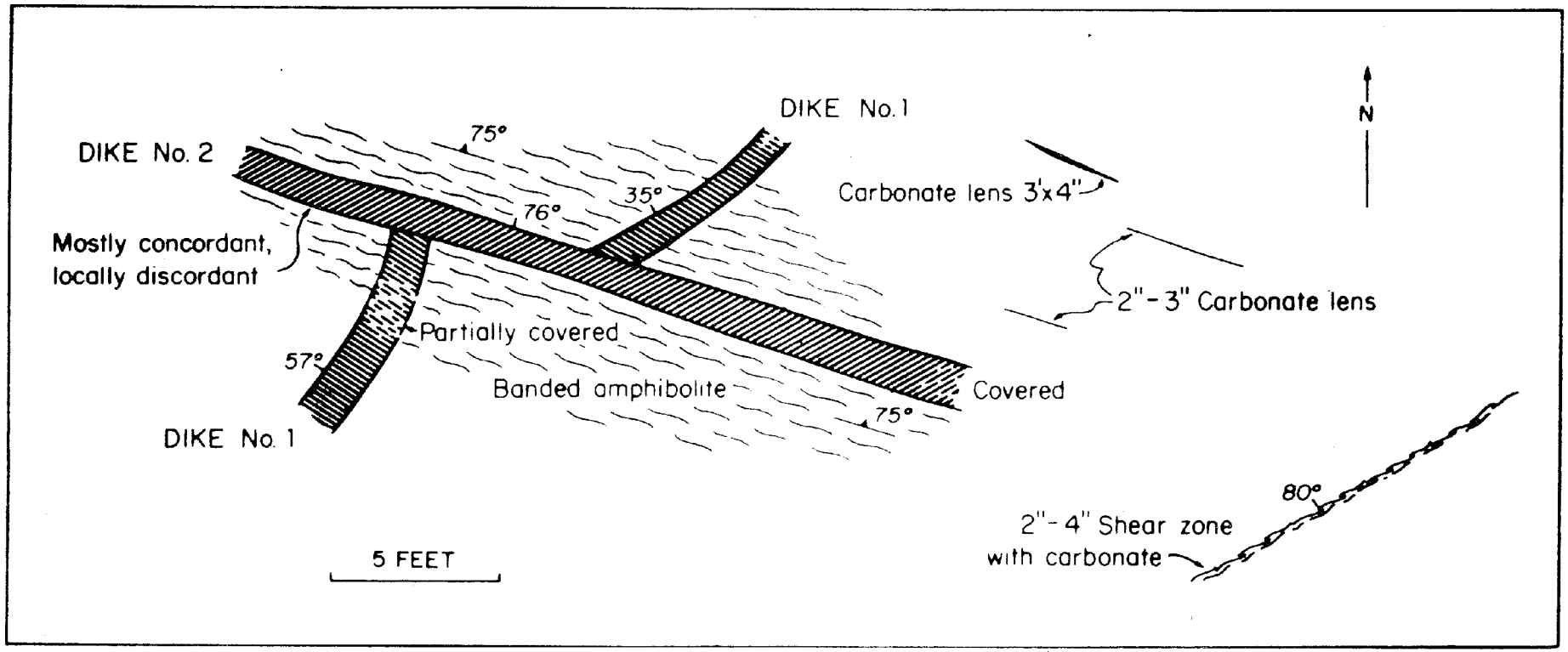


Figure 10. Bifurcate diabase dike cutting Pikes Peak granite in Highway 69 road-cut south of Rogers Gulch.

Figure 11. Sketch of lamprophyre sill cutting offset diabase dike in Baker Gulch, Sec. 29, T.18S., R.72W.



MAPPED BY E. Wm. HEINRICH

porphyritic and of basaltic or andesitic character. All consist of diopside to diopsidic-augite, labradorite, and magnetite and skeletal magnetite. A basaltic dike near the mouth of Baker Gulch consists of trachytic labradorite in a matrix of diopsidic-augite and magnetite. Euhedral labradorite is medium grained and commonly contains matrix inclusions. The pyroxene is totally interstitial and contains abundant skeletal magnetite (Figure 12). Another earlier generation of magnetite occurs as euhedra scattered throughout the rock. Calcite is the most common alteration product and replaces both labradorite and matrix pyroxene.

Another dike rock (Sec. 8, T.19S., R.73W.) consists of very fine pyroxene, magnetite, and plagioclase. Diopside phenocrysts contain inclusions of magnetite-pyroxene intergrowths. A porphyritic andesite from Turkey Gulch contains calcic-andesine (Ab_{51}) phenocrysts with inclusions of both fine-grained matrix constituents and a near opaque substance resembling a devitrified glassy matrix material.

ALKALIC ROCKS

Recently a new alkalic igneous province in the northern Wet Mountain-Wet Mountain Valley area has been described (Parker and Hildebrand, 1963; Heinrich and Dahlem, 1965). This province consists of three intrusive centers in Fremont and Custer Counties and covers an area in excess of 400 square miles. The three centers are at Democrat Creek (105°21'W.,



Figure 12. Photomicrograph of diabase dike in Figure 11. Labradorite and magnetite phenocrysts with interstitial pyroxene containing skeletal magnetite. Plane polarized light, x100.

38°15'N., location 3, Figure 1), Gem Park (105°32'W., 38°16'N., location 2, Figure 1), and McClure Mountain (105°28'W., 38°20'N., location 1, Figure 1). Each consists of (Table 11) a plutonic assemblage, associated peripheral dikes; two have associated breccia pipes. The host rocks at all three occurrences consist of the Idaho Springs metasediments and Precambrian granites. The Lookout Mountain area lies on the northwest corner of the McClure Mountain complex (one mile from McClure Mountain) and it

Table 11. Details of northern Wet Mountain alkalic province.

Complex Reference	Rock types & sequence	% of Complex	Nature of Intrusive	Dike Abundance	Age
Democrat Ck. (Christman, et al. 1959)	(4)Lamprophyre (3)Syenite (2)Breccia (1)Gabbro	 90% 10%	Elongate stock; 3 mi^2	Abundant	595 m.y. on zircon of syenite
Gem Park (Parker and Hildebrand, 1963)	(2)Carbonatite (1)Gabbro	 100%	Rectangular stock; 2½ mi^2	Abundant at periphery	Correlated on similarity of rock types
McClure Mtn-Iron Mtn (Parker and Hildebrand, 1963; Heinrich and Dahlem, 1965)	(7)Carbonatite (6)Breccia (Pinon) (5)Lamprophyre (4)Nepheline syenite (3)Ijolite (2)Syenite (1)Gabbro	 25% 10% 45% 20%	Ovoid outline, composite with units 1 thru 4, lamprophyre & carbonatite swarm	Common internal, abundant external toward NW.	"

is with the pheripheral alkalic and carbonatitic dike swarm transecting the host metamorphics that this report is chiefly concerned.

McCLURE MOUNTAIN COMPLEX

The McClure Mountain complex is the largest intrusive unit of the province. It is a composite ovoid mass approximately five miles (NE) by four miles (NW) consisting of three groups of intrusives in order of their intrusion: 1) gabbro-peridotite and syenite, 2) ijolite* and nepheline syenite, and 3) dikes of alkalic, lamprophyric, and carbonatitic character. Of these, gabbro, syenite, and nepheline syenite crop out in Indian Springs Park of the Lookout Mountain area.

Gabbro (Table 12), the most abundant constituent of the Gem Park stock, crops out in all three complexes (Table 11) but constitutes only 20% of the McClure mass. It forms the eastern intrusive contact of the alkalic rocks with Idaho Springs gneiss and is intruded to the west by syenite. The gabbro unit is a layered intrusive with a Ti-augite-labradorite-magnetite-rich upper zone (NE) and a Ti-augite-olivine-Ti-magnetite-rich base. The upper zone contains anorthositic lenses; the basal unit contains Ti-magnetite segregations. Gabbro typical of the upper zone crops out in Sec. 28, T.19S., R.72W., of the Lookout Mountain area.

Syenite (Table 12) is the most abundant unit of both the Democrat Creek and McClure complexes. It forms an arcuate unit between gabbro and the nepheline-bearing rocks at the center of the complex. It intrudes Precambrian metamorphics to the north (Sec. 30, T.19S., R.72W.) and south and is intruded by nepheline

*Unit not in the area mapped.

Table 12. Mineralogic summary of plutonic and hypabyssal dike rocks, northern Wet Mountain alkalic province.

Complex	Gabbro	Syenite	Ijolite	Neph.Sye.	Dike Rocks
Democrat Ck.	augite ±labradorite ±olivine magnetite	albite anti-perthite (65-80%) microcline (25%) quartz hornblende biotite	absent	absent	(6)Th-CO_3-Qtz. veins (5)Lamprophyre (4)Melasyenite (3)Syenite (2)Basalt-* andesite (1)Gabbro
Gem Park	"				(2)Carbonatite (1)Lamprophyre
McClure	" Ti-magnetite segregations apatite	perthite albite-oligoclase biotite hornblende	nepheline orthoclase Na-amphibole biotite	Na-orthoclase nepheline biotite hornblende ±sodalite	(4)Carbonatite (3)Lamprophyre (2)Nepheline syenite (1)Syenite

syenite on the west. Syenite is very coarse grained (0.5 mm-1.0 cm). It consists of essential blocky perthite and oligoclase in a trachytoid texture. Poikilitic, ragged hornblende, the dominant mafic mineral, is interstitial and commonly intergrown with biotite, sphene, and apatite.

*May be in part of Tertiary age (Heinrich, personal communication.

Nepheline syenite (Table 12) is the most abundant nepheline-bearing rock of the complex. It intrudes syenite to the east and biotite gneiss to the north and west. Outcrops in Indian Springs Park (Sec. 36, T.19S., R.73W.) are near the edge of the complex but representative in character. Nepheline syenite is medium gray, medium to coarse grained and is locally porphyritic. It consists of essential perthite, nepheline, hornblende, and biotite with accessory sodalite, oligoclase, magnetite, apatite, and sphene. Nepheline varies from blocky individuals (1 mm) in a trachytoid arrangement with perthite, to phenocrysts 2-3 cm across.

Mafic nepheline rock (ijolite) forms the core of the complex but does not crop out in the Lookout Mountain area (one-half mile southeast of Indian Springs Park). It is surrounded by nepheline syenite but an intrusive breccia found in the saddle west of McClure Mountain indicates the intrusion of ijolite predates that of nepheline syenite. Ijolite is black, coarse grained, and commonly coarsely porphyritic. It consists of essential hornblende, nepheline and biotite with accessory orthoclase, sphene, and Ti-augite. Nepheline and perthite are common phenocrysts.

Along the contact of nepheline-bearing units a discontinuous fenitic zone has developed in the Idaho Springs gneisses. This zone is characterized by medium- to coarse-grained orange potash feldspar (Parker and Hildebrand, 1963) with abundant fine-grained aegirine replacing the gneiss.

Numerous dikes and sills are associated with all three complexes (Christman, et al., 1959; Becker, et al., 1961; Parker and Hildebrand, 1963) and are particularly abundant within three miles northwest of McClure Mountain in the Lookout Mountain area. The dikes can be divided into three general types as follows: 1) syenite and nepheline-syenite--found principally within the complex or near its contacts in granite and gneiss, 2) lamprophyre--found principally in the gneisses within several miles of the contact of the complex, and 3) carbonatites--found near and within approximately three miles of the contact. Two breccia pipes five miles north of McClure Mountain (Pinon pipes, Sec. 7, T.19S., R.72W.) are of alkalic affinity and probably part of the McClure Mountain complex. Fragments of lamprophyre dike rock are caught in one of the pipes. Field relationships suggest the carbonatites are younger than the lamprophyres; therefore, the sequence of events in the peripheral area was as follows in order of decreasing age: 1) lamprophyres, 2) breccia pipes, and 3) carbonatites.

DIKE ROCKS

Within the three-mile peripheral zone northwest of the McClure Mountain plutonic complex, approximately 150 dikes and sills have been mapped and it is with this part of the complex that this investigation is concerned. Of these approximately 75% are lamprophyres, 15% are red trachyte and nepheline syenite, 5% are carbonatites, and 5% are diabase and basalts. Dikes, by far, predominate, though sills are not uncommon. Table 13 shows the

Table 13. Proposed age relationships between dike rocks and veins in and near the Lookout Mountain area.

(7) Carbonatite - Th-veins (youngest)
(6) Trachyte - rhyolite
Lamprophyres
(5) Vogesite
(4) Plagioclase spessartite
(3) Augite - barkevikite spessartite
(2) Nepheline syenite
(1) Olivine gabbro - lherzolite
Diabase (oldest)

proposed age relationships between the various dike types based on field and laboratory studies. All except the olivine gabbro-lherzolite and possibly some basalts and andesites are believed to be Precambrian in age because of their proximity and obvious petrologic consanguinity to rocks of the McClure Mountain complex. The placing of olivine gabbro-lherzolite with the alkalic rocks follows age relationships as described at Magnet Cove Arkansas, Gunnison Co., Colorado, etc. (Heinrich, 1958).

The age relationships between the dikes, sills, and the McClure Mountain plutonic series are incompletely known. All alkalic units transect the Idaho Springs gneisses and granites of the area. At the mouth of Baker Gulch a lamprophyre sill cuts a diabase dike. Another lamprophyre (Sec. 12, T.19S., R.73W.) transects the metasomatic muscovitized zone around a pegmatite of Pikes Peak affinity and lamprophyre and olivine gabbro-lherzolite both cut hornblende leucodiorite. All phases of the alkalic dikes--syenite, lamprophyre, carbonatite, cut the plutonic alkalic rocks and two nepheline syenite dikes (Sec. 30, T.19S., R.72W.) cut plutonic syenite.

Dikes range in thickness from a few inches to 10-20 feet and are commonly several hundred feet in length. Several have been traced in excess of one mile. They are resistant and can be traced either in outcrop or more commonly by abundant float. Several of the longer bodies exposed discontinuously may consist of a train of shorter parallel dikes (Sec. 30, T.19S., R.72W.). Dikes are locally faulted and commonly intersect, but intersections generally weather out giving no indication of the sequence of their intrusion.

The overall structure of the dike swarm is radial about the alkalic complex to the southeast, however, local deviations from this pattern are common. Within the swarm, two trends persist--N.30W. and E-W or N.80E. but no single rock type is particularly associated with either trend. Dips are uniformly steep where discernable and the lack of outcrop sinuosity suggests the majority are near vertical. That the fracture pattern guiding the dike emplacement was complex can be seen in Figure 13. Here a lamprophyre has intruded an offset fracture. Post cross-fault intrusion is demonstrated by a chilled margin in both segments of the dike.

OLIVINE GABBRO-LHERZOLITE DIKES

Near the southern contact, but well within the leucodiorite (Sec. 34, T.19S., R.73W.) a 10-foot wide, east-west-trending mafic to ultramafic dike can be traced discontinuously across the diorite. The rock is coarse grained, black, and deeply



Figure 13. Cross-faulted fracture controlling lamprophyre dike intrusion into sillimanite-biotite gneiss, Sec. 12, T.19S., R.73W.

weathered. Thin-sections from two outcrops disclose olivine-rich assemblages of olivine gabbro and lherzolite.

Olive gabbro consists of essential labradorite, olivine, hypersthene, augite, hornblende, and phlogopite with accessory blue-smoky apatite, actinolitic hornblende, and picotite. The texture is subhedral granular with corona textures around olivine consisting of hypersthene, augite, and hornblende. Labradorite is unaltered, zoned, with marginal mortaring and local brecciation. Red-brown phlogopite crystallized early as evidenced by its occurring both as local rims on hornblende in coronas and rimmed by late replacing actinolitic hornblende. A rim of actinolitic hornblende separates labradorite from all other mafic constituents. Picotite occurs as fine (75 micron) euhedral grains generally associated with other mafics and commonly surrounded by late amphibole.

Common alteration products are serpentine and magnetite after olivine and hypersthene, chlorite after phlogopite, and a fine-grained sericite-carbonate (?) alteration of plagioclase. Chlorite developing from phlogopite and in serpentinized masses after olivine and pyroxene is grass green suggesting it may be nickelian.

In outcrop, lherzolite is medium grained (1-2 mm) granular, brown-black, and almost indistinguishable from mafic olivine gabbro. It is so strongly serpentinized that the rock now consists essentially of serpentine, limonite, and magnetite. Textural features and mineral remnants show that the rock

originally contained olivine, orthopyroxene (diallage), augite, and hornblende. Coarse poikilitic hornblende is similar to overgrowths found in olivine gabbro.

NEPHELINE SYENITE DIKES

Nepheline syenite dikes, the oldest dikes definitely related to the complex are common only near or within the plutonic mass. Two such dikes crop out in Sec. 30, T.19S., R.72W. They are approximately 20 feet wide and persist for several hundred feet along strike. The rock is gray, medium grained and resembles its plutonic counter-part. Flow banding of constituent nepheline, orthoclase perthite, and hornblende is characteristic. Locally nepheline syenite dikes are porphyritic with nepheline phenocrysts up to 2-3 cm across and the variation from non-porphyritic to porphyritic varieties is characteristically abrupt. Small hornblende-albite pegmatite dikes locally cut the main dike.

LAMPROPHYRE

Lamprophyres are characteristically black but may be gray, green, or brown. They are resistant to erosion and commonly weather either tan or gray. In general, the following types can be recognized:

1. Aphanitic to medium grained, non-porphyritic
2. Spessartite--with the following phenocryst associations: Ti-augite, ±barkevikite, ±olivine, ±andesine, ±pyrite; barkevikite, andesine, magnetite
3. Vogesite--with the following phenocryst association: augite, andesine, barkevikite.

Carbonatite dikes are more closely related to lamprophyre than any other type of dike. Carbonatite dikes are, by far, less numerous but commonly take one of the following forms: 1) paralleling lamprophyres, 2) intruding brecciated lamprophyre, or 3) occurring as a local phase of the lamprophyre dike replacing all constituents except fine trains of magnetite which outline the relict panidiomorphic texture.

Most lamprophyres of the Lookout Mountain area are spessartites, a typical example of which is exposed 100 feet south of the Cabin Group carbonatite dike (Sec. 7, T.20S., R.73W.). The dike is approximately 5 feet thick and parallels the carbonatite for several hundred feet. It is dark gray, medium grained and porphyritic.

Spessartite consists of essential augite, barkevikite, and andesine (Ab_{52-66}) with variable orthoclase and magnetite, and accessory olivine, sphene, biotite, apatite, calcite, zircon, and epidote. Euhedral relict olivine, augite, and barkevikite are the most common phenocrysts and are randomly distributed in a matrix of coarse poikilitic or fine felted andesine. Phenocryst olivine is generally totally replaced by talc, serpentine, chlorite, magnetite, carbonate intergrowths. Matrix olivine is more commonly unreplaced. Two generations of augite are common. Augite phenocrysts are titanian, strongly zoned (Figure 14), twinned, and uncommonly poikilitic. Augite microphenocrysts are subhedral and occur as inclusions in poikilitic plagioclase and in mafic aggregates with magnetite and amphibole. Four

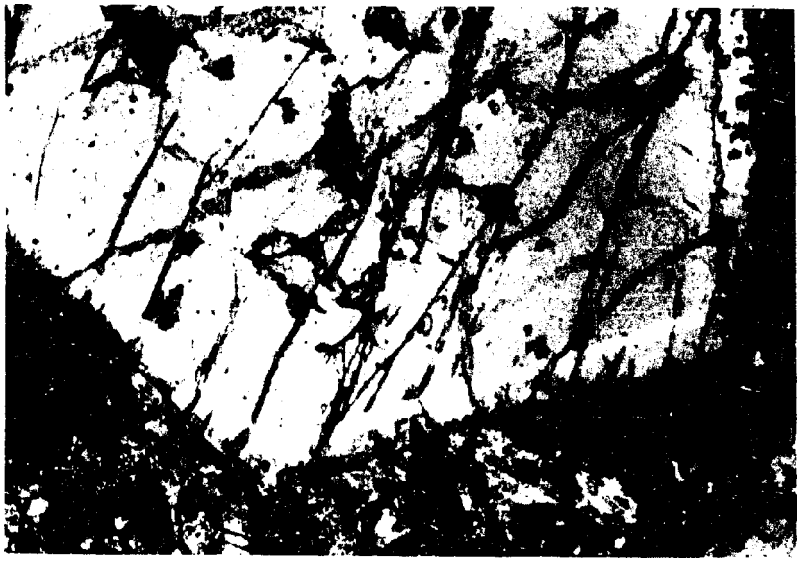


Figure 14. Photomicrograph of zoned augite phenocryst in spessartite dike. Matrix consists of microphenocrysts of augite, barkevikite, and magnetite with interstitial andesine. Plane polarized light, x100.

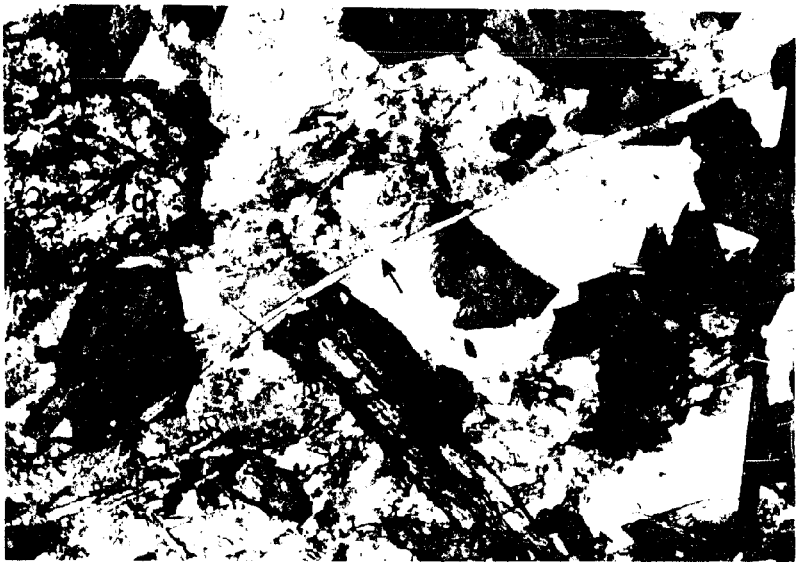


Figure 15. Photomicrograph of barkevikite (bk), augite (a), and magnetite phenocrysts in a spessartite lamprophyre. Matrix is andesine. Note apatite phenocryst (arrow) which is hollow throughout much of its length. Plane polarized light, x35.

generations of augite occur in one dike of Baker Gulch as follows in decreasing order of age: 1) olive green augite, center of phenocrysts, 2) pink, poikilitic augite, occurring as rims around the green type and as the center of phenocrysts, 3) pink to white augite, occurring as rims on the green and pink poikilitic types, and 4) fine-grained green matrix augite. Barkevikite occurs both as phenocrysts (Figure 15), as microphenocrysts or anhedral grains replacing phenocryst augite. It is pleochroic in shades of brown, green-brown, and tan and has the following parameters: alpha=1.688, and gamma=1.705 $\pm$.003. Barkevikite also occurs in corona structures rimming augite phenocrysts. Fine blue-green actinolitic hornblende commonly rims and replaces barkevikite. Magnetite occurs both as irregular phenocrysts and as fine individuals scattered throughout the matrix.

