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INTRUSIVE AND METAMORPHIC ROCKS OF THE SILVER LAKE FLAT AREA, AMERICAN FORK CANYON, UTAH

by

Donald L. Burge

Brigham Young University
Department of Geology
Provo, Utah

INTRUSIVE AND METAMORPHIC ROCKS
OF THE SILVER LAKE FLAT AREA,
AMERICAN FORK CANYON, UTAH

A Thesis

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ABSTRACT

This report concerns ten square miles in the Silver Lake Flat area, American Fork Canyon, Utah County, Utah. Most of the area, which includes the southeastern part of the Little Cottonwood Stock of quartz monzonite and the associated metamorphosed Precambrian and Paleozoic sediments, is situated on the southern slope of the divide between American Fork Canyon and Little Cottonwood Canyon.

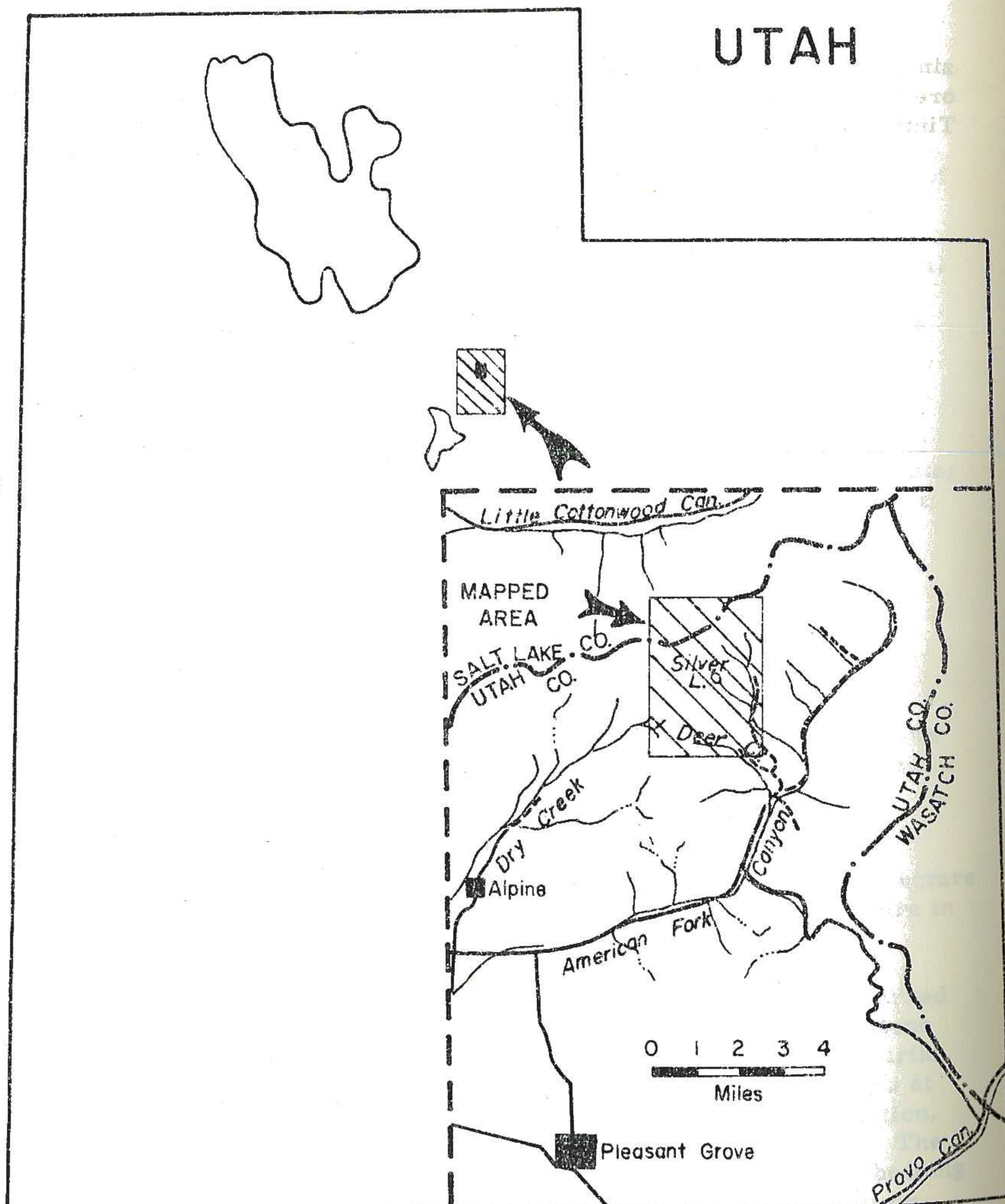
Metamorphism of the thin mantle of Mississippian limestones overlying the southeastern margin of the stock produced a striking suite of metamorphic minerals. The limestones were divided into four zones in order of increasing metamorphism: (Zone 1) unmetamorphosed dark gray slightly dolomitic limestone; (Zone 2) dark gray to black amphibolic limestone containing abundant graphite; (Zone 3) white to light gray silicious limestone characterized by the presence of wollastonite, diopside, and idocrase; and (Zone 4) abundant brown garnet with lesser amounts of olivine, epidoite, zoisite, serpentine, and microcline. Zone 2 represents a simple rearrangement of elements existing in a pre-metamorphosed limestone similar in composition to that of Zone 1, whereas the limestones of Zones 3 and 4 have been strongly altered by the metasomatic introduction of large amounts of silica and smaller amounts of aluminum, magnesium, and iron. Carbon and carbonate were eliminated from the two zones nearest to the intrusive contact, probably in the form of volatile compounds. A change in atomic structure of the diagnostic minerals with increasing metamorphic rank is represented by the predominance of the double chain inosilicate structure in Zone 2, the single chain inosilicate structure in Zone 3 and the independent tetrahedral orthosilicate structure in Zone 4.