Andesine, the most abundant matrix mineral is strongly zoned and complexly twinned. It may be unaltered or completely altered to various combinations of epidote, carbonate, sericite, and chlorite. Strongly altered matrix orthoclase is a common constituent of some specimens. It is commonly perthitic and altered to kaolinite and fine-grained hematite. Apatite is the most abundant accessory. It occurs as slender needles, commonly hollow (Figure 15) and sheaths of needles. Uncommon calcite amygdules are rimmed by radial books of chlorite commonly containing zeolites (scolecite ?). Augite phenocrysts in one dike of the Cabin Group claims area are rimmed by pyrite. Biotite

locally becomes an important constituent of the matrix and is accompanied by a decrease in augite and amphibole.

Table 14 indicates the mineralogical and textural variety exhibited by the lamprophyres. The most common variety is fine grained, and porphyritic in which euhedral phenocrysts vary from 1 mm to 5 mm in a matrix averaging 1.0 mm to 0.3 mm. Mafics ±plagioclase also commonly occur as microphenocrysts in

Table 14. Textural varieties of lamprophyre dike rocks.

Phenocrysts	Matrix
Augite, barkevikite, magnetite, relict olivine	Coarse poikilitic andesine, interstitial hematitic orthoclase, carbonate
Augite, relict olivine	Intergrown andesine with microphenocrysts of barkevikite, magnetite, biotite, apatite, carbonate
Augite, relict olivine	Very fine-grained augite, magnetite, plagioclase, barkevikite, chlorite, epidote
Augite, relict olivine Vesicles--calcite, chlorite, epidote	Intergrown andesine, with microphenocrysts of magnetite, barkevikite, augite, apatite; sub-ophitic relationship
Augite rimmed by barkevikite, relict olivine, augite, andesine	Coarse intergrown andesine, epidote, magnetite, carbonate, chlorite, interstitial orthoclase
Very coarse andesine, augite relict olivine Vesicles--chlorite, zeolite, carbonate	Andesine, augite, magnetite, biotite, relict olivine, apatite, altered orthoclase
Augite (slightly porphyritic), andesine Vesicles--calcite	Olivine, augite, andesine, barkevikite, magnetite, biotite, apatite

Table 14 (cont'd.)

Phenocrysts	Matrix
Augite rimmed by barkevikite, andesine, magnetite	Coarse intergrown andesine, apatite, epidote, interstitial orthoclase
Barkevikite, relict olivine magnetite Vesicles--carbonate, chlorite, zeolite	Barkevikite, andesine, augite, epidote, carbonate, magnetite, orthoclase (?)
Microphenocrysts of augite, magnetite, barkevikite, biotite Vesicles--calcite, scolecite, chlorite	Very fine altered feldspars, apatite, hematite
Very coarse andesine, augite Vesicles--chlorite, calcite	Oriented andesine, augite, epidote, magnetite, chlorite, carbonate
Augite--replaced by actinolite, chlorite, epidote	Sub-ophitic intergrowth of andesine, augite, magnetite, barkevikite, apatite

the matrix. Giant phenocrysts in excess of 1 cm across are uncommon, as are matrix textures less than 20 microns average grain size.

Very few truly non-porphyritic lamprophyres have been found in the Lookout Mountain area. One persistent dike cutting hornblende leucodiorite (Sec. 34, T.19S., R.73W.) and several smaller dikes in Sec. 12, T.19S., R.73W. (unmapped) are locally non-porphyritic. Most occurrences of this type exhibit a microporphyritic texture with the same mineral distribution as augite spessartite.

Porphyritic plagioclase spessartite is an important variety of the McClure spessartite lamprophyres and intermediate members containing both plagioclase and augite phenocrysts are

common. In plagioclase spessartite, subhedral andesine (Ab_{53-66}) and anhedral magnetite are the only phenocrysts. Andesine is strongly zoned and complexly twinned, and occurs in a matrix of andesine with microphenocrysts of biotite, barkevikite, apatite, and magnetite. Augite microphenocrysts are abundant in biotite-poor specimens and is uncommonly altered to serpentine. Orthoclase is an important interstitial matrix constituent in some varieties. Common matrix alteration products are serpentine, chlorite, kaolinite, and carbonate.

Some lamprophyres along Turkey Gulch (Sec. 8, T.20S., R.73W.) are considerably more potassic than those described above and can be termed vogesite. These are medium grained, green-gray and contain essential to accessory plagioclase in addition to barkevikite, and augite phenocrysts in a matrix of orthoclase ±plagioclase. Biotite, magnetite, pyrite, augite, and barkevikite are common microphenocrysts. Sericite, carbonate, and kaolinite are common matrix alteration products. Orthoclase may be blocky or interstitial and is generally strongly altered. Carbonate alteration is more widespread than in most spessartites and may constitute a significant part of the matrix.

Spherulitic hematite-stained aggregates of albite, carbonate, ±epidote, ±chlorite occur in all types of lamprophyres. These are commonly radioactive.

Two types of alteration are common in the lamprophyre and related dike rocks. The first is deuteric and includes the

following changes: olivine → talc, magnetite, serpentine, carbonate, chlorite; augite → chlorite, talc, magnetite, epidote, carbonate, actinolite; barkevikite → biotite, actinolitic hornblende; plagioclase → sericite, chlorite, epidote, carbonate; magnetite → limonite; and orthoclase → sericite, kaolinite, hematite. The second type of alteration is related to the introduction of magmatic carbonate fluids giving rise to the associated Th-veins and carbonatite dikes. This stage of alteration consists of wholesale carbonate replacement of all dike constituents, leaving the paniodiomorphic dike texture largely unchanged. These will be discussed further in the section on carbonatite dikes. The amygdule fillings could have developed at either stage.

Augite dike. Several of the lamprophyre dikes exhibit bizarre textural features but one is particularly spectacular because of its coarse phenocrysts and abundant xenoliths. A 4- to 6-foot thick spessartite dike (Figures 16 and 17) crops out in a small gulch one-half mile south of the Cabin Group of carbonatites (Sec. 7, T.20S., R.73W.). In its most coarsely porphyritic area, it consists of a typical augite-barkevikite spessartite matrix in which the following are imbedded:

1. Augite phenocrysts from ½" to 2½" with glomeroporphyritic aggregates up to 4"
2. Barkevikite individuals and aggregates up to 1½" across
3. Epidotized xenoliths of granite gneiss to 6" across containing recrystallized acicular hornblende from 1/8" to 1½" long
4. Andesitic dike rock, syenite, and ultramafic rock xenoliths.

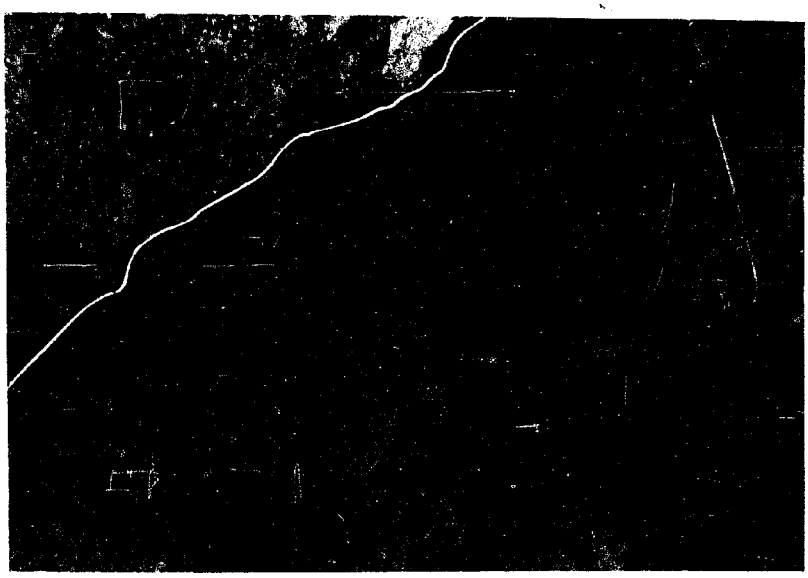


Figure 16. Chilled contact (arrows) at margin of augite breccia dike (lower right), Sec. 7, T.20S., R.73W.



Figure 17. Center of augite breccia dike of Figure 16. Note granite gneiss fragments in different stages of assimilation. Glomeroporphyritic augite (arrows) phenocrysts dispersed in lamprophyre matrix among breccia fragments.

Spessartites, in general, do not contain abundant epidote; however, in the augite dike, epidote is abundant, replacing mafic phenocrysts and xenoliths. Vugs locally contain epidote, prehnite, and calcite developed in that order. In addition, magnetite, augite, and biotite have been added to felsic xenoliths and mafic xenoliths are reduced to serpentine and magnetite. The major spessartite change near a xenolith is increased orthoclase in its matrix and the substitution of biotite for barkevikite in the microphenocryst stage.

Ovoid lamprophyre. The chilled margin of a lamprophyre dike in Goldie Gulch (Sec. 34, T.19S., R.73W.) is of particular interest. The dike is a typical porphyritic olivine-plagioclase spessartite. Along its margin is an irregular banded chilled zone containing concentrically-zoned, light-gray ovoid masses ranging from circular to elongate, from 1/8 to 2½ inches in diameter. Ovoids commonly contain plagioclase or xenolithic nuclei but may also contain megascopically featureless interiors (Figure 18) and are surrounded by a dark gray aphanitic dike rock matrix. Parts of the matrix contain color flow-banding (Figure 19) around the ovoids and feldspar phenocrysts, and concentric banding of the matrix in the interstices between ovoids is not uncommon.

On a microscopic scale there is little difference between the matrix and centers of ovoids (Figure 18) and since the average grain size of constituents is less than 5 microns,

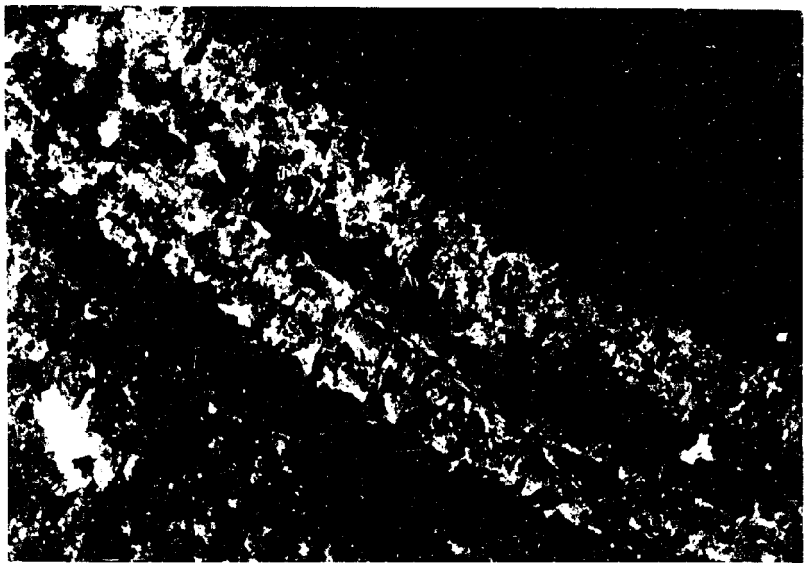


Figure 18. Photomicrograph of an ovoid lamprophyre, Sec. 27, T.19S., R.73W. Concentric bands outlining an ovoid separates the interior (upper right) from spessartite matrix. Microphenocrysts are magnetite and pyroxene in an andesine matrix. Plane polarized light, x35.



Figure 19. Photomicrograph of an ovoid lamprophyre, Sec. 27, T.19S., R.73W. Color-flow-banding around feldspar phenocryst. Plane polarized light, x35.

identification of the different phases is necessarily uncertain. The chilled dike-rock which constitutes the ovoid matrix contains biotite-plagioclase-sericite-carbonate-magnetite intergrowths after pyroxene and sericite-hematite after plagioclase phenocrysts. Sanidine-high-albite phenocrysts and granite gneiss xenoliths are common ovoid nuclei, but are not restricted to ovoid centers. The fine-grained matrix aggregate consists of granular pyroxene (?) in a subordinate feldspar matrix and is commonly replaced by carbonate in some specimens. X-ray diffraction patterns indicate the feldspar is probably andesine.

Because there is no zonal arrangement specifically related to phenocrysts, such ideas as chilling of the dike fluid at a phenocryst surface or nucleation along this interface is improbable. Diffusional processes remain as the most probable origin. Since granite gneiss xenoliths are present, concentric banding probably resulted from a xenolith reaction with dike fluid during consolidation which continued in the solid state after consolidation while the rock mass was still at elevated temperatures. Relict panidiomorphic textures within ovoids suggest a xenolithic origin. The fracturing of ovoid shells must have taken place after consolidation but while the rock was at sufficiently elevated temperatures for healing to have taken place.

TRACHYTE

Trachyte dikes are the thickest and most persistent dikes of the area and are typically exposed north of Lookout Mountain (Sec. 33, T.19S., R.73W.). They are brick-red to red-brown, medium grained to aphanitic porphyritic with pink aphanitic chilled margins. Dikes near or within the plutonic complex commonly exhibit a well-developed flow structure with the alignment of both phenocryst and matrix feldspars.

Trachyte consists of essential orthoclase, $\pm$plagioclase with variable biotite and hornblende, and accessory quartz, magnetite, sphene, apatite, and calcite. Two matrix textures are common--fluidal and spherulitic aphanitic. In rocks containing the fluidal texture, Na-amphibole, plagioclase (Ab_{85}), and orthoclase phenocrysts are oriented in a fluidal matrix of orthoclase with minor blue-green amphibole, biotite, and magnetite. In rocks exhibiting the spherulitic texture, orthoclase phenocrysts are imbedded in a matrix of orthoclase exhibiting patches of radiating orthoclase and anastamosing trains of accessory biotite and amphibole (Figure 20). Calcite, chlorite, and kaolinite are the most common alteration products and finely dispersed hematite accounts for the red to pink rock color.

One variety of trachyte contains abundant chlorite and calcite apparently pseudomorphous after pyroxene, amphibole, and biotite phenocrysts and is considered an altered representative of the vogesitic rock type.

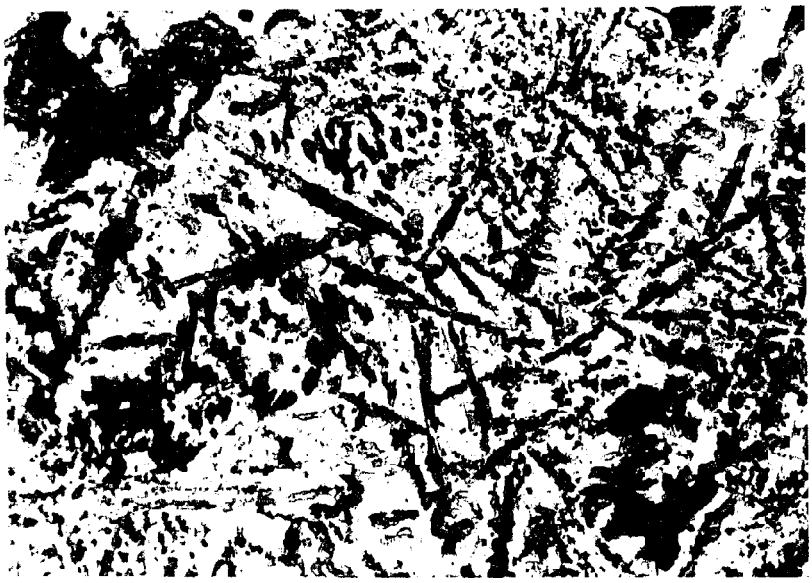


Figure 20. Photomicrograph of spherulitic trachyte, Sec. 2, T.20S., R.73W. Radiating trains of hornblende and biotite outlining matrix orthoclase. Plane polarized light, x100.

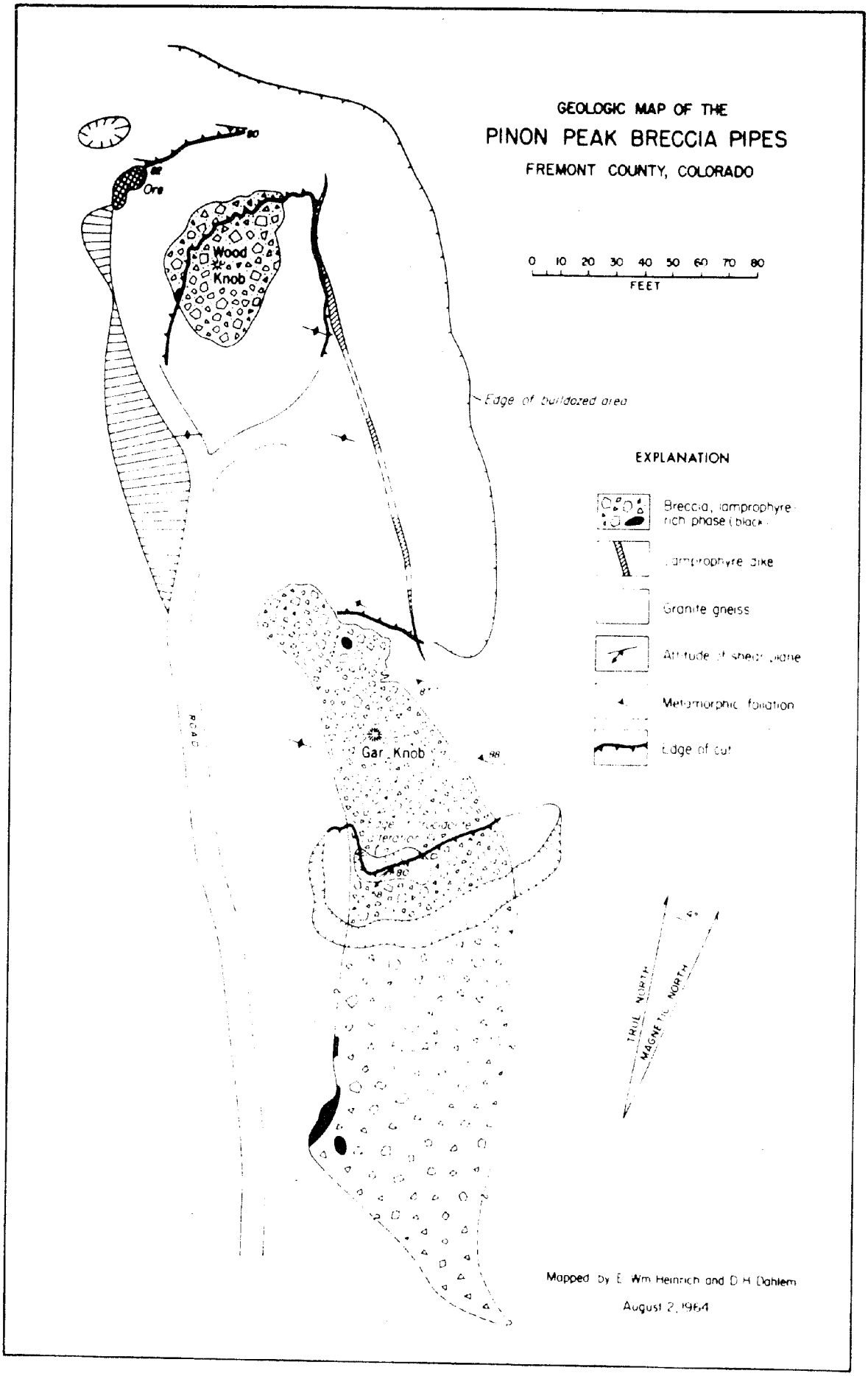
BRECCIA PIPES

Two small breccia pipes related to the McClure Mountain alkalic center are exposed as two small knobs (Gar and Wood knobs) approximately three-fourths mile north of Pinon Peak (Sec. 7, T.19S., R.72W., Plate 1, Figure 21). Bulldozing around a hematitized outcrop has more fully exposed the northern and part of the southern pipe, and float from the latter can be traced along a ridge 150 feet south from the bulldozed area.

Both pipes have been developed in granite gneiss of the Idaho Springs formation. The Wood pipe is circular, approximately 35 x 50 feet in maximum dimension. It consists of granite gneiss fragments up to several inches across in a matrix of more finely comminuted gneiss. On the northeast and southwest sides a strongly altered basic dike rock locally constitutes the matrix (Figure 24). The northwest edge is strongly hematitized and coarse hematite flakes and rosettes are common throughout the matrix of the Wood pipe.

The larger, southern, or Gar pipe is approximately 20-60 x 250 feet in plan. Both pipes, the float extension, and a nearby lamprophyre have been developed along an axis that trends N.20°W. The breccia of the Gar pipe is similar to that of the Wood pipe, but contains some fragments as much as several feet across. Lamprophyre fragments are abundant on the northeast corner, and it is difficult to determine whether lamprophyre that crops out to the southwest is part of the breccia or represents a dike intruding the gneissic country-rock. Near the center of

Figure 21. Geologic map of the Pinon Peak breccia pipes, Sec. 7, T.19S., R.72W. Fremont County, Colorado.


GEOLOGIC MAP OF THE
PINON PEAK BRECCIA PIPES
FREMONT COUNTY, COLORADO
0 10 20 30 40 50 60 70 80
FEET
Wood Knob
Gar Knob
Edge of bulldozed area
EXPLANATION
Breccia, lamprophyre-rich phase (black)
Lamprophyre dike
Granite gneiss
Attitude of shear plane
Metamorphic foliation
Edge of cut
TRUE NORTH
MAGNETIC NORTH
Mapped by E. Wm. Heinrich and D. H. Dahlem
August 2, 1964

the Gar pipe crocidolite is abundant as fibro-radial aggregates in the altered breccia matrix. Pink feldspathic rims commonly surround breccia fragments (Figure 22), particularly mafic fragments, and aegirine is common on slip surfaces and in fine veinlets, close to a fault that cuts N.70°E. across the pipe.

Detailed examination shows that in the breccia along with the granite gneiss, fragments of mafic dike rock and lamprophyre are also common. Mafic rock pieces, totally replaced, now consist of biotite, oligoclase (Ab_{75-80}), chlorite, goethite, and scapolite (?), and are commonly rimmed by a pink border consisting of finely granular oligoclase-albite and finely dispersed hematite. The feldspars of the granite gneiss fragments are commonly altered to sericite and kaolinite and generally replaced by albite and carbonate. The characteristic panidiomorphic texture is discernable in the lamprophyre fragments in spite of almost complete carbonate replacement. Lamprophyre fragments also are rimmed by feldspathic borders. Matrix constituents are oligoclase, carbonate, crocidolite, and aegirine. Oligoclase occurs both as fine-grained interlocking aggregates replacing comminuted breccia pieces, and as coarse, anhedral, poikilitic grains surrounding or interstitial to breccia pieces. Two generations are present; the earlier being sericitized. Carbonate is ubiquitous, replacing all other constituents. Aegirine is commonly fibrous and crocidolite is fibro-radial (Figure 23)--both commonly occurring along the outer margins of pink feldspathic rims around breccia pieces and as clumps throughout the



Figure 22. Pinon Pipe breccia. Note feldspathic rims around fragments (arrows). Matrix consists of comminuted granite gneiss with interstitial crocidolite.