Prismatic amphiboles characteristic of Zone 2 show preferred orientations of axes concentrated in bedding planes of the limestone with directions parallel to the strike and at right angles to the strike of the bedding. The most frequent orientation of the axes occurs at right angles to the strike of the bedding in a northwestern direction, closely paralleling a line drawn toward the center of the stock. The northwest axes were probably orientated by slippage along the bedding planes of the limestone resulting from stresses that radiated from the stock during its intrusion. Orientation of amphibole axes along

the strike of the limestone bedding was most likely due to secondary slippage produced by tensional stresses working at right angles to the compressive stresses.

Mines in the area have produced moderate amounts of lead, zinc, and silver in the past but are presently inactive. Most of the ore production has been from northeasterly striking fissures in the Tintic Quartzite.

Plate I



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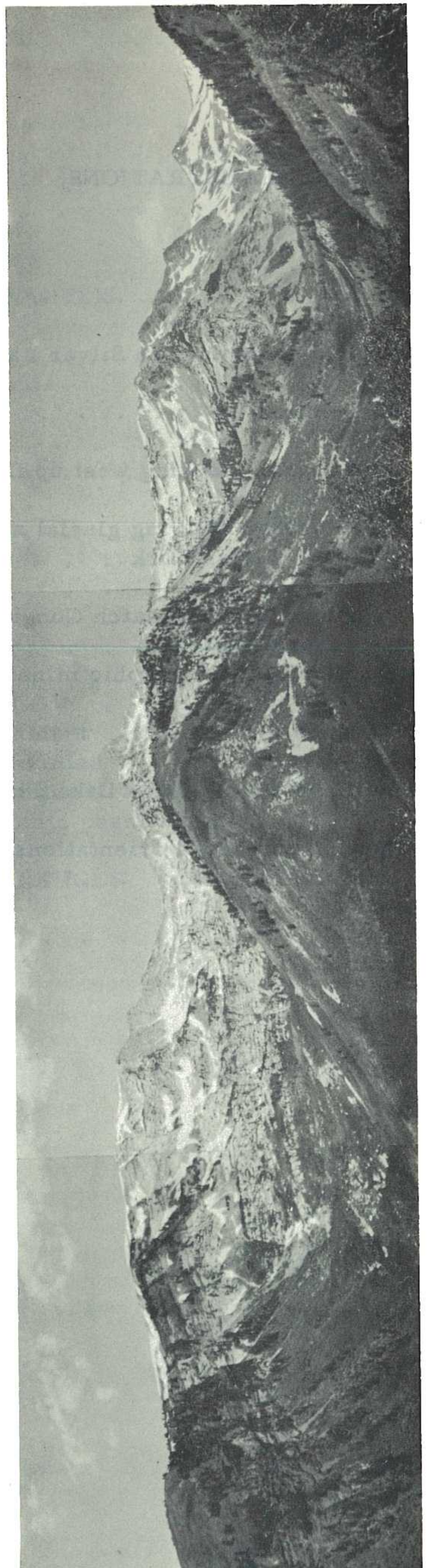


VIEW LOOKING NORTH FROM SILVER LAKE FLAT

Silver Creek is on the left and Silver Fork is on the right; they represent glacial cut U shaped valleys. Mississippian limestones overlie quartz monzonite at the left. The hill at the center is composed of Tintic Quartzite. The hill at the extreme right consists of Madison Limestone thrust over Ophir Shale.

INTRODUCTION

Location and Accessibility

The Silver Lake Flat Area lies in the central Wasatch Mountains, approximately eight miles east of the mouth of American Fork Canyon, Utah County, Utah. It is roughly bounded by the parallels 40°29'50" and 40°33'5" north and the meridians 111°39'15" and 111°42'9" west. The area is located on the southern edge of the Dromedary Peak quadrangle, Salt Lake County and on the northern edge of the Timpanogos Cave quadrangle, Utah County, Utah.