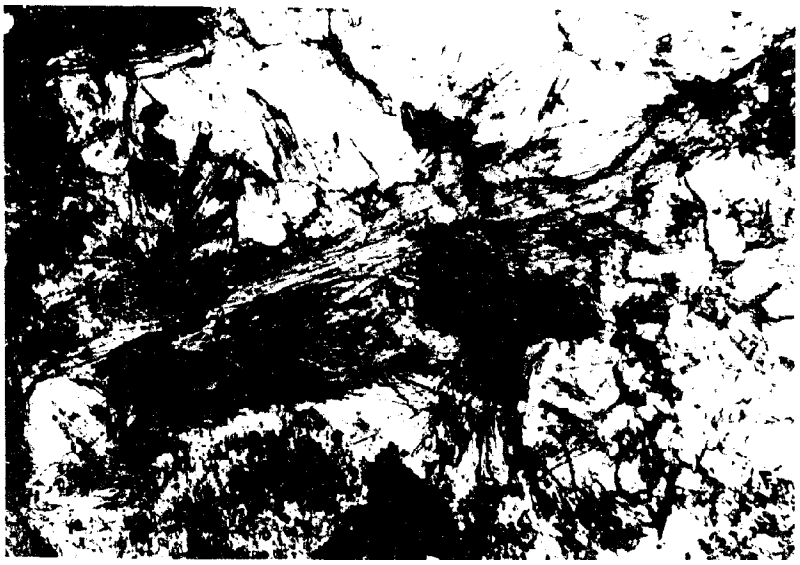


Figure 23. Photomicrograph of crocidolite (cr) and aegirine (aeg) interstitial to comminuted granite gneiss fragments in Pinon Pipe breccia. Plane polarized light, x100.

matrix material. Crocidolite generally replaces aegirine. Fine stringers of albite with central carbonate cores commonly contain aegirine and may indicate that carbonate was introduced at a relatively late stage. At least some carbonate is post albite.

The most probable paragenetic sequence of minerals added to the breccia matrix is (1) albite-oligoclase, (2) aegirine, (3) crocidolite, (4) carbonate, and (5) hematite. Of these, crocidolite and hematite may result from replacement processes, i.e. crocidolite from aegirine, and hematite from the replacement of ankerite by calcite.

At the northeast corner of the Wood pipe an intrusive breccia of granite gneiss fragments (Figure 24) contains a mafic dike-rock matrix similar to mafic rock fragments found in both pipes. This dark dike material is strongly altered, containing biotite, chlorite, plagioclase, and sericite with amygdules of zeolite and carbonate. Along the margin of each granite gneiss fragment carbonate has replaced feldspar in the gneiss.

A small dike east of the Wood pipe (Figure 21) has been traced approximately 150 feet south to the Gar pipe. It also is strongly altered and consists of biotite (or chlorite), oligoclase, magnetite, and secondary quartz. The similarity between biotitic fragments in the Gar pipe, the vesicular dike-rock matrix northeast of the Wood pipe and the associated dike to the east suggest they are all the same material and that the dike was emplaced prior to breccia-pipe formation. Likewise, the occurrence of lamprophyre fragments in the breccia suggests



Figure 24. Basic dike intrusive breccia with granite gneiss, cropping out on northeast corner of Wood breccia pipe. (Hammer handle in lower left for scale.)

that the pipe development is a post-lamprophyre phenomenon, possibly the last event prior to carbonatite dike development.

Breccia-containing lamprophyre dikes similar to both the augite dike and the intrusive breccia phase of the Wood pipe crop out twice north of the pipes in Secs. 6 and 7, T.19S., R.72W. In both cases, the dike consists of granite gneiss fragments up to 1 inch in diameter in a brown spessartite matrix.

CARBONATITES

Of the three alkalic complexes in Fremont and Custer Counties, Colorado, two have associated carbonatites--McClure Mountain and Gem Park--and two have associated thorite-barite-carbonate veins--McClure and Democrat Creek. Actually the distinction between the carbonatites and the Th-veins is indistinct and the two types intergrade. In contrast to the Gem Park occurrence where carbonatites are mainly found in the peripheral parts of the complex, carbonatites of the McClure Mountain massif occur both within the complex and in the Precambrian country-rocks as distant as 12 miles north and 18 miles northwest, although they are most numerous within two miles of the margin of the alkalic body.

In the Lookout Mountain area there are five major areas of carbonatite concentration:

1) Cabin Group-Homestake (Secs. 7 and 8, T.20S., R.73W.)

2) Dreamers Hope-June (Sec. 4, T.20S., R.73W.; Sec. 34, T.19S., R.73W.)

3) Jim No. 6-Goldie (N½, Secs. 33 and 34, T.19S., R.73W.)

4) Klondike (Sec. 24, T.19S., R.73W.)

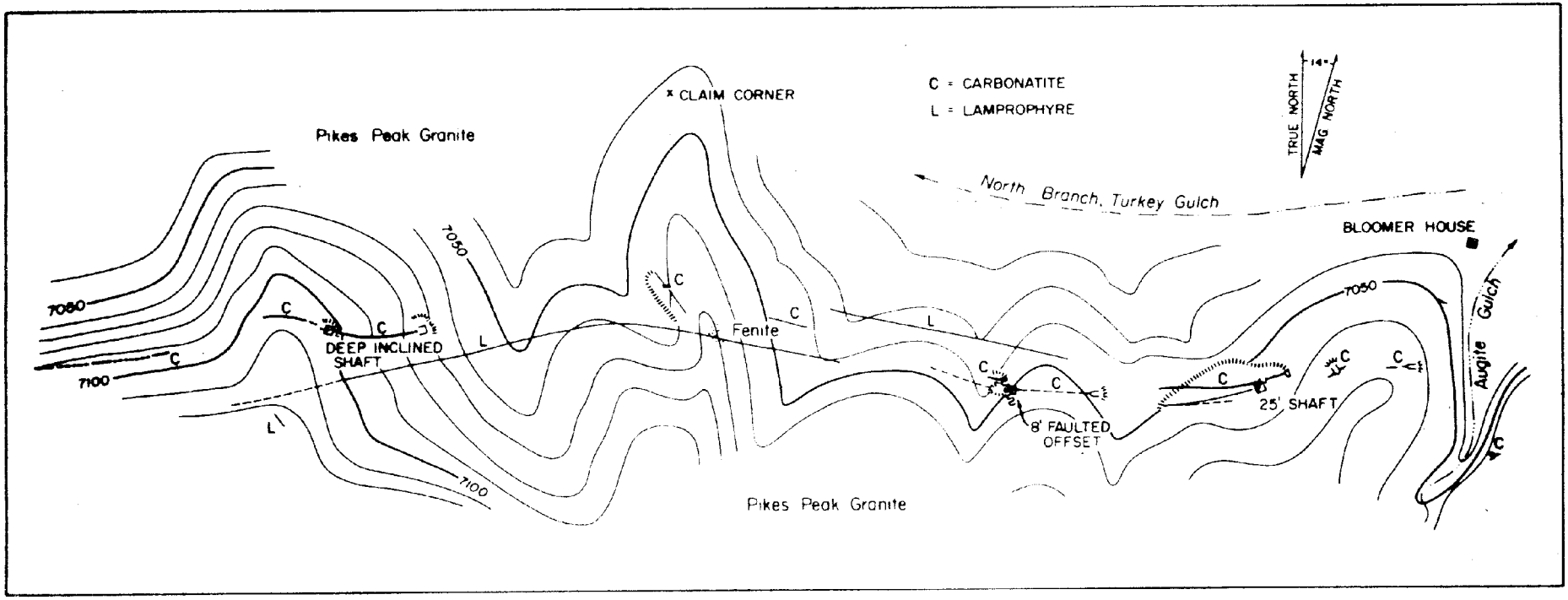
5) Scattered occurrences from Indian Springs to Pinon Peak.

In addition to these, at least 100 more small dikes are not of mappable dimensions.

Carbonatites of the Lookout Mountain area are predominantly dikes ranging from less than a foot to 7-10 feet in thickness and up to one-third mile in length (Cabin Group, Figure 25). They are generally light brown to gray or chocolate brown on the weathered surface, commonly solution pitted and poorly resistant to erosion. The thicker carbonatites are commonly straight, steeply dipping or vertical, trending either NE or approximately E-W, commonly paralleling associated lamprophyres (Cabin Group, Dreamers Hope-Figure 26, Goldie-Figure 27, Theobold-Figure 28, Klondike). Smaller, less persistent individuals are anastamosing and may be shallow dipping (minor dikes at the Dreamers Hope and Cabin Group).

Dike contacts are commonly sharp and only rarely exhibit chilled margins (Goldie, Figure 29) but vary widely in the degree of wall rock alteration. The most widespread effect is the introduction of aegirine into country-rock gneiss and granite. Aegirine veinlets are common and persist to 75 feet from the carbonatite contact at the Klondike prospect (Plate 2). Aegirine totally replaces biotite gneiss in some cases and may form

Figure 25. Geologic map of the Cabin Group carbonatites, Sec. 7, T.20S., R.73W.



GEOLOGIC MAP OF THE CABIN GROUP OF CARBONATITES, FREMONT COUNTY, COLORADO

0 100 200 300
FEET

Contour Interval 10'

MAPPED BY D. H. DAHLEM

Figure 26. Geologic map of the Dreamers Hope carbonatite, Sec. 4, T.20S., R.73W.

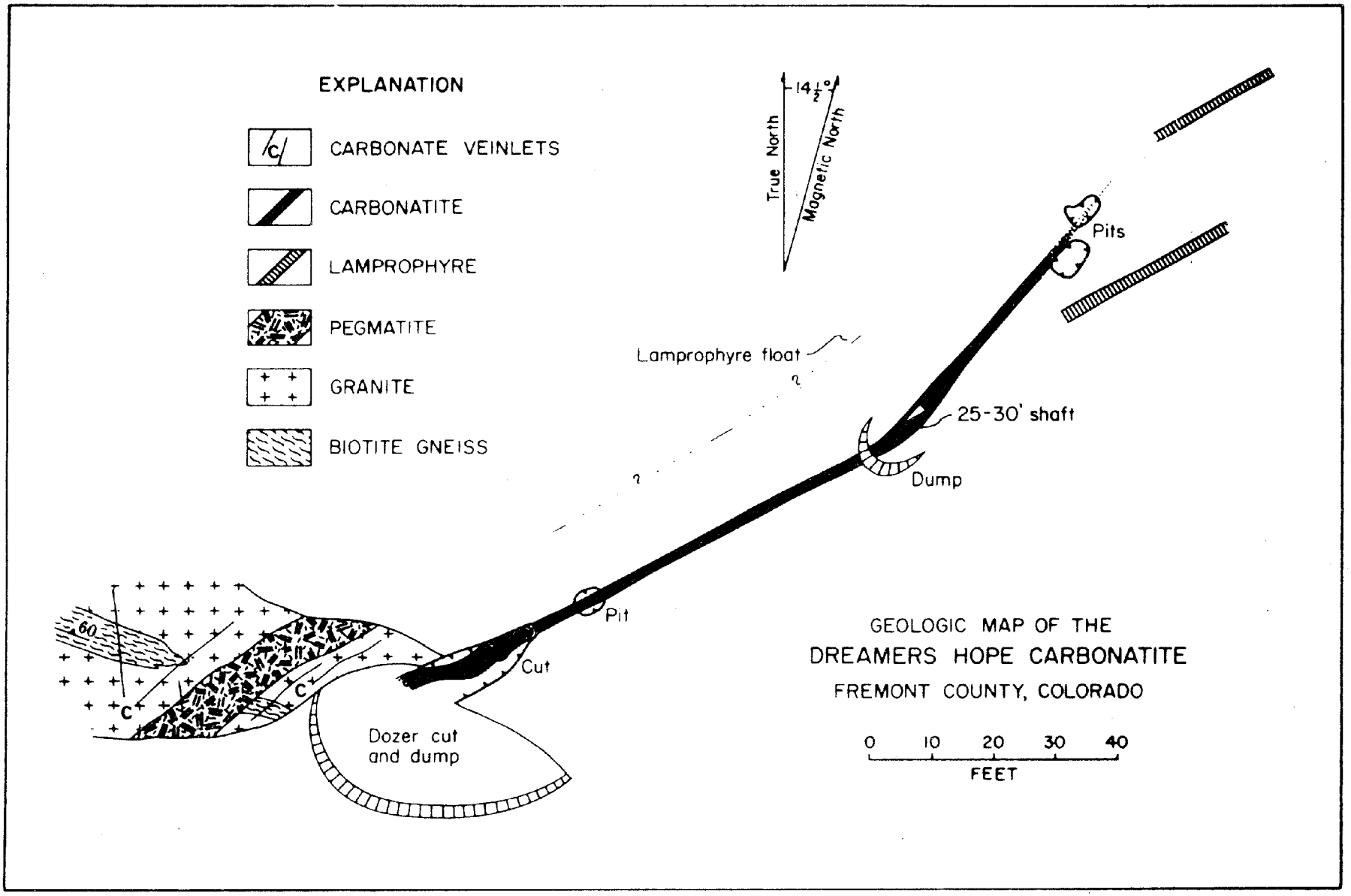
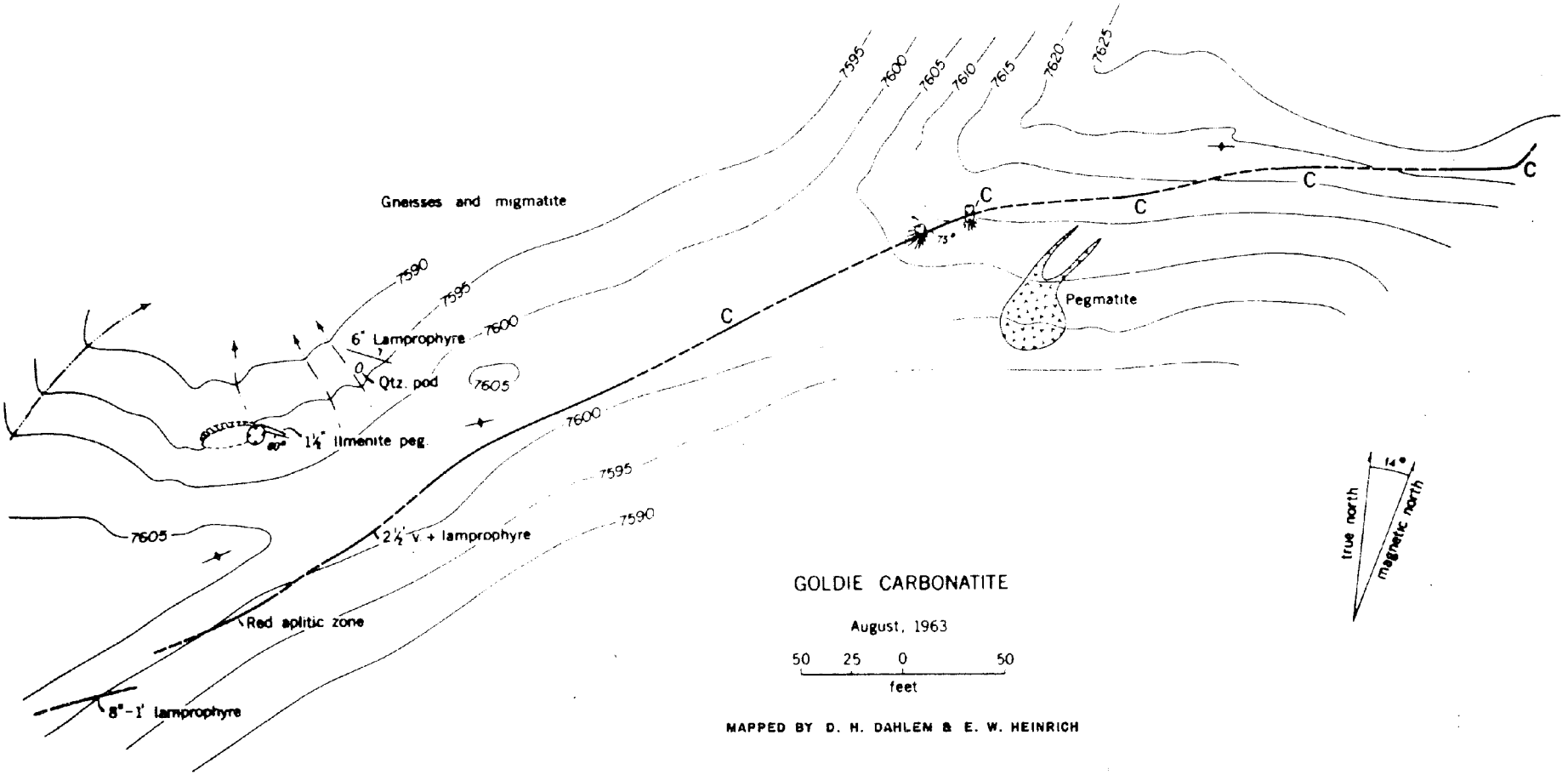

EXPLANATION
/c/ CARBONATE VEINLETS
CARBONATITE
LAMPROPHYRE
PEGMATITE
GRANITE
BIOTITE GNEISS
14½°
True North
Magnetic North
Pits
Lamprophyre float
25-30' shaft
Dump
Pit
Cut
Dozer cut and dump
60
C
C
GEOLOGIC MAP OF THE
DREAMERS HOPE CARBONATITE
FREMONT COUNTY, COLORADO
0 10 20 30 40
FEET
MAPPED BY D. H. DAHLEM

Figure 27. Geologic map of the Goldie carbonatite, Sec. 27, T.19S., R.73W.



GOLDIE CARBONATITE

August, 1963

50 25 0 50

feet

MAPPED BY D. H. DAHLEM & E. W. HEINRICH

Figure 28. Geologic map of the Theobold carbonatite, Sec. 32, T.19S., R.73W.

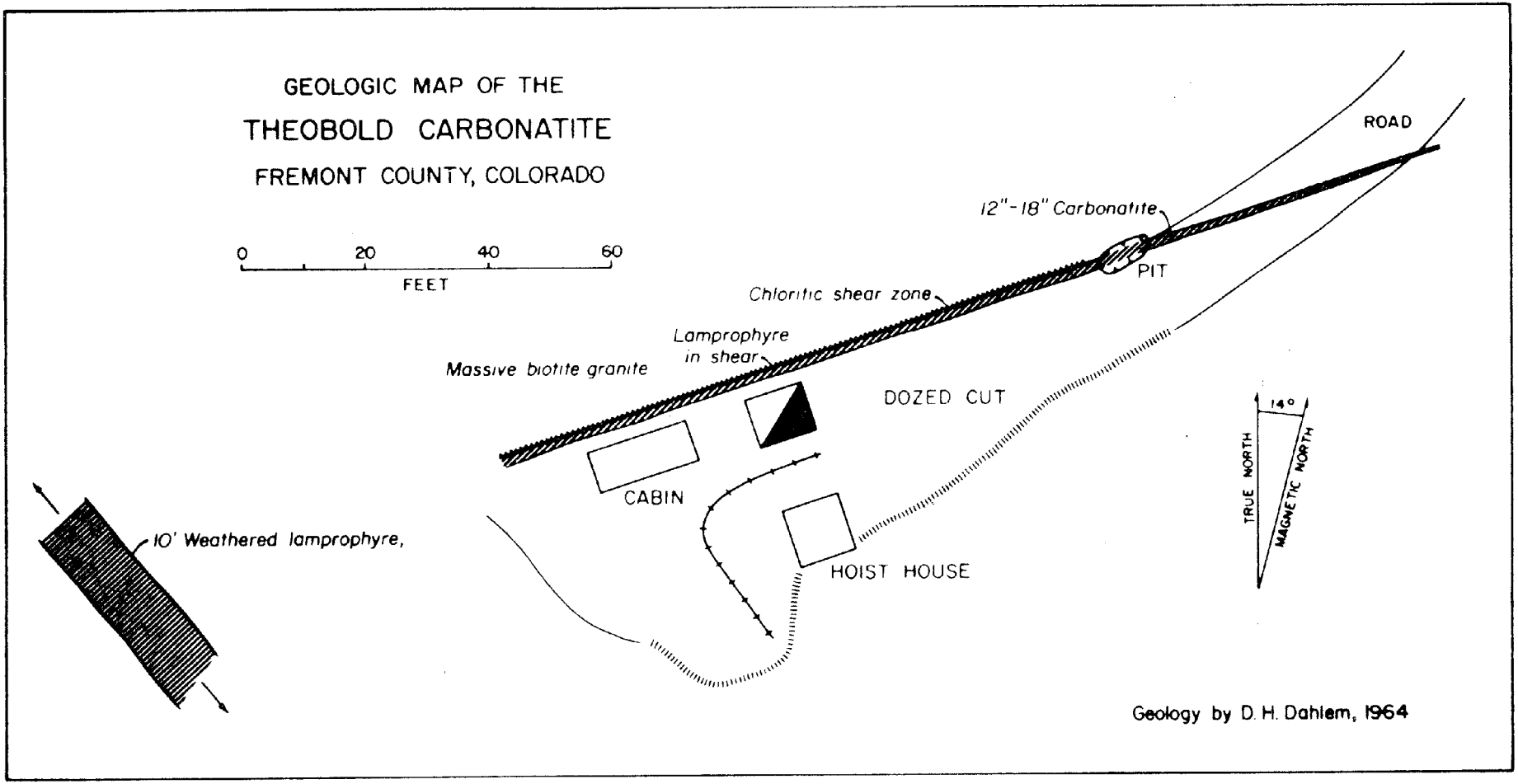

GEOLOGIC MAP OF THE
THEOBOLD CARBONATITE
FREMONT COUNTY, COLORADO
0
20
40
60
FEET
ROAD
12"-18" Carbonatite
PIT
Chloritic shear zone
Lamprophyre
in shear
Massive biotite granite
DOZED CUT
CABIN
HOIST HOUSE
10' Weathered lamprophyre,
14°
TRUE NORTH
MAGNETIC NORTH
Geology by D. H. Dahlem, 1964



Figure 29. "Chilled" feldspathic margin of a carbonatite near Goldie dike, Sec. 35, T.19S., R.73W. Country-rock is biotite gneiss.

pods and veinlets 3-4 inches wide. At some contacts, wall rocks are totally replaced by carbonate, and at others (Klondike) hematitic alkali feldspar has been introduced. Along carbonatite dikes of the Cabin Group, wall rock alteration is minor and a 5-foot dike commonly ends abruptly against migmatitic wall rock, with less than ½ inch of hematitic alteration. Three- to four-inch dikes east of the main Goldie dike are surrounded by aegirine veinlets, carbonatitization, and hematitic feldspathization in gneissic country-rock as far as 10 feet from the contacts. Where dikes are covered by colluvium or are weathered out, they may be traced by float or country-rock containing aegirine and hematitic fenitization products.

Cross-faulting offsets both the Cabin Group and Klondike carbonatites (Plate 2). Longitudinal faulting was also noted along the carbonatite margin of the Theobold dike (Figure 28) and at the east end of the Cabin Group main dike. At the Cabin Group dike, fragments of a brecciated, juxtaposed lamprophyre are included in a carbonate matrix along the longitudinal fault. The field relations show that the sequence has been (1) lamprophyres, (2) faulting, and (3) carbonatites.

Not all carbonatites are entirely carbonatic. The Klondike dike is predominantly feldspathic and contains pods of coarse chocolate brown carbonate (marked "C", Plate 2) scattered along its length. Pods are both marginal and central and commonly pinch and swell in a feldspathic dike of almost constant thickness. Other feldspathic carbonatites, such as the dike in Sec. 24,

T.19S., R.73W., consist predominantly of alkali feldspars (albite and orthoclase) with dispersed hematitic carbonate rhombs. Another dike (June, Figure 30) is dominantly carbonatitic, having only a thin feldspathic wall-zone (6 inches) along a 5-7-foot thick dike.

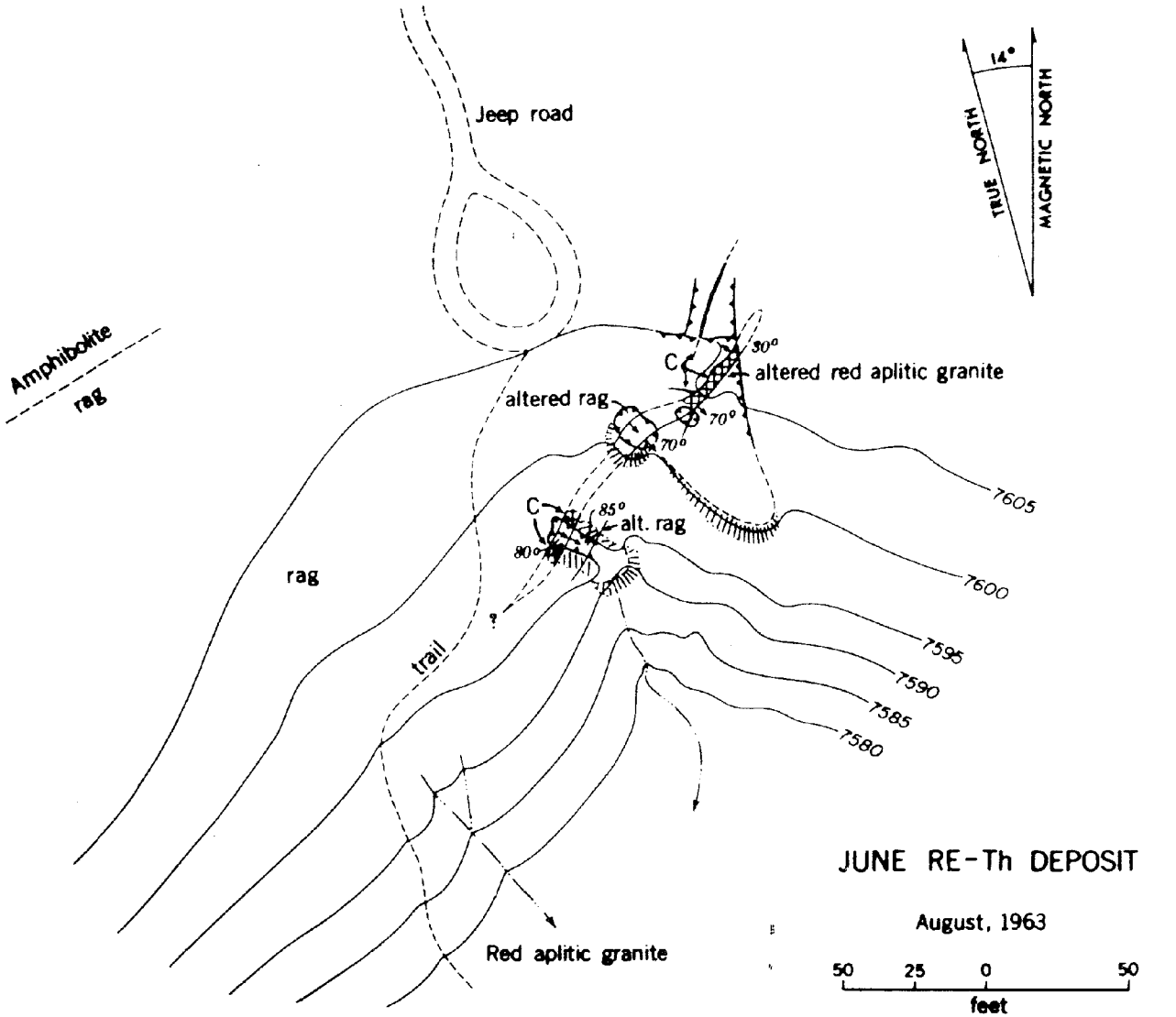
Carbonatites of the Lookout Mountain area have been divided into the following three groups (Heinrich and Dahlem, 1965) on the basis of mineralogical characteristics:

1) Feldspathic carbonatites. Examples of this type vary between two extremes (a) in which the dike is zoned with a hematitic alkali feldspar wall-zone surrounding a carbonate core (June 2), and (b) in which the dike is dominantly feldspathic with carbonate occurring as discontinuous pods (Klondike). These are common in the Lookout Mountain area.

2) Homogeneous carbonatites. Examples of this type are dominantly carbonatitic--sövites greatly predominating over rauhaugites. They contain a varied accessory suite, including magnetite, ilmenite, apatite, feldspar, biotite or vermiculite, and crocidolite. This type is more characteristic of the carbonatites within the alkalic rocks--both at McClure Mountain and Gem Park--than those external to the complexes.

3) Ba- F-rich carbonatites. Examples of this type are commonly zoned, containing barite and fluorite masses in the carbonate part of the dike (Dreamers Hope, Goldie). Pyrite, galena, sphalerite, chalcopyrite, apatite, aegirine, and quartz are common accessory minerals.

Figure 30. Geologic map of the June RE-Th carbonatite dike, Sec. 34, T.19S., R.73W.


Jeep road
14°
TRUE NORTH
MAGNETIC NORTH
Amphibolite
rag
altered red aplitic granite
altered rag
30°
70°
70°
C
C
85°
80°
alt. rag
rag
trail
?
7605
7600
7595
7590
7585
7580
Red aplitic granite
JUNE RE-Th DEPOSIT
August, 1963
50 25 0 50
feet
MAPPED BY D. H. DAHLEM & E. W. HEINRICH

Staining slabs of carbonatite dikes and carbonatized lamprophyres by means of an alazarin red dye (Friedman, 1959) indicates no preferential regional distribution of calcite or dolomite. The most abundant carbonate mineral in the Lookout Mountain area is calcite: dolomite is an important constituent in only two dikes. In both cases--the June and Dreamers Hope--the dikes are zoned with dolomite more common toward the dike core. Other, locally essential minerals are albite-oligoclase, orthoclase, quartz, and barite, however all of these may be absent. Common accessory species are aegirine, fluorite, magnetite, sphalerite, bastnäsite, ancylite (?), biotite, galena, pyrite, chalcopyrite, and crocidolite. Chlorite, sericite, hematite, and limonite are common alteration products.

Calcite is commonly anhedral with an average grain size from 0.5 mm to 1-1.5 mm. It may be poikilitic with inclusions of hematite and limonite, or it may be clear and inclusion-free. It commonly forms in an aggregate of interlocking grains or individuals or aggregates in a matrix of feldspar, quartz or barite. At least three generations of calcite are common. Poikilitic, hematite-bearing calcite is commonly cut by veins of clear calcite (Figure 31) containing interstitial quartz and pods of barite. The vein calcite is not uncommonly twinned and biaxial in contrast to the relatively untwinned poikilitic type. Both of these types are, in turn, veined by a third generation of clear calcite which cuts all other constituents.

In addition hematitic carbonate euhedra possibly represent another earlier generation of carbonate--possibly ankerite.

The most abundant feldspar is albite-oligoclase (Ab_{85-93}) which is an essential mineral in the Cabin Group and Klondike dikes. It is commonly coarse grained (0.5 to 2.0 mm) anhedral, and occurs in an aggregate of mortared, strained, and bent individuals with interstitial calcite, quartz, and barite. Replacement antiperthite and chess-board textures are not uncommon. Microcline perthite is an abundant constituent in the feldspathic border zone of the Klondike carbonatite. It occurs as an interlocking strongly hematitized aggregate commonly in bands parallel to the dike wall.

Quartz, locally abundant, occurs in anhedral mutually bounding to interlocking aggregates. It is commonly strained. It rarely constitutes the matrix of brecciated carbonate, but is generally corroded and replaced by calcite. Barite occurs as pods in calcite, as fine-grained aggregates interstitial to carbonate aggregates, and as fine acicular individuals in carbonate. In the Goldie dike barite is intergrown with rare alumino fluorides in nodules up to 4 inches in diameter which replace a carbonate-fluorite matrix. Aegirine is the most widespread mafic silicate. It occurs primarily as acicular crystals in interstitial quartz and is abundant in specimens from the lower Jim prospect.

Sulfide minerals are abundant in the Dreamers Hope dike and sparingly present at the Alice and Jim prospects. Sphalerite

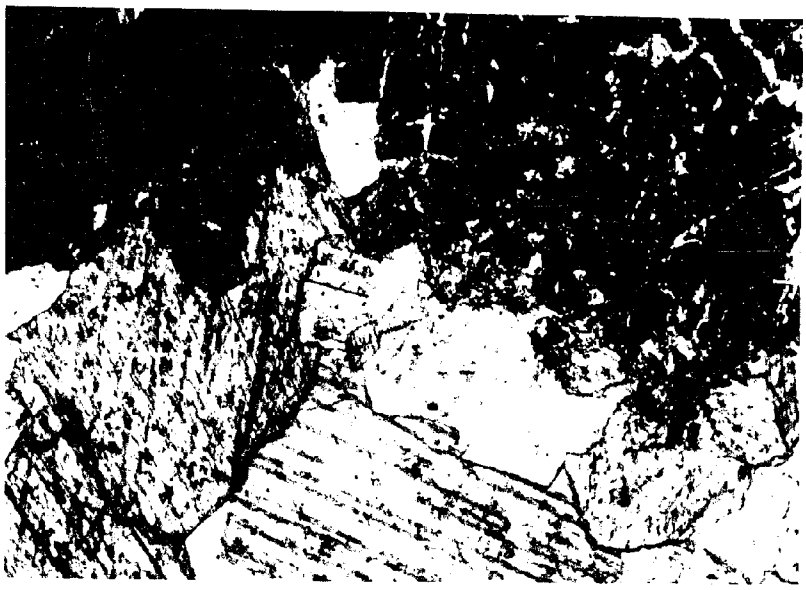


Figure 31. Photomicrograph illustrating clear carbonatite intruding earlier hematitic carbonatite, Sec. 3, T.20S., R.73W. Plane polarized light, x35.

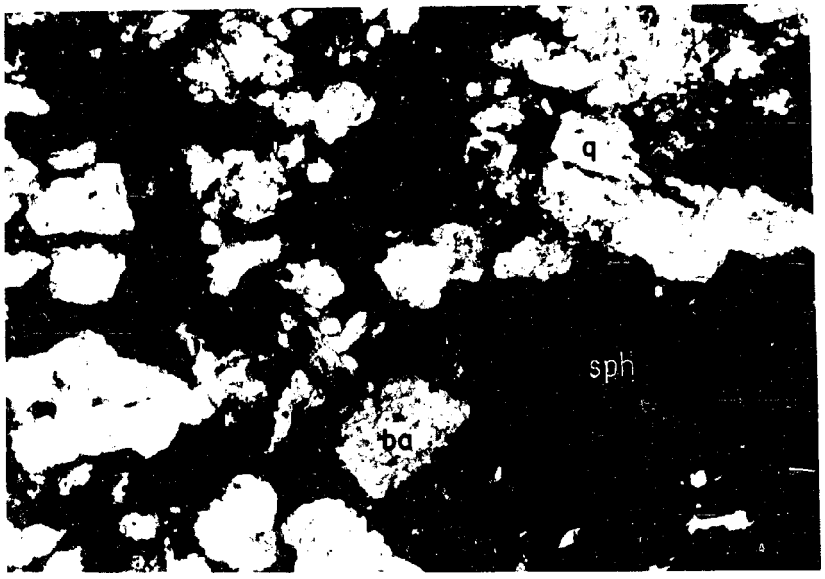


Figure 32. Photomicrograph of brecciated sphalerite (sph), quartz (q), and barite (ba) in a hematitic siliceous matrix. Dreamers Hope carbonatite, Sec. 4, T.20S., R.73W. Plane polarized light, x35.

is the most widespread species. At the Dreamers Hope, low-iron sphalerite occurs as pods up to 1½ inches across and is intergrown with galena and barite that has been brecciated and cut by late generations of quartz and carbonate (Figure 32).

The Goldie carbonatite (Heinrich and Quon, 1963) contains a unique mineral assemblage. The dike is 1-1½ feet wide and 750 feet long, sandwiched between lamprophyre and aplite dikes. It consists of a barite-fluorite-carbonate matrix containing replacement masses up to 10 inches long of complexly intergrown aluminofluorides among which Heinrich and Quon report cryolite, weberite, ralstonite, pachnolite, prosopite, and possibly gearksutite.

Thorium veins of the Wet Mountains (Christman et al. 1959) are closely related to carbonatites associated with the Wet Mountain alkalic province (Heinrich, 1958) and are probably gradational into feldspathic carbonatites. Typical thorium veins are characterized by abundant fine-grained hematite and contain potash feldspar, quartz, barite, iron-bearing carbonate with accessory sulfides, fluorite, alkali amphibolite, xenotime, bastnäsite, thorite, thorogummite, and brockite (Heinrich and Dahlem, 1965). In the Lookout Mountain area the June prospect and a number of un-named dikes south of the leucodiorite contain abundant hematite and very fine-grained, high index accessory minerals. One dike is complex containing (1) an earlier hematitic carbonate-quartz-barite phase with essential euhedral bastnäsite

and acicular ancylite (?) (Figure 33), and (2) a later coarse-grained carbonate-fluorite phase.

RELATIONSHIP OF CARBONATITE AND LAMPROPHYRE DIKES TO THE McCLURE MOUNTAIN COMPLEX

The McClure Mountain complex is an alkalic multiple-intrusive massif characterized by a sequence of rock units that begins with mafic-ultramafic types, progresses through saturated light-colored types and continues with highly undersaturated light and dark types (Table 12). Although similar in petrology and in petrologic sequence to other alkalic-carbonatitic complexes, the McClure massif lacks the typical ring-dike-cone-sheet structures characteristic, for example, of Iron Hill, Colorado and Magnet Cove, Arkansas (Heinrich, 1958).

The center of the Iron Mountain-McClure Mountain complex lies approximately one mile southeast of Indian Springs Park, and the Lookout Mountain area covers only its northwestern perimeter and its halo of associated dikes.

Three types of dike rocks are associated with the McClure massif: 1) alkalic light-colored types, 2) lamprophyres, and 3) carbonatites. Type 1 representatives are predominantly trachytes and nepheline syenite and are more common within the complex, but also occur in the country-rock near its margin. Lamprophyre dikes are most numerous in a three-mile-wide halo surrounding the complex. Carbonatite dikes, though most abundant in the halo, also occur within the complex near its margins.

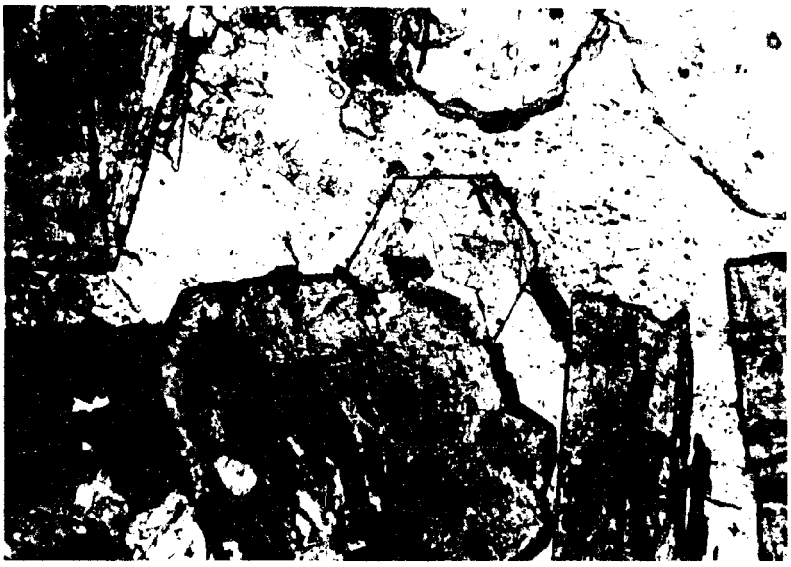


Figure 33. Photomicrograph of euhedral bastnäsite in carbonatite, Sec. 3, T.20S., R.73W. Plane polarized light, x100.

Lamprophyre and carbonatite dikes, in that order, clearly post-date all units of the massif. Some of the early light-colored types, such as nepheline syenite, while post-dating early units of the complex, may have been intruded during the plutonic stages of complex formation.

Because of the close association of lamprophyre and carbonatite dikes in the peripheral zone northwest of the massif, the two types of dikes are most certainly not only spatially but also temporally and genetically related to the complex. Since the alkalic rocks of the massif lie predominantly southeast of the Lookout Mountain area and have been studied by the U. S. Geological Survey (Parker and Hildebrand, 1963), a detailed discussion of the geology and origin of this complex is not germane to this dissertation.

TERTIARY VOLCANICS

The southern edge of the Thirtynine Mile volcanic field near South Park extends to a point approximately five miles north of the Arkansas River at Five Point Gulch (Figure 2). Other occurrences of volcanics have been described south of Cotopaxi and at Hillside--five miles southwest of Lookout Mountain--and all are believed related to a volcanic center near Guffey (Bever, 1954) to the north. The series that most closely resembles the Lookout Mountain volcanics is that described by Salotti (1960) near Cotopaxi. This consists of a basal rhyolite tuff, overlain by trachyte tuff, in turn overlain by andesite. In the Lookout Mountain area the lower two members are present. Only very minor patches, remnants of these volcanics, occur on the south side of the Arkansas River in the Lookout Mountain area.

These uncommon pyroclastics are exposed in Sec. 14, T.19S., R.73W. and in Sec. 18, T.19S., R.72W. They consist of two major tuff units--a lower, light gray, poorly consolidated and stratified unit lying unconformably on Precambrian metamorphics and an upper unit of pink to orange, dense welded tuff.

The basal unit--a lithic crystal vitric latite tuff--is from 20-30 feet thick and crops out along the south and west edges of the volcanic pile. It is relatively homogeneous consisting of approximately 20% phenocrysts and 5-15% lithic fragments in a matrix of glass shards or devitrification products. The most common phenocryst minerals are sanidine and albite-oligoclase (Ab_{86-93})--less common are quartz, hornblende (or

oxyhornblende), biotite, sphene, zircon, and magnetite. The most common lithic fragments consist of andesite, trachyte, and granite. Pumice fragments are common and not completely compressed. The matrix consists of glass shards which commonly exhibit only incipient devitrification but may also be totally altered to a mixture of tridymite and sanidine. The matrix texture is characterized by poor compaction and little welding. Irregular shards are loosely packed and surrounded by finer material.

The upper pyroclastic unit is approximately 80 feet thick and crops out primarily on the northern of the two volcanic-covered knobs. It conformably overlies the lower gray tuff but the contact between the two is weathered out or covered with colluvium. The upper unit is principally a lithic-crystal-vitric tuff or latitic or quartz-latitic composition. The most common phenocrysts are sanidine, oligoclase-andesine, biotite, and hornblende with variable yellow (stained) quartz. The most common lithic fragments are of andesite and pumice. Most of the phenocrysts are a complexly twinned oligoclase-andesine (Ab_{70-68}) which uncommonly is intergrown with sanidine. Sphene is locally abundant as medium-grained euhedra. The matrix is largely devitrified, exhibiting ideal axiolitic texture. Shards are strongly compressed and welded, with individuals tightly molded about phenocrysts. Pumiceous fragments are totally compressed. Uncommon vesicles contain chalcedony, quartz, rarely tridymite, and zeolites (?).

A black tuffaceous unit (2 feet thick) near the base of the upper unit is iron-rich and contains a few sanidine and plagioclase phenocrysts in a totally vitric matrix (Figure 34). Incipient axiolitic development outlines the compressed shards of the matrix.

In addition to the major pyroclastic occurrence near Colony Gulch, two other occurrences have been found south of the Arkansas River. Tuffs mapped near Washtub Gulch are of latitic composition and resemble the upper unit of the southern occurrence. Tuffs were also noted east of the Lookout Mountain area in Sec. 14, T.19S., R.72W., north of Iron Mountain.

Little indication of the pre-volcanic topography can be seen but since the two occurrences lie near 8,000 feet in elevation, and a number of ridges and peaks in the surrounding area rise to 8,500 feet with no volcanic capping, the pre-volcanic surface had a local relief of at least 500 feet. Near Colony Gulch the gray latite tuff rests on Idaho Springs gneisses, and in turn is overlain by the pink quartz latite tuff. Near Washtub Gulch only the upper pink quartz latite is present, resting unconformably on the Idaho Springs gneisses. Whether the spotty occurrence of the lower unit is the result of erosion before deposition of the upper unit or a characteristic of its deposition cannot be determined.

Stratification of the lower unit suggests it may have, at least in part, been waterlain in a local basin. The lower and upper pyroclastic units of Lookout Mountain have been correlated

respectively with the lower two tuffaceous units near Cotopaxi on the basis of 1) the stratified character of the lower, and 2) the tridymite content of the upper. The capping andesites found near Cotopaxi are not to be found near Lookout Mountain. Chapin and Epis (1964) suggest there are seven tuffaceous units in the Thirtynine Mile area. The deposits of Lookout Mountain most closely approximate "ash flow" 4 in composition and character which has been dated as post-lower Oligocene and pre-late Miocene (Chapin and Epis, p. 155).



Figure 34. Photomicrograph of welded vitric tuff, Sec. 14, T.19S., R.73W. illustrating partly collapsed pumice fragment in matrix of partly devitrified glass shards. Plane polarized light, x35.



Figure 35. Exhumed, terraced travertine deposit near the mouth of Rito Gulch.

QUATERNARY ROCKS

TRAVERTINE DEPOSITS

Travertine deposits and calcite-cemented conglomerates were first noted at the mouth of Thomas Gulch at its confluence with Texas Creek and one-half mile east of Texas Creek Junction (Plate 1). In addition approximately 20 other outcrops not of mappable dimensions were found. Two types can be distinguished. The less abundant type is a true hot springs deposit. In Sec. 14, T.19S., R.73W., travertine crops out in the latite tuffs demonstrating a clearly later origin. Travertine in the form of calcite-cemented terrace gravels (Figure 35), stream gravels, and talus has been found near the mouth of every gulch between Road Gulch and the Arkansas River. At the mouth of Road Gulch the deposits are near 7,200 feet in elevation. They consist of calcite-cemented colluvial aggregates approximately 15-20 feet above the present creek level. Further north toward Rito Gulch masses of calcite-cemented stream gravels crop out in creek bottoms and in nearby colluvium. Between Rito and Thomas Gulches travertine crops out immediately east of Texas Creek and can be seen in recent down-cutting of tributaries at the edge of the Texas Creek channel. One-half mile east of Texas Creek Junction calcite-cemented conglomerates from 3 to 4 feet thick crop out on the south side of the Arkansas River at an elevation of 6,320 feet, approximately 140 feet above the present river elevation.

The conglomerates cemented by carbonate consist of poorly sorted and rounded fragments of biotite gneiss, granite gneiss, and andesite. Andesite is the only exception to the fragments being of local derivation.

In an area containing no carbonate deposits other than those related to the McClure Mountain alkalic complex, the source of original carbonate material is difficult to determine. Travertine has been reported from Bernard Creek, north of Cotopaxi (Salotti, 1960), McCoy Gulch, south of Cotopaxi (personal observation), in Echo Canyon (Vian, 1965), and in the vicinity of McClure and Iron Mountains. In all but the latter two cases travertine is localized near major N-S trending shear zones thought to be of Tertiary age. It is not improbable that at least some of the carbonate may have been derived from deeply circulating solutions that have had access to carbonatite bodies at depths.

ALLUVIUM

Several types of alluvial cover have here been grouped as "Qal" (Plate 1). All major gulches are, at least in part, alluviated--Turkey and Texas Creek, Road, Copper, and Five Point Gulches. In several cases cross-faulting is the cause of local damming, (Secs. 16 and 31, T.19S., R.73W.) and thickening of valley fill. Indian Springs Park is covered with a thin veneer of alluvium through which some dikes of the alkalic complex can be traced by float.

Along the south side of the Arkansas River two terraces at 20 and 140 feet above the river level can be traced discontinuously from Texas Creek Junction to Baker Gulch. Both are cut predominantly on bedrock, but are gravel covered. In addition, high-level gravels cropping out near the mouth of Lakey Gulch (6,880 elevation) have been tentatively correlated with those at 6,400 feet elevation in Sec. 18, T.19S., R.73W. and with those of the upper Arkansas River terrace.

STRUCTURAL GEOLOGY

GENERAL

The major structural features of the Lookout Mountain area are 1) structural elements indigenous to the Idaho Springs metasediments, 2) structural elements indigenous to the Precambrian granites, 3) folds in the Idaho Springs metasediments, and 4) faults which cross-cut various Precambrian (and younger) rocks. Since within the map area, there is no geologic record between the Precambrian and early Tertiary and none of the above features effect the Tertiary pyroclastics in the Lookout Mountain area, distinguishing between Precambrian and Tertiary faulting is necessarily difficult.

METAMORPHIC STRUCTURAL FEATURES

The most conspicuous structural features of the Idaho Springs formation are the mineralogical banding and parallel foliation which by their continuity along strike suggest a thick sedimentary series. Foliation is considered to have developed parallel to the original sedimentary bedding primarily because the foliation is parallel to the bulk chemical and mineralogical banding of gneisses. The lineation, defined by the elongation of quartz and mafic minerals, is poorly defined but commonly oriented at a maximum angle to the strike and in the plane of the foliation.

PRIMARY IGNEOUS STRUCTURAL FEATURES

The most common structural feature of the Pikes Peak granite is a foliation defined by parallel biotite flakes and tabular microcline phenocrysts. It is best developed in coarse-grained parts of the intrusive, near contacts, and generally parallels the foliation of the gneissic country-rocks. Pegmatites associated with the Pikes Peak granite are commonly discordant and non-foliated. The foliation resulting from the orientation of blocky feldspars is only poorly developed in the Silver Plume and Red granites and because its attitude does not parallel that of the surrounding gneisses it is considered to be a primary flow structure.

Injection-gneiss and lit-par-lit gneiss both near granite contacts and in granite migmatite have distinct foliations continuous with that of less injected metasediments. In most cases, control of granite injection by the foliation of the gneiss is apparent, i.e. lit-par-lit injection is most common.

FOLDS

Two large folds have been mapped in the Idaho Springs gneisses. The Texas Creek Anticline is southeast of Texas Creek Junction and consists of Idaho Springs gneisses bowed around Pikes Peak granite, trending approximately N.75°-80°W. and plunging steeply SE. Gneisses at least two miles east of the Pikes Peak contact are involved in the fold which is the major structural feature west of the Five Point Gulch fault zone. Phacoidal sillimanite

gneiss can be traced around part of the fold and parallels the Pikes Peak contact.

The Washtub Syncline can be traced by means of a 700-foot-thick muscovite-sillimanite schist layer from the mouth of Washtub Gulch northward. The axial trace trends approximately E-W and the fold plunges moderately E. Gneisses are involved in the synclinal fold at least one mile east of the mica schist zone, and the structure is cut off by the NW-trending fault of Spring Creek.

Previous descriptions (Lovering and Goddard, 1950; Salotti, 1960) emphasize isoclinal folding and regional trends of foliation in the Idaho Springs rocks. In the Idaho Springs formation which underlies the northern half of the Lookout Mountain area any regional trend has been completely disrupted by the above two folds and by widespread faulting. Isoclinal folding has been noted locally in several areas but can, in each case, be related to a linear zone of deformation such as the Precambrian faults described below. Aside from these and several other minor examples, isoclinal folding does not exist in this area.

FAULTS

Three major fault trends are conspicuous in the Lookout Mountain area--NE, N-S, and NW--of which the N-S trend is dominant. The major NW-trending fault can be seen at the mouth of Spring Gulch and can be traced by means of the related drag folding and brecciation to the Arkansas River. The fault

truncates an amphibolite lens in Sec. 17, T.19S., R.72W., separates gneisses folded in the Washtub Syncline from highly injected biotite gneiss in Sec. 1, T.19S., R.73W., and related drag folding can be seen where the fault crosses the south bank of the Arkansas River. Other NW-trending faults are conspicuous in the eastern half of the map area. A breccia zone over 100 feet wide crops out in Sec. 3, T.19S., R.73W. where a NW fault truncates a N-S fault of the Five Point zone.

In the western half of the area NE faults predominate. These are of two types, deep level and shallow, both trending from N.30°-45°E. The best example of a deep level fault is in Sec. 7, T.20S., R.73W. It is a zone of extreme deformation at least one-fourth mile wide. Within this zone both isoclinal and open folds are equally abundant. The attitudes of gneiss on either side of the zone are similar, yet the foliation cannot be traced through the one-fourth-mile interval. Since the fault is entirely in migmatite there is no way of estimating either direction or magnitude of the relative movement. This zone is considered to represent a deep-level adjustment along which brecciation would certainly have taken place, at a shallower depth. The northeast-trending fault of Sec. 12, T.19S., R.73W. is similar, and both probably represent "true" Precambrian faulting.

Typical exposures of NE faults that developed under shallower conditions are one-half mile south of Texas Creek Junction and in Sec. 32, T.19S., R.73W., where a NE-trending fracture

originally controlling the emplacement of a diabase dike was re-brecciated. The shallower NE-trending faults, although commonly brecciated have little associated drag-folding. At least the last movements along the NE faults are post N-S faulting as evidenced by offset of the N-S Texas Creek shear-zone. Bedrock dams in Five Point Gulch in Secs. 10 and 16, and offset of the Five Point channel in Sec. 21, T.19S., R.73W., are probably the result of right lateral high-angle faults with the up-thrown side to the north. Northeast faulting controls the major drainage along the northwestern area border and may be the dominant control of the Arkansas River near Texas Creek Junction.

Two major N-S fault zones have been mapped in Texas Creek and Five Point Gulch. The Texas Creek fault zone is several hundred yards wide at the Arkansas River and tapers to 50-200 feet wide two miles south. At the Arkansas River the zone consists of iron-stained crushed Idaho Springs gneisses and granite. Further south near the mouth of Thomas and Rito Gulches the zone consists of a number of N-S trending major faults with chloritized and iron-stained breccia in which granite monoliths up to 100 feet across are embedded. The attitude of all subsidiary faults is from N.20°E. to N.20°W. with dips of 80+° both east and west. Farther south near Rogers Gulch the fault is concealed by alluvium. The Texas Creek fault cuts both Pikes Peak and Red granites as well as a large carbonatite dike several

hundred yards south of the Arkansas River and is therefore established as being active in post-Precambrian time.

The Five Point Gulch fault zone is very complex and consists of at least four separate, distinguishable faults with associated brecciation and deformation. Its average trend is N-S to N.15°W. with a steep to vertical dip. The Echo Canyon graben north of the Arkansas River (Vian, 1965) is bounded by faults trending toward the mouth of Five Point Gulch. The faults of Five Point Gulch are high-angle faults with the east side probably up-thrown. Their control of the topography extends at least as far south as Sec. 10, T.19S., R.73W., and photogeologic evidence suggests this control persists almost to Road Gulch. The faults bounding the Echo Canyon graben have been described as having developed before volcanic activity with movement continuing during the deposition of pyroclastics (Vian, 1965). Similar faulting as in Bernard Creek has been described as block-faulting developed in response to the relaxation of Laramide compressive forces (Salotti, 1960), with the up-thrown side on the east. North-south to NW-trending faults and shear zones of the Tallahassee Creek area have been assigned to the Laramide Revolution (Shappirio, 1962), the result of east-directed lateral compressive forces.

In summary, faulting in the Lookout Mountain area is complex. Each of the three major fault sets--NS, NE, and NW--shows evidence of multiple activity. Northeast-trending faults developed under plutonic conditions during Precambrian time.

North-south and NW-trending high-angle faults developed under shallower conditions at a later time. Northwest-trending faults, because of their related drag effects and subordinate brecciation are considered to have developed under marginal plutonic conditions and probably earlier than the N-S faults. The prominent NW-trending fault near Spring Gulch parallels the "ancestral" Wet Mountain core and probably developed during up-lift of the Wet Mountains; either during the late Paleozoic Rocky Mountain or early in the Laramide Revolution. North-south faults were active during the Laramide Revolution and early Tertiary time during vulcanism at the center near Guffey.

Northeast-trending faults re-activated in late Tertiary to Recent time displaced both N-S and NW faults and are responsible for the majority of the structurally controlled geomorphic features.

ECONOMIC GEOLOGY

IRON MOUNTAIN MINE

The Iron Mountain Mine is within the McClure alkalic complex, about one mile southeast of Indian Springs Park (Sec. 3, T.20S., R.72W., location 1, Figure 1). It is the only operating mine in the region, and lies just outside the thesis area. The property was patented in 1872 (Singewald, 1913) when the Mining Law of 1872 was enacted by Congress, therefore it must have been developed earlier. Its ownership has changed several times, and the mine is now (1964) jointly owned by the Ellison family of Hillside and Adolph Poston of Canon City, Colorado. The only noteworthy production came in 1955, when ore was trucked to Canon City and hauled by rail to Texas by the Florence Aggregate Company for heavy concrete aggregate. At present (1964), ore is being sent to Kuwait for the same purpose, and a limited amount is being sold as colored aggregate in Canon City.

The ore consists of ultra-mafic segregations in a peridotitic phase of the McClure Mountain gabbro. The segregations are subparallel, discontinuous lenses and pods in the banded peridotite. They trend from N.25°E. to N.15°W. and dip steeply west (Becker, et al., 1961). Lenses crop out for about 2,200 feet along strike; the largest single segregation being 25 feet thick and over 400 feet long. The ore is massive Ti-magnetite with accessory ilmenite and spinel. Other common accessories--

minerals common in the surrounding peridotite--are labradorite (Ab_{37}), augite, biotite, and olivine. Partial analyses of the ore assay total iron up to 51% and up to 14% titania. Until recently the beneficiation of iron from ore containing more than 1-2% or less then 50-70% titania was not economic. At present, processes are available to treat such ores, but unfortunately the Iron Mountain mine has only a limited ore reserve (Becker, et al., 1961).

RARE-EARTH PEGMATITES

JIM 3 MINE

The Jim 3 Mine is the largest of the Lookout Mountain rare-earth properties. It is situated in Sec. 27, T.19S., R.73W., on the east fork of upper Five Point Gulch. The claims on which the Jim 3 is situated are not patented but were first developed by G. C. Addey (Canon City, Colorado) in 1953. Addey leased the prospect to Minerals Refining Company of Salt Lake City, Utah, in 1954, who worked the mine for approximately one year while trying unsuccessfully to develop an economic flow-sheet for beneficiation. Since then Addey has continued development work on underground workings and surface pits--stockpiling muscovite and samarskite. At present, the underground workings consist of about 250 feet of 7 x 8 foot or larger drifts and one stope of unknown dimensions. Most of the

workings are in good condition, with minor sluffing from untimbered areas and the raise into the stope.

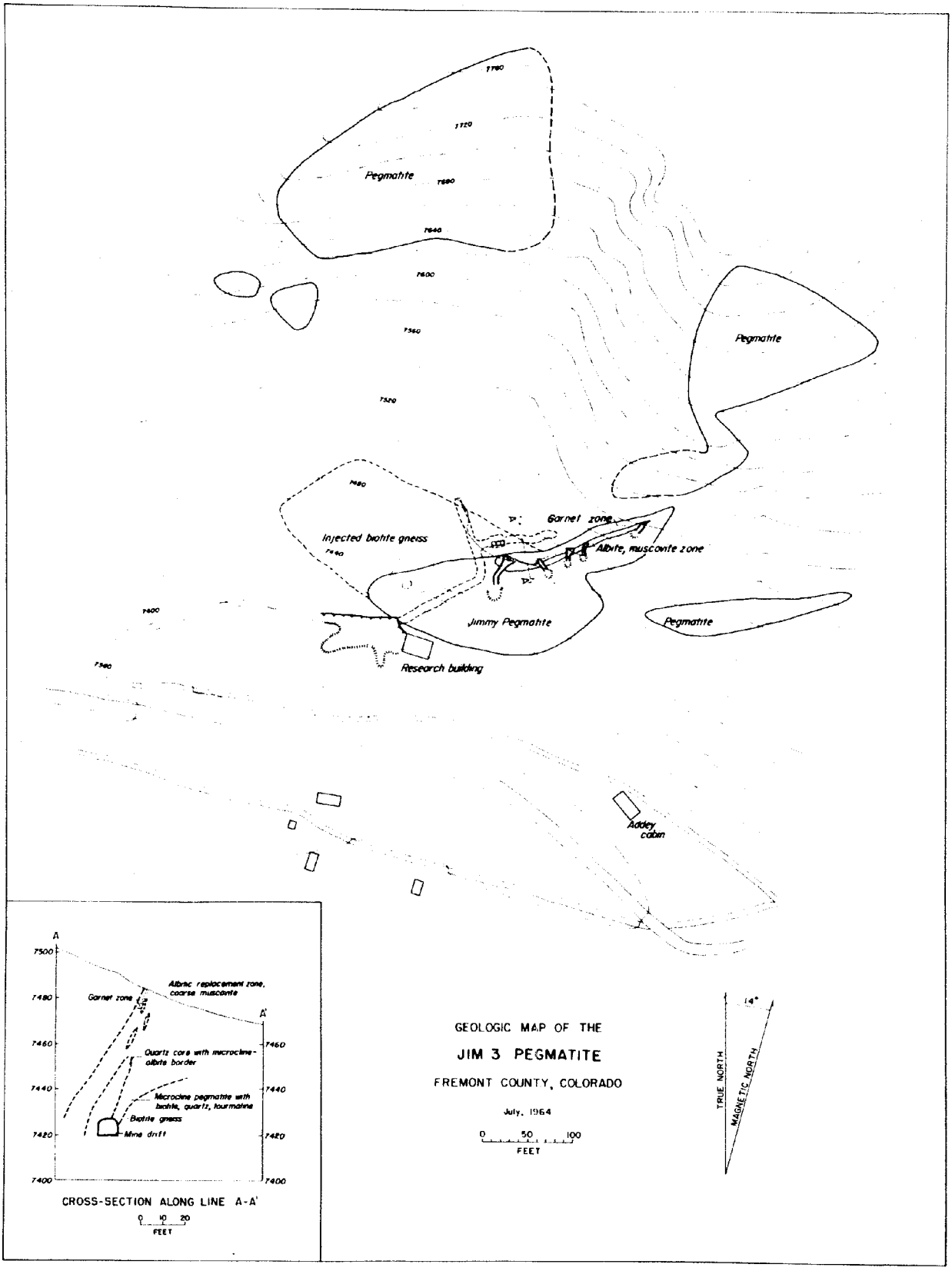
The pegmatite in which the Jim 3 Mine is developed is only one of a number of similar dikes intruding the Idaho Springs biotite gneiss in this area (Figure 36). The Jim 3 pegmatite is about 300 feet long in outcrop trending approximately N.70°E. and dipping 65°NW. As seen in the underground workings the pegmatite has at least two keels or a large roll near its keel. Biotite gneiss within 10 feet of the contacts is deformed and highly injected.

The Jim 3 pegmatite exhibits complex structure (Figure 37) with the following well-developed zones:

1. Wall-zone--aplitic
2. Intermediate zone--coarse-grained microcline-quartz
3. Core--quartz
4. Cleavelandite--core-margin replacement unit
5. Muscovite-tourmaline--core-margin replacement unit.

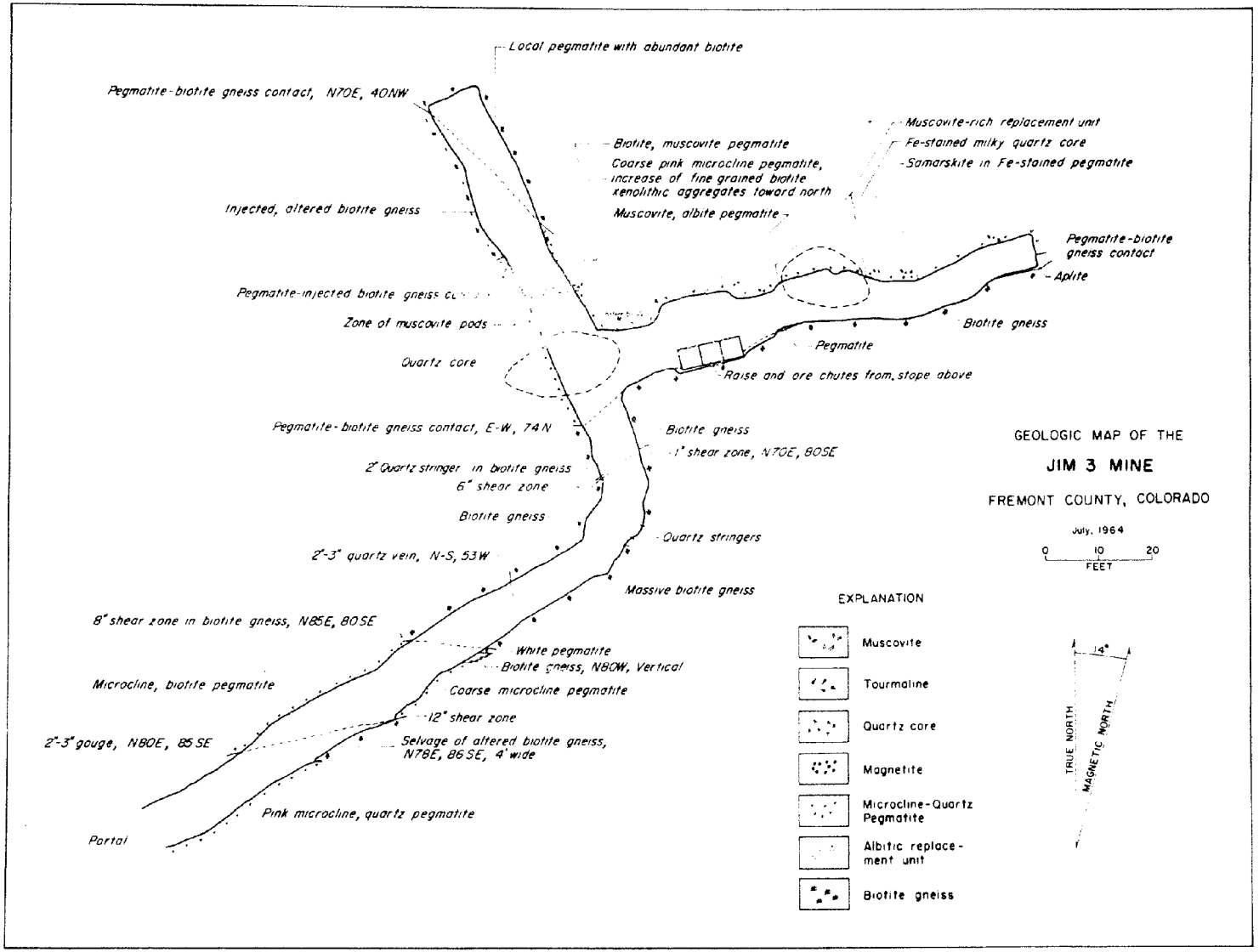
The aplitic wall-zone is exposed both in outcrop and at the end of the eastern drift. It is not thick (from 1 to 3 feet) and does not envelope the entire pegmatite. It consists of equigranular albite, microcline, and quartz with accessory biotite and magnetite, and some xenolithic biotite from the surrounding wall-rocks. Garnet is abundant in outcrop within several feet of the northern pegmatite contact both at the surface and in the mine workings. The bulk of the pegmatite consists of coarse pink or white microcline with intergrown quartz, commonly occurring as well-defined pods. Mine workings transect two quartz pods, each on the order of 10 feet in diameter.

Figure 36. Geologic map of the Jim 3 pegmatite, Sec. 28, T.19S., R.73W.



MAPPED BY D. H. DAHLEM

Figure 37. Underground mine map of the Jim 3 pegmatite, Sec. 28, T.19S., R.73W.



MAPPED BY D. H. DAHLEM

The core-margin replacement unit consists of cleavelandite replacing microcline of the intermediate zone with the addition of variable amounts of tourmaline and muscovite. In addition to widespread fine-grained muscovite, a 1½-foot zone of coarse muscovite pods occurs about 10 feet north of the western quartz core. Here muscovite books range up to 8 inches across in a matrix of albite containing abundant tourmaline and fine-grained biotite. Rare books of muscovite up to 10 inches across occur in the western quartz core.

The eastern quartz core and surrounding replacement unit are iron-stained and it is within these units that the only samarskite was found "in place". From material on the mine dump and prospect pits along the upper part of the pegmatite, samarskite is seen to be intergrown with biotite and muscovite in cleavelandite of the core margin replacement unit. It occurs as tablets from less than 1/8-inch long to rare spectacular specimens 4-5 inches across. Hanley et al. (1950) have shown that along with samarskite, cerite, euxenite, monazite, and allanite are also present in rare-earth-bearing pegmatites of the region.

Several small exploratory pits have been opened at the top of the pegmatite outcrop which expose parts of the samarskite-bearing replacement unit. Beryl, not found elsewhere in the pegmatite, has been found in these pits. It is in these pits that Addey indicates further development will take place. Unless extensions of the samarskite-bearing secondary unit are found

either up or down the plunge of the pegmatite, the Jim 3 pegmatite will probably not produce more than specimens of interest to the mineral collector.

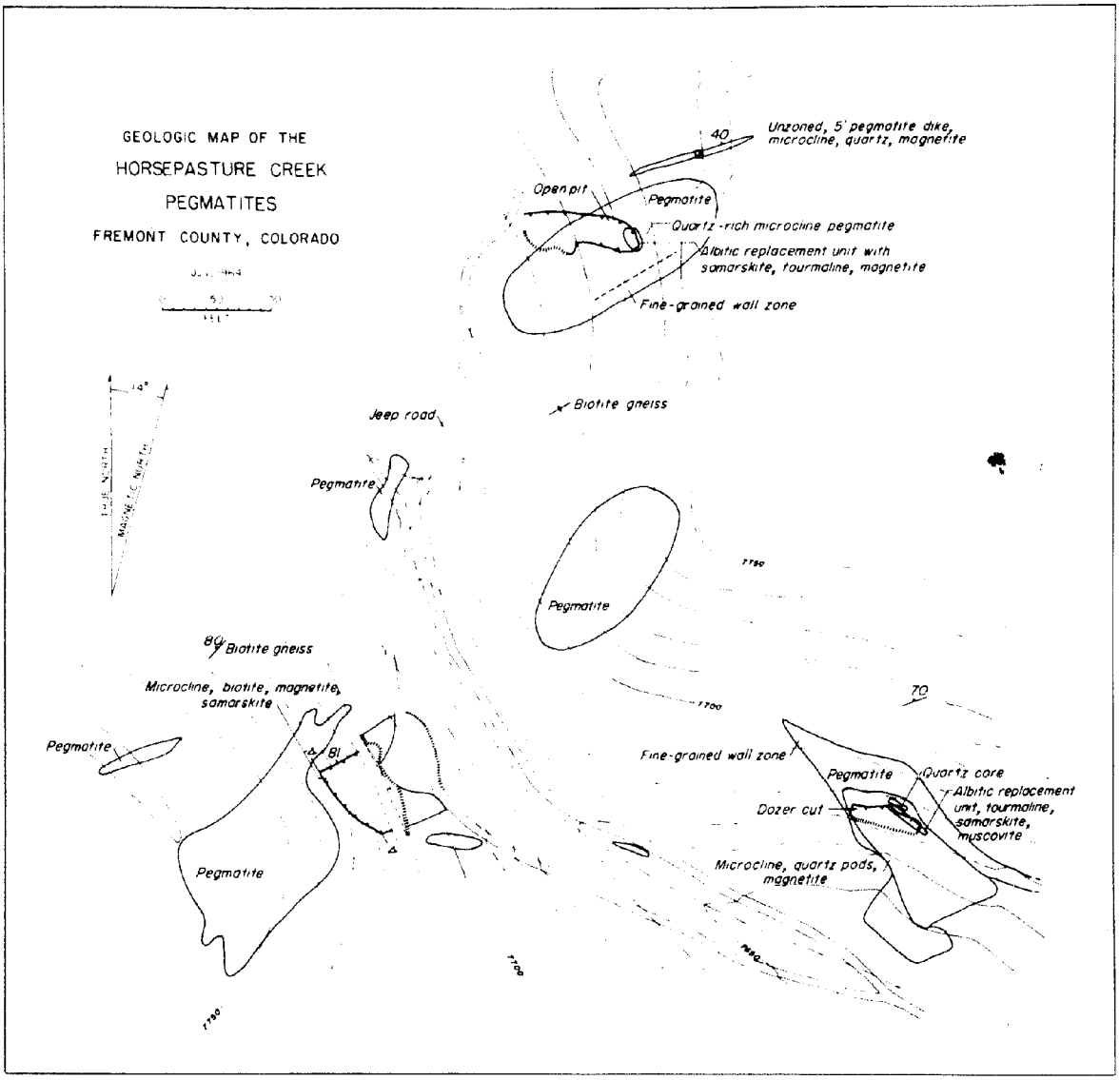
HORSEPASTURE PEGMATITES

The Horsepasture pegmatites are one-half mile north of the Jim 3 Mine (Sec. 23, T.19S., R.73W.) and can be reached by a jeep road up Horsepasture Gulch from its junction with the east fork of Five Point Gulch. Four separate pegmatites have been worked--the southwest pit most extensively (Figure 38). According to G. C. Addey, these pegmatites were developed for their feldspar content prior to 1945.

The Horsepasture pegmatites are similar to the Jim 3 in most respects. They have been intruded into granite-injected biotite gneiss, are dikes, but although zoning is present, it is not so regularly developed as in the Jim 3 pegmatite.

The southwest pegmatite is the largest--250 feet long--and appears to be tabular with a trend of N.30°E., dipping southwest. It is bounded on the northwest by a steep fault trending N.62°E., and dipping 81°NW. The open-pit has stripped through the gneissic overburden. The pegmatite consists of a thin aplitic wall-zone which gives way to an intermediate zone of coarse microcline and quartz, with accessory biotite and magnetite. Microcline is extremely coarse grained, some individuals exceeding 2 feet in diameter, and is commonly graphically intergrown with quartz. Quartz may be milky or smoky and three small

Figure 38. Geologic map of the Horsepasture pegmatite, Sec. 27, T.19S., R.73W.



MAPPED BY D. H. DAHLEM

pods form the pegmatite core (Figure 39). Cleavelandite replacing microcline of the intermediate zone crops out near the center of the pit and contains, in addition, coarse muscovite, tourmaline, samarskite, and magnetite. Biotite also occurs in a later generation as fracture-controlled plates up to 12 inches across.

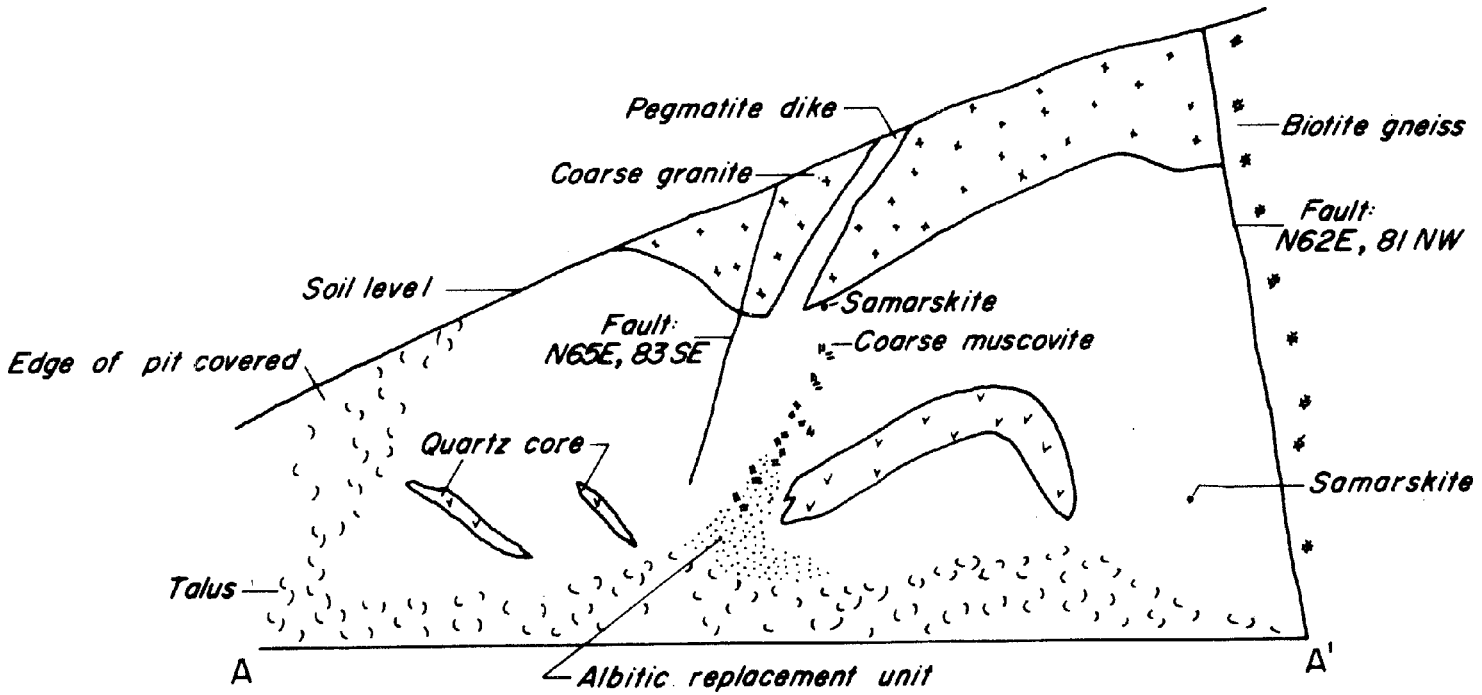
The southeast pit is much smaller but the pegmatite is more distinctly zoned. The wall-zone, exposed along the north and south sides of the dike, is aplitic and gives way to an intermediate zone of coarse microcline containing quartz pods and abundant magnetite. A bulldozer cut transects several small quartz cores around which an irregular albitic replacement unit containing tourmaline, quartz, and samarskite is disposed.

The two northern workings are similar, though the one furthest north is an unzoned dike 5 feet thick. Samarskite occurs in both pegmatites, associated with biotite and/or cleavelandite.

MISCELLANEOUS RARE-EARTH PEGMATITES

In the vicinity of the Jim 3 Mine a number of small pegmatites have been opened on the basis of their radioactivity. Among these are the Jim 8 and the Ilmenite. The Jim 8 pegmatite is at the mouth of Horsepasture Gulch. Its workings consist of a 10-foot starter-shaft and some general bulldozer stripping of the surrounding colluvium. The pegmatite consists of an unzoned, iron-stained pegmatitic granite dike from

Figure 39. Cross-section of the southwest Horsepasture pegmatite, Sec. 27, T.19S., R.73W.



GEOLOGIC CROSS-SECTION ALONG LINE A-A'

SOUTHWEST HORSEPASTURE PEGMATITE

July, 1964

0 5 10

FEET

MAPPED BY D. H. DAHLEN

which xenotime and monazite have been identified (Heinrich, personal communication). According to G. C. Addey, one truck-load of ore was shipped to Canon City by him and Jose Medford (Canon City, Colorado) for its feldspar content. Inspection of dump material and examination of two thin-sections disclosed no rare-earth minerals.

The Ilmenite pegmatite is immediately west at the mouth of Goldie Gulch. The pegmatite consists primarily of microcline and quartz with scattered pods of ilmenite and accessory samarskite and tourmaline. The samarskite occurs as small tabular crystals in quartz or microcline, not specifically associated with any other mafic species.

MICA AND FELDSPAR PEGMATITES

Several pegmatites of the Lookout Mountain area, believed related to the Pikes Peak granite, have been of commercial interest for their feldspar and scrap mica content. Hanley et al. (1950) have described the Spikebuck feldspar mine (Secs. 27 and 28, T.18S., R.72W.) as a potential potash feldspar source. The pegmatite is zoned, over 800 feet long and consists of at least 40% coarse, blocky microcline, and in addition would yield by-product muscovite.

Landes (1935) has described a pegmatite high on the south Arkansas River canyon rim (Sec. 26, T.18S., R.73W.) which he suggests is a multiple lit-par-lit injection in Idaho Springs mica schist. The pegmatite is unzoned, consisting predominantly

of microcline and quartz with subordinate mica. At one time the pegmatite was mined by a 500-foot adit and the feldspar ore trammed to a station on the Arkansas River below.

Sheet mica is a rarity in the Lookout Mountain area, but scrap mica is common. A pegmatite developed by Adolph Poston (Sec. 13, T.19S., R.73W.) has been exploited for scrap mica, which occurs both in a core margin replacement unit and in a muscovitized corona of country-rock gneisses. To date, the small production (25-30 tons) has been stockpiled.

THORIUM PROSPECTS

Thorium deposits of the Lookout Mountain area are a part of the Wet Mountain thorium province described by Christman et al. (1953) and Christman et al. (1959). Conclusions from their studies are that thorium mineralization is associated with NW-trending shear zones, commonly containing feldspar-barite-sulfide veins post-dating associated basic dikes (probably lamprophyres). The most characteristic feature of the thorium-bearing zones is abundant hematite introduced into both vein and wall-rocks. Two deposits were described in these previous reports--the Dreamers Hope and Homestake--which have, in this study, been called carbonatites. In addition, the June, Klondike, Alice group (Sec. 8, T.20S., R.73W.), and unnamed, smaller dikes immediately south of the leucodiorite (Sec. 3, T.20S., R.73W., Plate 1) are of this general character. With the

exception of the Alice dikes, all contain abundant hematite staining and feldspathic introduction into the wall-rocks.

In general the thorium mineralization of the Lookout Mountain area is associated with hematitized carbonate-barite-sulfide veins or dikes. At the Dreamers Hope, carbonate pre-dates the hematite-feldspar introduction. However, in the bastnäsite-bearing carbonate dikes south of the leucodiorite, bastnäsite occurs in a hematitic carbonate part of the dike which is intruded by the major carbonatite.

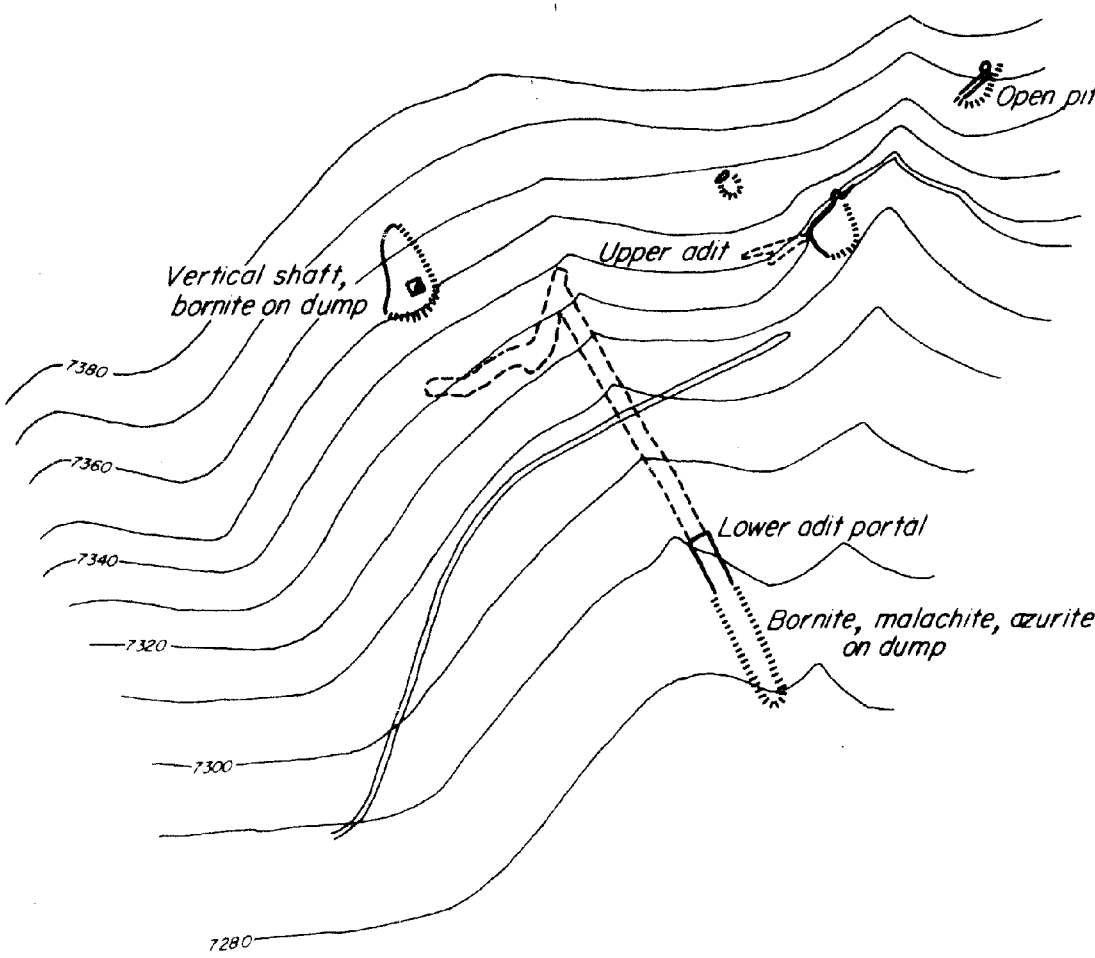
MISCELLANEOUS DEPOSITS

LEEKS LODE

Leeks Lode is one of several mineralized pegmatites along Washtub Gulch, so named for its occurrence on the property of Max E. Leek of Pueblo, Colorado (Secs. 5 and 9, T.19S., R.72W.). The mine (Figure 40) consists of approximately 180 feet of adits and drift, a shaft approximately 60-80 feet deep, and two small open-pits. The east and west adits (Figure 41) were driven in the pegmatite, and to intersect the pegmatite at depth, respectively. The shaft was sunk in the hanging-wall of the dike.

The pegmatite consists of a 5-10-foot sill and numerous smaller parallel bodies in mica schist country-rock. Limited gossan with malachite and azurite are exposed at the surface both in the pegmatite and mica schist. At depth, bornite, chalcopyrite, chalcocite (?), and pyrite are disseminated in

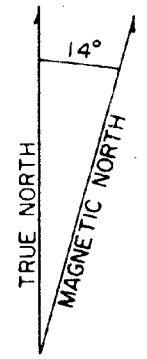
Figure 40. Geologic map of Leeks Lode copper prospect, Sec. 5, T.19S., R.72W.



GEOLOGIC MAP OF
LEEKS' LODE
FREMONT COUNTY, COLORADO

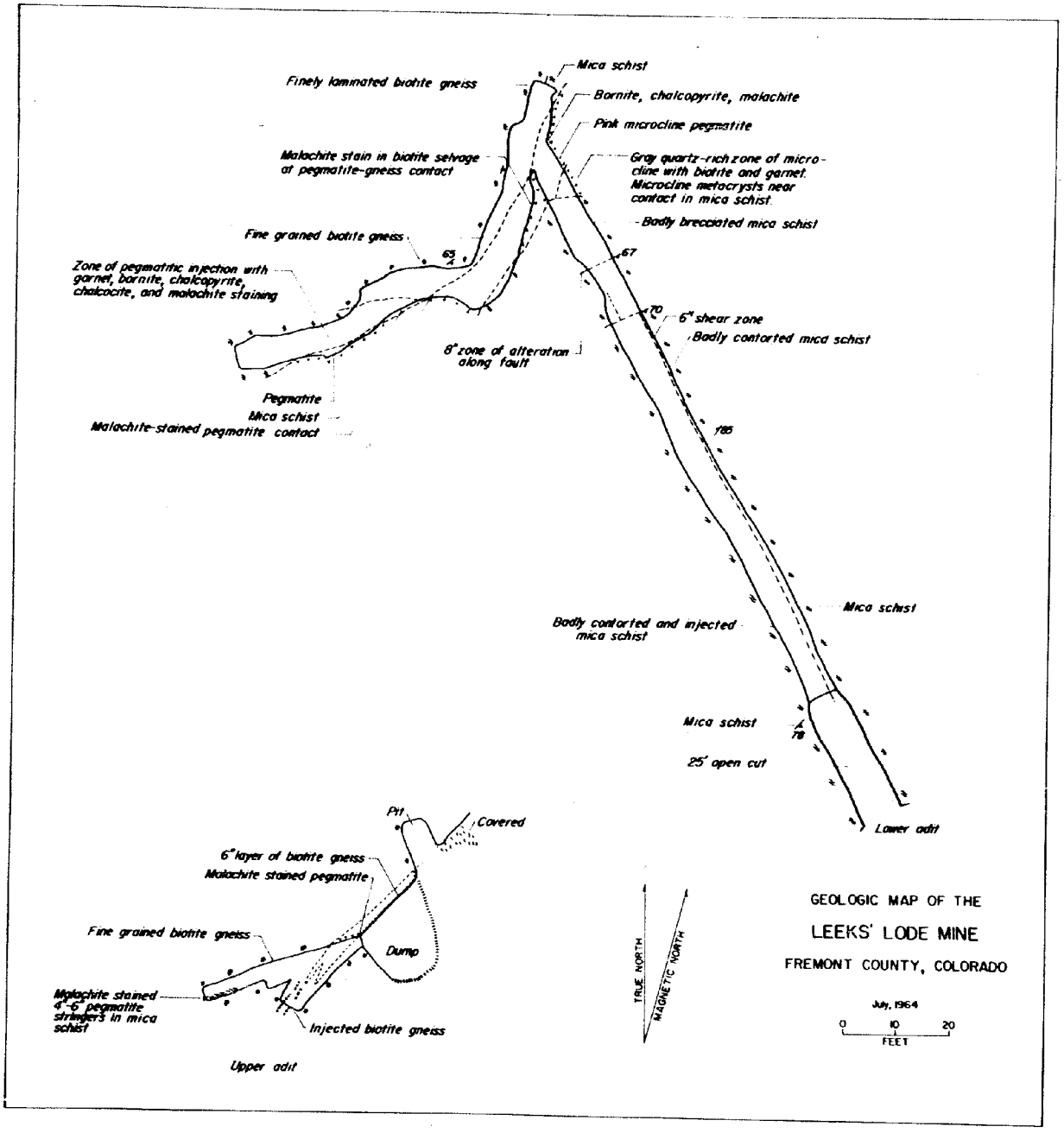
July, 1964

0 50 100
FEET



MAPPED BY D. H. DAHLEM

Figure 41. Underground mine map of Leeks Lode copper prospect, Sec. 5, T.19S., R.72W.



MAPPED BY D. H. DAHLEM

the pegmatite. The most common gangue minerals are microcline, quartz, garnet, biotite, and magnetite of the pegmatite. The sulfide-bearing ore-shoots are discontinuous lenses rarely more than 1 foot wide and 1½ to 2 feet long commonly surrounded by a corona of carbonate alteration products which may persist where the pegmatite or mica schist is barren of sulfides.

In Sec. 30, T.18S., R.72W. a similar occurrence has been developed by open-pit. Bornite and chalcopyrite from hydrothermal mineralization in a pegmatite have been stockpiled but the pegmatite appears to have been entirely mined out.

GREEN DOVE

Epidotized rocks are widespread in the southern part of the Lookout Mountain area and have been developed from two sources as follows: 1) replacement of the granites and gneisses by deuteric fluids from the Silver Plume "type" granite, and 2) as part of the metamorphosed calcareous metasediments in the Idaho Springs formation. Several discovery pits have been dug on both types of epidote rock, the largest of which is the Green Dove prospect in Sec. 4, T.20S., R.73W.

The Green Dove I, II, and III claims were staked by D. L. Banks, Q. Barnes, and J. Wadsworth, and accessment work was continued until 1963. The main pit is 12 x 20 feet, around which "ore" has been stockpiled. The epidote rock consists of 90% epidote minerals (pistacite and clinozoisite) in a subordinate

matrix of plagioclase and accessory sphene, magnetite, and carbonate.

Epidote rock from this and other small quarries in the area has been marketed in Florence as colored aggregate.

GEOLOGIC HISTORY AND SUMMARY

Rocks underlying the Lookout Mountain-Five Point Gulch area are a part of the Precambrian belt extending from Wyoming, through the core of the Front Range to the southern tip of the Wet Mountains. Paleozoic and Mesozoic sediments are overturned and lie in fault contact against this metamorphic core on both east and west and are exposed within the belt only in rare graben. The metamorphic core consists of paragneisses and schists of the Idaho Springs formation which, in the southern Front Range, have been subjected to two stages of Precambrian batholithic intrusion. The most southerly pluton is the Pikes Peak batholith which extends south of Eight-Mile Park.

The Wet Mountain alkalic province consists of three plutonic complexes of late Precambrian age. The largest of these--the McClure Mountain complex--lies near the southeast corner of the Lookout Mountain area and satellitic bodies and peripheral effects extend as far north as the Arkansas River at Texas Creek Junction. The Wet Mountain thorium province covers an area of approximately 400 square miles extending from Rosita to Lookout Mountain and is essentially co-extensive with the alkalic province.

Pyroclastics related to Tertiary vulcanism near Thirtymine Mile Mountain crop out from South Park to the Arkansas River with important remnants south of Cotopaxi and near Hillside in the Wet Mountain Valley.

The original sediment from which the Idaho Springs formation was derived was a fine-grained cyclic sediment deposited in a large basin or trough. The source area was predominantly granitic and of low relief and the sediment was predominantly feldspathic-siliceous with local impure calcareous and pelitic facies. Deposition took place in water far enough from shore that sorting was not complete, but not so far that banding resulting from the seasonal erosional variation was absent. A shelf depositional environment is suggested by the alternating clastic and calcareous layering, and the extreme thickness is suggestive of sediments in the present day Gulf Coast geosyncline or the late-Precambrian Beltian geosyncline of the northern Rocky Mountains.

Basic flows or sills and dikes were emplaced either during sedimentation or shortly after, and this sedimentary-igneous assemblage was transformed to a series of gneisses and schists. The most common assemblage developed was quartz-oligoclase ±microcline-biotite gneiss with interlaminated hornblende gneiss and amphibolite developing from the original calcareous and mafic igneous parts of the assemblage.

Subsequent to the metamorphism of the Idaho Springs rocks of the Lookout Mountain area a long interval preceded granite intrusion during which thick sedimentary assemblages were deposited in nearby areas. Leucodiorite, because of its foliate character was intruded possibly syntectonically during the latter stages of Idaho Springs metamorphism. The diorite of

Sheep Basin appears to have been intruded later, probably immediately preceding granite emplacement, and may represent an early mafic phase of the batholithic cycle.

Following a period of tectonic quiescence, the Idaho Springs metasediments were deformed and subjected to a pervasive metasomatism, vanguard of the first stage of batholithic intrusion. The Boulder Creek granodiorite-tonalite invaded the Idaho Springs gneisses closely followed by the major (Pikes Peak) batholithic intrusion at approximately 1350-70 m.y.--both under catazone-mesozone (Buddington, 1959) conditions. In the Lookout Mountain area small satellitic bodies at the mouth of Road Gulch and east of Texas Creek Junction were emplaced. Intrusion began by lit-par-lit injection, continuing into injection gneiss, the pluton finally shouldering aside the metasediments. Toward the end of the tectonic cycle, approximately 50 m.y. later, Silver Plume "type" and Red granite were intruded in that order under mesozonal conditions.

Quartz and potash feldspar were added to the Idaho Springs gneisses to some extent during each stage of granite intrusion, though by far the most voluminous additions were contributed during the catazone phase. Residual solutions segregated during the terminal stages of Boulder Creek granite crystallization gave rise to metasomatic sillimanite in the Idaho Springs gneisses and abundant marginal ptygmatic pegmatites. Solutions concentrated during the Pikes Peak phase gave rise to muscovitization of sillimanite and potash feldspar and massive pegmatites with

associated aplitic dikes. Peripheral effects of the Silver Plume "type" granite are local, but Red granite injection-gneiss and late Red aplitic dikes are important.

Migmatite of the Lookout Mountain area is then a complex mixture of Idaho Springs gneiss and quartzofeldspathic material related to several different stages of granitic intrusion.

After the period of granite emplacement diabase dikes were intruded into the granite-gneiss Precambrian complex. A diabase dike in Baker Gulch is cut by a lamprophyre, clearly demonstrating the earlier age of the diabase.

The McClure Mountain-Iron Mountain complex was probably intruded in late-Precambrian time. Gabbro was first introduced at sufficient depth for the differentiation of Ti-magnetite, anorthosite, and peridotite lenses and layers to take place. Syenite was next, followed by ijolite and nepheline syenite. These four units, together make up the plutonic core of the complex which is cut by numerous alkalic dikes. The first alkalic dikes were probably olivine gabbro-lherzolite dikes which were intruded at approximately the same time as the gabbro stock. Nepheline syenite dikes post-date the nepheline syenite stock and are followed by lamprophyre and trachyte dikes. Most of the lamprophyres are spessartites. In general, the dikes are leucocratic within the complex but melanocratic outside and most numerous within two miles of the complex margin.

The Pinon explosion breccia pipe developed after lamprophyre intrusion in the granite-gneiss complex. It consists

predominantly of granite and gneiss fragments with little matrix material, but interstitial crocidolite, aegirine, and albite demonstrate its alkalic affinity.

Carbonatites were the last dikes to develop in the alkalic series, later even than the lamprophyres.

Faulting in the Lookout Mountain area cannot be dated more exactly than post Precambrian. Graben blocks in which Paleozoic and Mesozoic sediments are exposed in Echo Canyon and Webster Park are bounded by Laramide faults similar in trend to the major faults of the Lookout Mountain area.

Pyroclastic deposits are correlated with Oligocene tuffs of the Thirtynine Mile volcanic series north near Guffey. These welded tuffs were extruded onto an erosional surface which had developed on Precambrian granite and gneiss. Since extrusion, erosion has stripped all but a few small outcrops of volcanics in the area south of the Arkansas River and north of Lookout Mountain.

Travertine and calcite-cemented gravels are localized near the north-south Texas Creek fault zone and probably represent continued movement of the "Laramide" faults into Quaternary time.

REFERENCES

Ball, S. H. (1906) Precambrian rocks of the Georgetown Quadrangle, Colorado. Am. Jour. Sci. 4th ser., 125, 371-389.

Becker, R. M., S. S. Shannon and C. K. Rose (1961) Iron Mountain titaniferous magnetite deposits, Fremont County, Colorado. U. S. Bur. Mines R. I. 5864.

Bever, J. E. (1954) Geology of the Guffey area, Colorado. Ph.D. dissertation, University of Michigan.

Boos, M. F. and C. M. Boos (1957) Tectonics of the eastern flank and foothills of the Front Range, Colorado. Am. Assoc. Pet. Geol. Bull. 41, 2603-2676.

Boyer, Robert E. (1959) Geology of the Southern Wet Mountains, Colorado. Ph.D. dissertation, University of Michigan.

Braddock, W. A. (1964) Geological Survey Research 1964, U. S. Geol. Survey Prof. Paper 501, A94.

Buckwalter, T. V., Jr. (1950) Geology of the Never Summer Mountains, Colorado. Ph.D. dissertation, University of Michigan.

Buddington, A. F. (1959) Granite emplacement with special reference to North America. Geol. Soc. Am. Bull. 70, 671-747.

Burbank, W. S. and E. N. Goddard (1937) Thrusting in Huerfano Park, Colorado, and related problems of orogeny in the Sangre de Cristo Mountains. Geol. Soc. Am. Bull. 48, 931-976.

Campbell, M. R. (1922) Guidebook of the Western United States. U. S. Geol. Survey Bull. 707, 80.

Chapin, C. E. and R. C. Epis (1964) Some stratigraphic and structural features of the Thirtynine Mile volcanic field, central Colorado. The Mountain Geologist 1, 145-160.

Christman, R. A., M. R. Brock, R. C. Pearson and Q. D. Singewald (1959) Geology and thorium deposits of the Wet Mountains, Colorado, a progress report. U. S. Geol. Survey Bull. 1072-H, 491-535.

_____ A. M. Heyman, L. F. Dellwig and G. B. Gott (1953) Thorium investigations 1950-52, Wet Mountains, Colorado. U. S. Geol. Survey Circ. 290.

Chronic, John (1960) Geology of southcentral Colorado. Guide to the Geology of Colorado, Rocky Mountain Assoc. Geol., p. 115.

Cross, W. (1893) On a series of peculiar schists near Salida, Colorado. Proc. Colorado Sci. Soc. 4, 286-293.

_____ (1896) Geology of Silver Cliff and the Rosita Hills, Colorado. U. S. Geol. Survey Ann. Report 17, 272-273.

Eardley, A. J. (1962) Structural Geology of North America. Harper-Row, New York, pp. 28, 390, 394, 395.

Endlich, F. M. (1874) Report upon the geology of the San Luis District. U. S. Geol. and Geog. Survey Terr., 7th Ann. Report, 305-351.

Francis, G. H. (1956) Facies boundaries in pelites of the middle grades of regional metamorphism. Geol. Mag. 93, 353-368.

Friedman, G. M. (1959) Identification of carbonate minerals by staining methods. Jour. Sed. Pet. 29, 87-97.

Gabelman, John W. (1952) Structure and origin of Northern Sangre de Cristo Range, Colorado. Am. Assoc. Pet. Geol. Bull. 36, 1574-1612.

Gross, E. B. (1962) Alkalic granites and pegmatites of the Mount Rosa area, El Paso and Teller Counties, Colorado. Ph.D. dissertation, University of Michigan.

Hanley, J. B., E. Wm. Heinrich and L. R. Page (1950) Pegmatite investigations in Colorado, Wyoming, and Utah, 1942-44. U. S. Geol. Survey Prof. Paper 227.

Harker, Alfred (1950) Metamorphism. Methuen, London, p. 246.

Harrison, J. E. and D. A. Jobin (1963) Geology of the Clark Fork Quadrangle Idaho-Montana, U. S. Geol. Survey Bull. 1141-K, 38.

Heinrich, E. Wm. (1948) Pegmatites of Eight-Mile Park, Fremont County, Colorado. Am. Mineral. 33, 420-448, 550-588.

_____ (1958) Mineralogy and Geology of Radioactive Raw Materials, McGraw-Hill, New York, pp. 353-355.

_____ and D. H. Dahlem (1965) Carbonatites and alkalic rocks of the Arkansas River area, Fremont County, Colorado. Inter. Mineral. Assoc. 4th Gen. Meet. India Carbonatite Symp. (in press).

Heinrich, E. Wm. and Shi H. Quon (1963) New type of deposit of alumino-fluoride minerals from Fremont County, Colorado (abs.). Geol. Soc. Am. Spec. Paper 73, 169.

Landes, K. K. (1935) Colorado pegmatites. Am. Mineral. 20, 319-333.

Lovering, T. S. (1929) Geologic history of the Front Range, Colorado. Proc. Colorado Sci. Soc. 12, 59-111.

_____ (1935) Geology and ore deposits of the Montezuma Quadrangle, Colorado. U. S. Geol. Survey Prof. Paper 178.

_____ and E. N. Goddard (1950) Geology and ore deposits of the Front Range, Colorado. U. S. Geol. Survey Prof. Paper 223.

Mathews, E. B. (1894) The granites of Pikes Peak, Colorado. Geol. Soc. Am. Bull. 6, 471-473.

_____ (1900) The granitic rocks of the Pikes Peak Quadrangle. Jour. Geol. 8, 214-240.

Moench, R. H., J. E. Harrison and P. K. Sims (1962) Precambrian folding in the Idaho Springs-Central City area, Front Range, Colorado. Geol. Soc. Am. Bull. 73, 35-58.

Noble, J. A. and J. O. Harder (1948) Stratigraphy and metamorphism in a part of the northern Black Hills and the Homestake Mine, Lead, South Dakota. Geol. Soc. Am. Bull. 59, 941-976.

Nolan, Thomas B. (1964) Geological Survey Research 1964. U. S. Geol. Survey Prof. Paper 501-A.

Parker, R. L., J. W. Adams and F. A. Hildebrand (1962) A rare sodium niobate mineral from Colorado. U. S. Geol. Survey Prof. Paper 450-C, C4-C6.

_____ and F. A. Hildebrand (1962) Preliminary report on alkalic intrusive rocks in the northern Wet Mountains, Colorado. U. S. Geol. Survey Prof. Paper 450-E, E8-E10.

Pettijohn, F. J. (1960) Sedimentary Rocks. Harper and Brothers, New York, p. 106.

Salotti, C. A. (1960) Geology and petrology of the Cotopaxi-Howard area, Fremont County, Colorado. Ph.D. dissertation, University of Michigan.

Seager, G. F. (1944) Gold, arsenic, and tungsten deposits of the Jardine-Crevasse Mountain district, Park County, Montana. Montana Bur. Mines Geol. Memoir 23.

Shappirio, J. R. (1962) Geology and petrology of the Tallahassee Creek area, Fremont County, Colorado. Ph.D. dissertation, University of Michigan.

Singewald, J. T. (1913) Titaniferous iron ore in the United States. U. S. Bur. Mines Bull. 64, 128-135.

Singewald, Q. D. (1963) Geological Survey Research 1963. U. S. Geol. Survey Prof. Paper 475-A, A86.

_____ and M. R. Brock (1956) Thorium deposits in the Wet Mountains, Colorado. U. S. Geol. Survey Prof. Paper 300, 581-585.

_____ and others (1955) Geologic and radiometric maps of the McKinley Mountain area, Wet Mountains, Colorado. U. S. Geol. Survey Mineral Invest. Field Studies Map 37.

Snively, Norman (1948) Genesis of the migmatites and associated Precambrian formations near Bergen Park, Colorado Front Range. Ph.D. dissertation, University of Michigan.

Spurr, J. E., H. Garrey and S. H. Ball (1908) Economic Geology of the Georgetown Quadrangle, Colorado. U. S. Geol. Survey Prof. Paper 63.

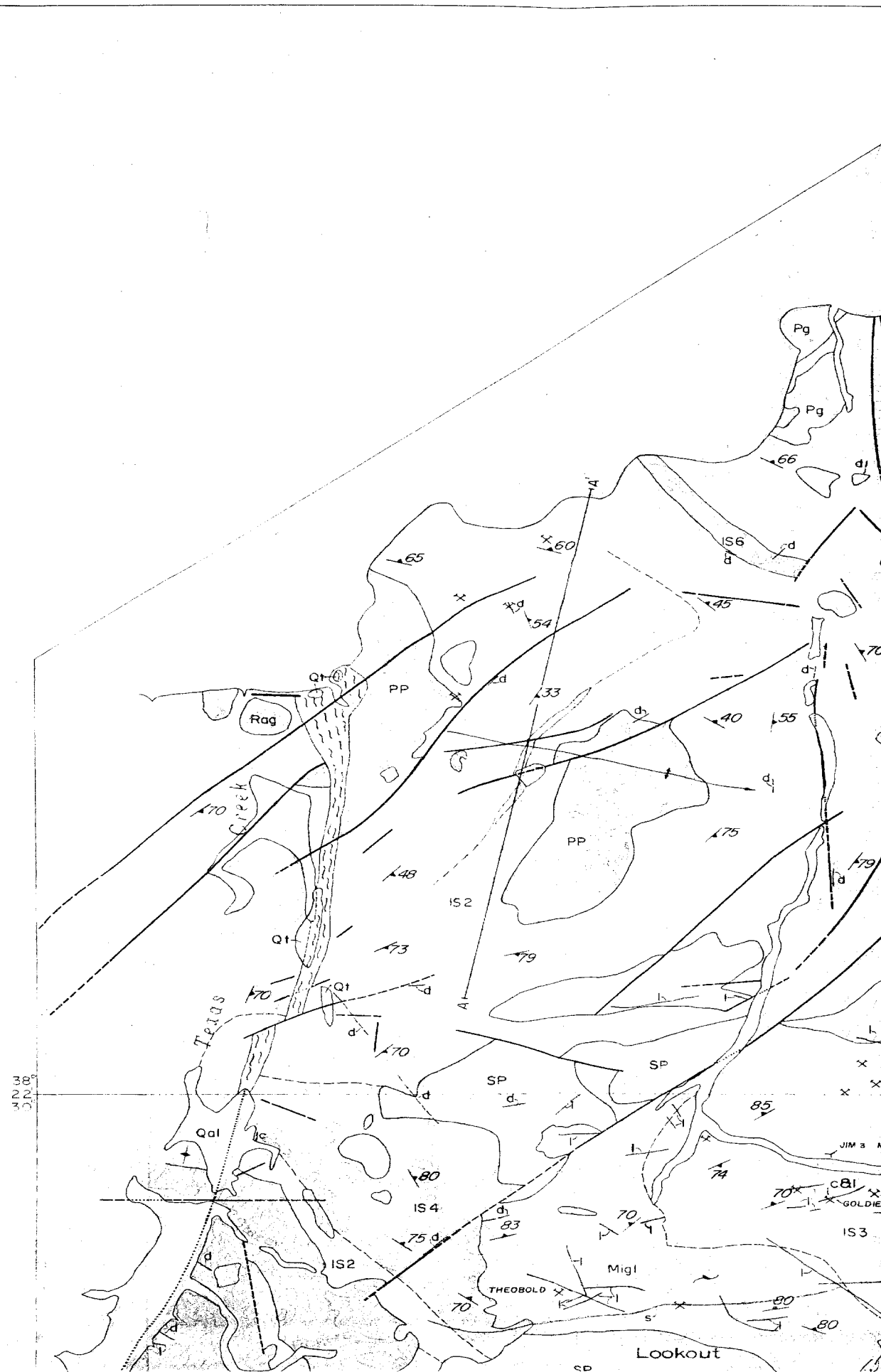
Stark, J. T., J. H. Johnson, C. H. Behre, Jr., W. E. Powers, A. L. Howland, Don B. Gould, and others (1949) Geology and origin of South Park, Colorado. Geol. Soc. Am. Mem. 33, 17-19.

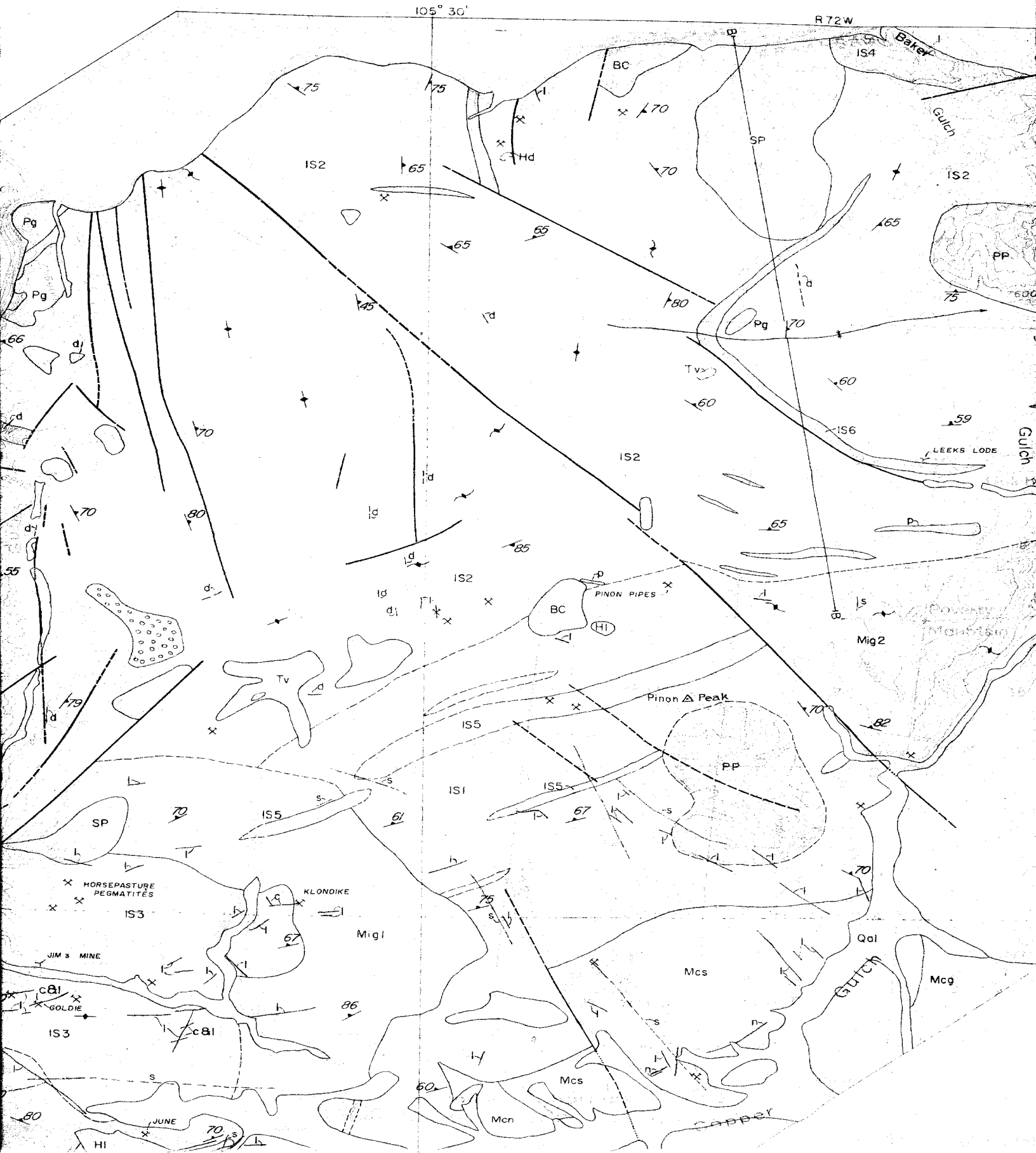
Travis, R. B. (1956) Note on large cordierite porphyroblasts, Fremont County, Colorado. Am. Mineral. 41, 796-799.

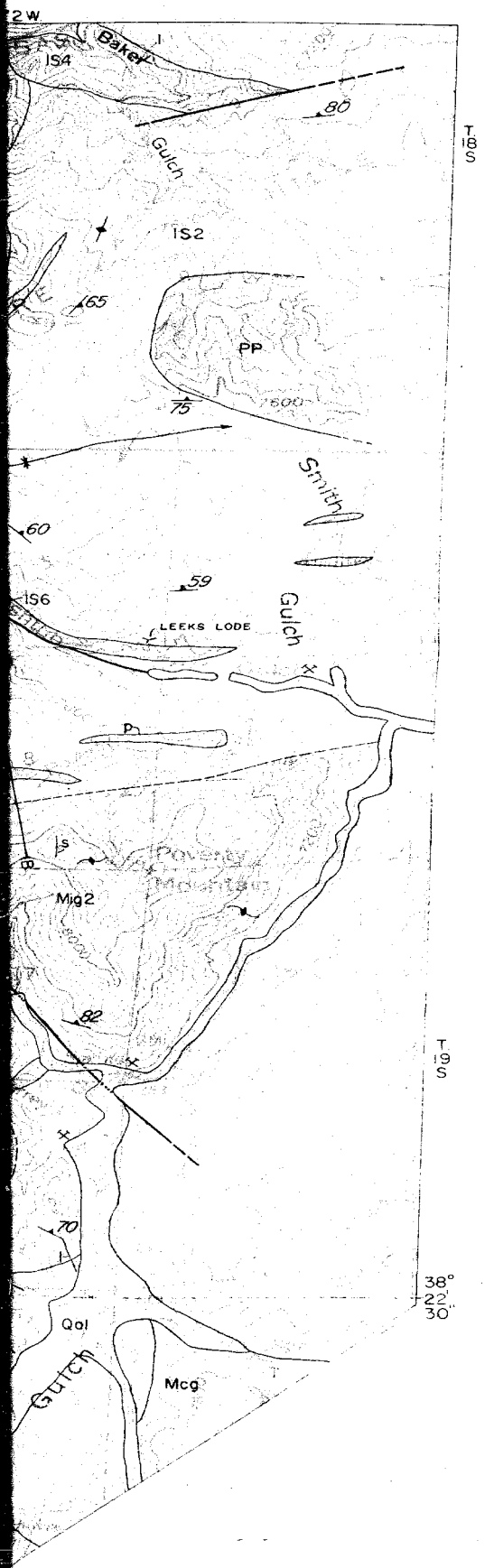
Turner, Francis J. and John Verhoogen (1960) Igneous and Metamorphic Petrology. McGraw-Hill, New York, p. 544.

Vian, R. W. (1965) Geology of the Devil's Hole area, Fremont County, Colorado. Ph.D. dissertation, University of Michigan.

Wells, J. D., Douglas M. Sheridan and Arden J. Albee (1964) Relationship of Precambrian quartzite-schist sequence along Coal Creek to Idaho Springs Formation, Front Range, Colorado. U. S. Geol. Survey Prof. Paper 454-O.


Pg
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Creek
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Lookout
SP


105° 30'
R 72 W
Baker
Gulch
IS4
BC
SP
Hd
IS2
Pg
PP
Tv
IS6
LEEKS LODE
Gulch
PINON PIPES
H1
Mig2
Pinon Peak
IS5
IS1
HORSEPASTURE PEGMATITES
KLONDIKE
IS3
Mig1
JIM 3 MINE
GOLDIE
c81
Qal
Mcs
Mcg
Gulch
Mcn
JUNE
Copper
HI



EXPLANATION

QUATERNARY

Qal — Alluvial and Colluvial Valley Deposits

Qt — Travertine and Cemented Fluvial Deposits

Unconformity

TERTIARY

Tv — Pyroclastics

Unconformity

d — Diabase Dikes

c, l, n — Alkalic Dikes

c, carbonatite; l, lamprophyre, n, nepheline syenite

s — Syenite Dikes

Mc Clure Mountain Series

Mcn — Nepheline Syenite

Mcs — Syenite

Mcg — Gabbro

Rag — Red Aplitic Granite

SP — Silver Plume - Baldy Granite

Pg p — Pegmatitic Granite and Dikes

PP — Pikes Peak Granite

BC — Boulder Creek - Parkdale Tonalite

Mig 1 — Granite Migmatite

Mig 2 — Biotite Gneiss Migmatite

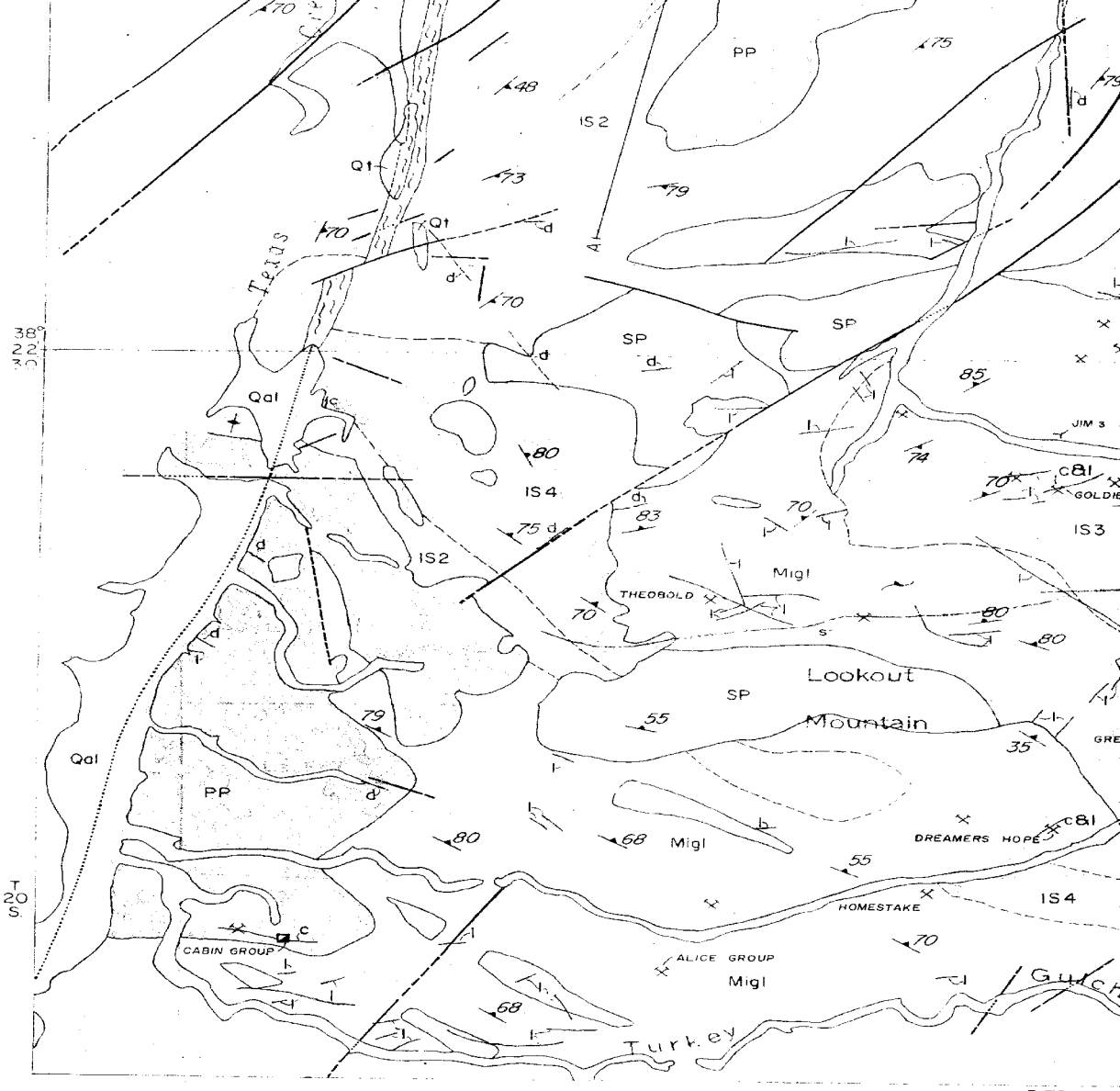
Unconformity

Hd Hl — Hornblende Diorite - Leucodiorite

IS 1 — Feldspathic Gneiss

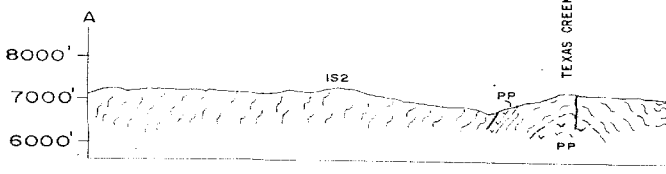
IS 2 — Foliated Biotite Gneiss

PRECAMBRIAN



6	5	4	3	2	1
7	8	9	10	11	12
18	17	16	15	14	13
19	20	21	22	23	24
30	29	28	27	26	25
31	32	33	34	35	36

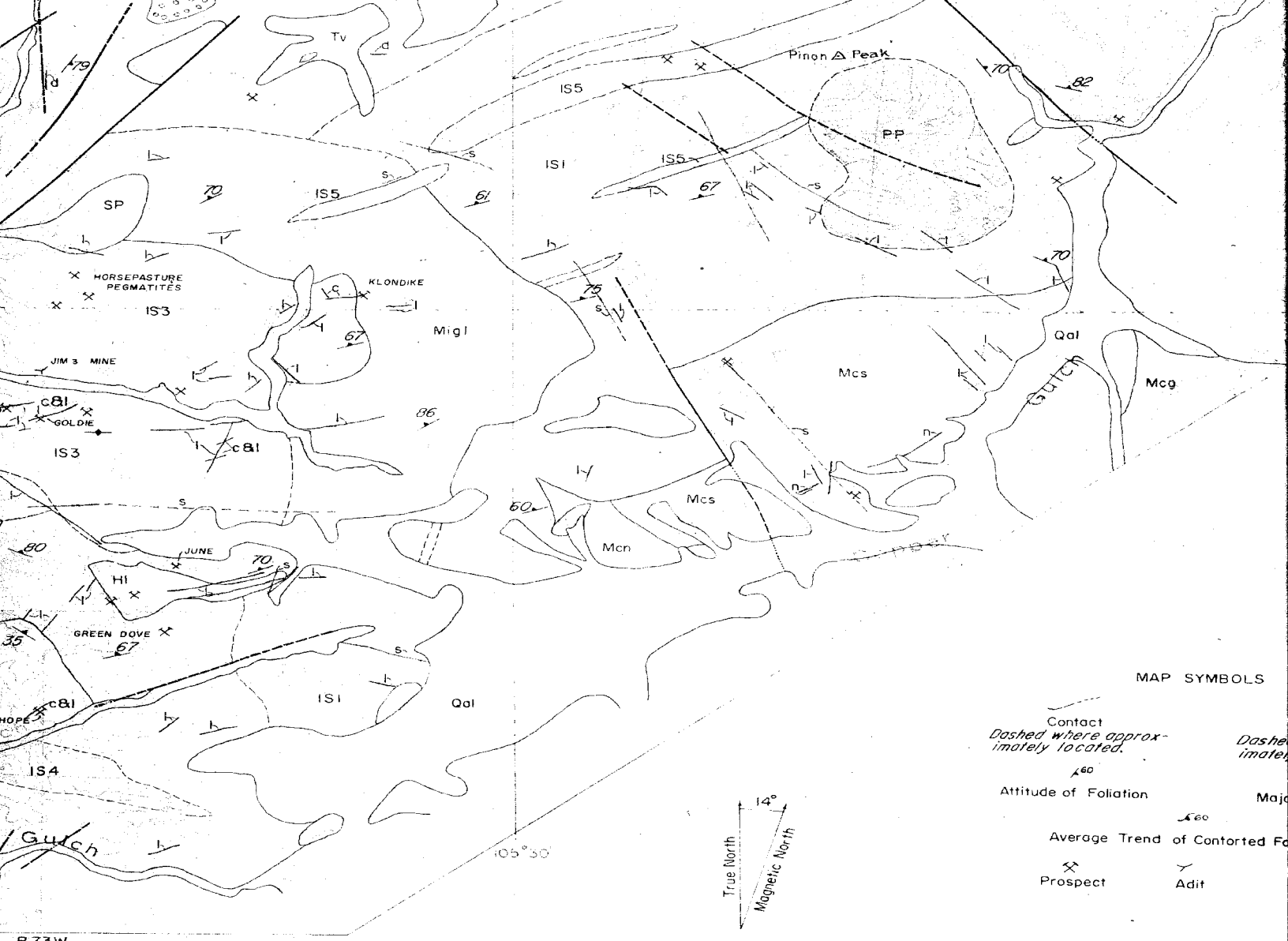
T.19S., R.73W. not surveyed. Location by interpolation.

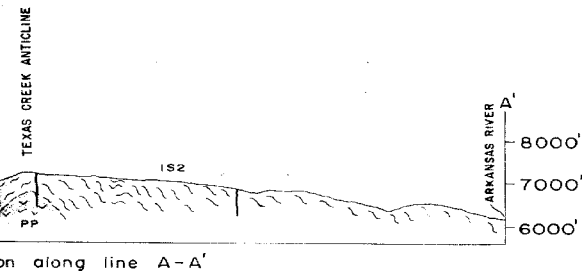


Cross section along lin

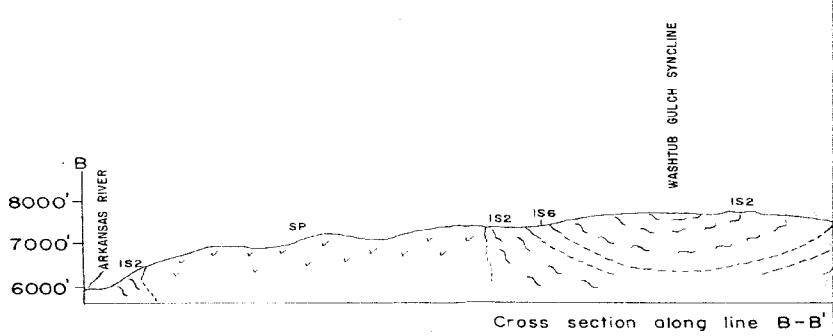
Base from U. S. Geol. Survey Cotopaxi and Royal Gorge Quadrangle maps.

GEOLOGIC MAP AND SEC





on along line A-A'



Cross section along line B-B'

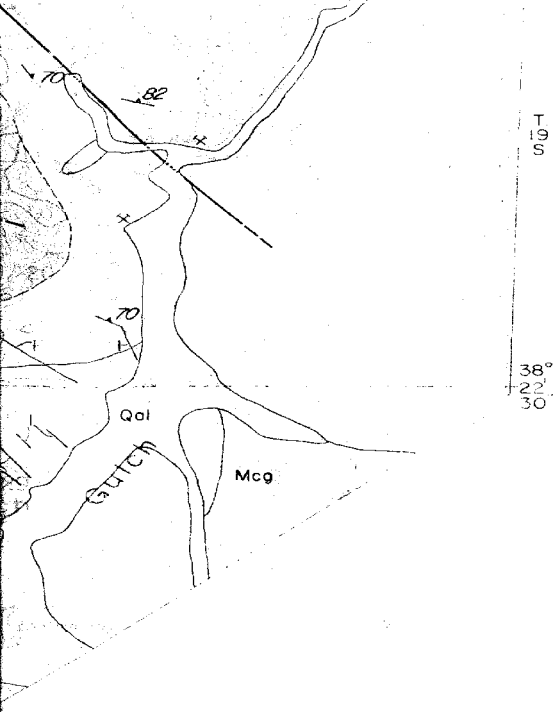
O SECTIONS OF THE LOOKOUT MOUNTAIN AREA, FREMONT COUNTY, COLO

SCALE

1 0 1 2

MILES

Contour interval 80 feet



SP
Silver Plume - Baldy Granite

Pg p
Pegmatitic Granite and Dikes

PP
Pikes Peak Granite

BC
Boulder Creek - Parkdale Tonalite

Mig 1
Granite Migmatite

Mig 2
Biotite Gneiss Migmatite

PRECAMBRIAN

Unconformity

Hd Hl
Hornblende Diorite - Leucodiorite

Idaho Springs Series

IS 1
Feldspathic Gneiss

IS 2
Foliated Biotite Gneiss
Sillimanitic and nodular sillimanitic biotite gneiss

IS 3
Massive Biotite Gneiss

IS 4
Foliated Hornblende Gneiss

IS 5
Amphibolite

IS 6
Muscovite Schist

MAP SYMBOLS

Contact
Dashed where approximately located.

Fault
Dashed where approximately located.

60
Attitude of Foliation

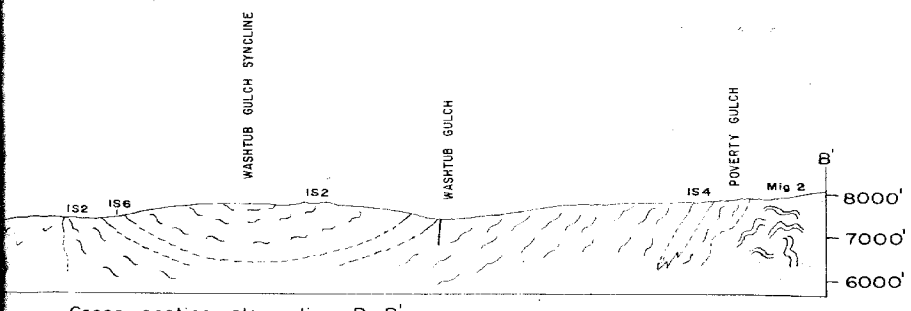
Major Shear Zone

60
Average Trend of Contorted Foliation

Prospect

Adit

Shaft



Cross section along line B--B'

Geology by D. H. Dahlem, 1964

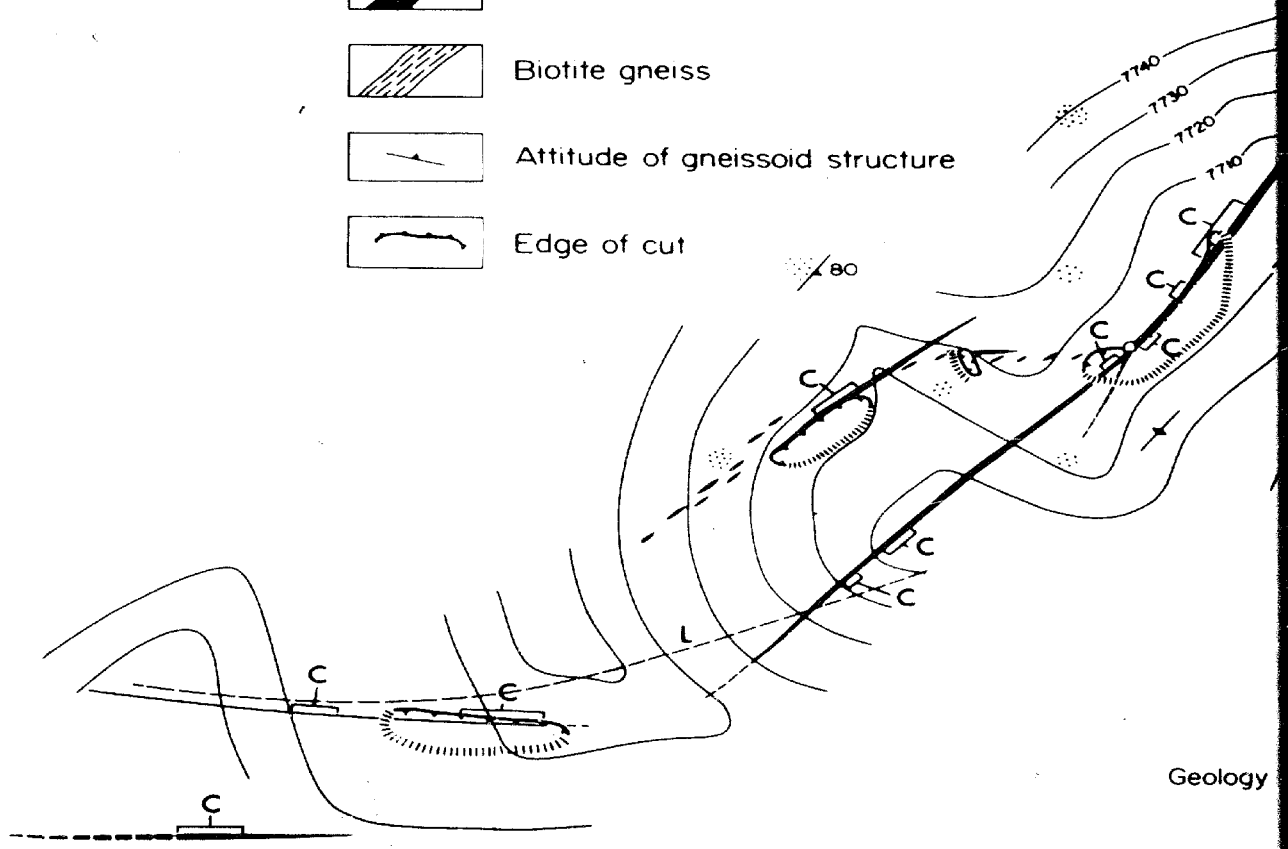
NT COUNTY, COLORADO

GEOLOGIC MAP OF THE
KLONDIKE PROSPECT
FREMONT COUNTY, COLORADO

0 50 100 150 200
FEET

EXPLANATION

- C — Silico-carbonatite; C, carbonate-rich phase
- Fenite
- L — Lamprophyre
- Granite gneiss
- Amphibolite
- Biotite gneiss
- Attitude of gneissoid structure
- Edge of cut



Geology

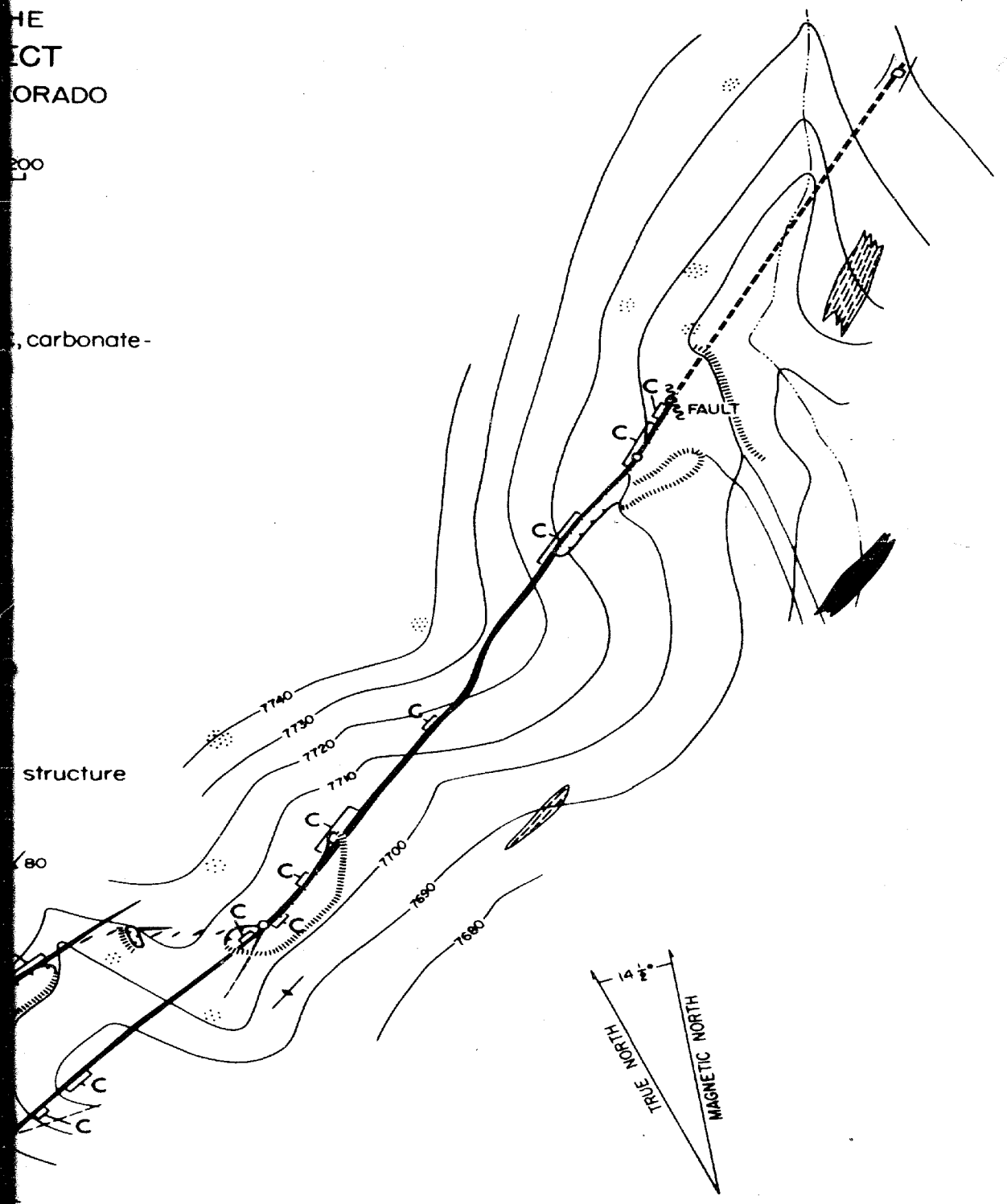
HE
CT
ORADO

200

, carbonate -

structure

80



Geology by E. Wm. Heinrich and D. H. Dahlem, July, 1963 and July, 1964