The area is reached by turning northward from Highway 168 on to the dirt road immediately east of Deer Creek approximately 2 miles northeast of the Alpine Scenic Highway in American Fork Canyon (Plate I). Heavy snow makes the road impassable from late December to May.

Physical Features

The Silver Lake Flat area is located along the summit and southern slope of the divide between American Fork Canyon and Little Cottonwood Canyon (Plate IX). Erosive action of Alpine glaciers has resulted in a rugged, steep topography. Relief in the area is over 4,000 feet; the highest point is the divide at Twin Peaks (11,489 feet), and the lowest point is along Deer Creek (7,400 feet). The divide runs in a northeasterly-southwesterly direction and represents the boundary between Salt Lake County on the north, and Utah County on the south. Erosion on the southern slope of the divide has developed a series of small tributaries and ridges running in a southerly direction.

The area is drained by Deer Creek on the south and Silver Fork on the east. The southeasterly flowing streams represent two of the main tributaries of the southwesterly flowing American Fork Canyon stream. Silver Fork is a southernly flowing tributary of Silver Creek and forms the eastern margin of the mapped area.

Silver Lake occupies a glacial cirque surrounded on 3 sides by sheer cliffs. The lake covers an area approximately 200 yards by 300 yards and owes its present size to a man-made dam at the head of the natural depression. Three slightly smaller lakes occupy somewhat similar surroundings on the north side of the divide.

Large bodies of talus have accumulated at the base of the glacially cut cliffs, and are especially conspicuous near the summit of the divide.

Climate and Vegetation

The climate of the area is fair in the summer and severe in the winter. The first snow storms generally arrive early in October, but snow ordinarily does not accumulate until late in December. Annual snowfall is heavy, measuring 100 inches or more on the higher slopes. The heavily laden slopes often give rise to snow slides in the early spring. These avalanches are extremely dangerous.

Snow melts rapidly in late spring, and leaves isolated patches on higher slopes, some of which survive until the succeeding fall. Showers occur throughout the summer months.

Conifers cover northerly facing slopes and occur as patches on the high near barren slopes near the divide. Aspens and scrub oaks are very abundant along the canyons. Alpine flowers bloom in the spring and early summer.

Present Work

The present work consists of a detailed geologic study made of 10 square miles along the southern border of the Little Cottonwood Stock. Field work began during August, 1957, and was completed during June, 1959.

The study was undertaken because of the interesting nature of the contact zone of the stock, and because of the limited amount of previous work in the area. The purpose of this study is to prepare an accurate geologic map and report giving special interest to minerals and rock types found. This report represents the first detailed geologic and mineralogic investigation specifically pertaining to the Silver Lake Flat area.

Aerial photographs from the U. S. Department of Agriculture (1940) were used for mapping purposes. The final geologic map was drawn on the Dromedary Peak and Timpanogos Cave quadrangles of the 7.5 minute series.

More than 200 selected rock samples were taken in the field, and thin section studies were made of many of the samples in the laboratory.

Previous Work

The earliest study of the geology of the Wasatch Range was made by Clarence King and S. F. Emmons members of the Fortieth Parallel Survey (1878). In some parts of the range today, this early work stands unsuperseded.

Boutwell (1912) made a brief geologic study of the Little Cottonwood area. In 1902 he established the intrusive nature of the Little Cottonwood granite. Emmons (1903) revived the evidence presented by Boutwell and published an acknowledgment of the intrusive nature of the granite.

Atwood (1909) published a report on the glaciation of the Wasatch Mountains. In 1912 studies were made of the Cottonwood-American Fork area by Butler (1915), Loughlin (1915) and Hintze (1913). Stillman (1928) made a geologic reconnaissance of the Wasatch Front between Alpine and American Fork Canyons. Christensen (1928) wrote a Master's Thesis on the geology and physiography of Deer Creek and Silver Fork.

Butler and Calkins (1943) prepared a report on the geology and ore deposits of the Little Cottonwood-American Fork area. This report deals with the area to the north and east of the present work.

At the present time, Arthur A. Baker and Max W. Crittenden of the U. S. Geological Survey are studying the geology of the central Wasatch Range. The results of this study are as yet unpublished.

GENERALIZED STRATIGRAPHIC SECTION OF AMERICAN FORK CANYON

(After Butler and Calkins, 1943, Plate 5)

PLATE III

System	Series		Formation	Section	Thickness	Kind of Rock
Ter.		Tw	Wasatch Conglomerate		200'	Conglomerate, pink.
Carboniferous	Pennsylvanian	Cw	Weber Quartzite		1,350'	Quartzite, homogeneous fine grained, white to pale gray, weathering pale buff, interbedded with calcareous sandstone and gray limestone.
		Cw	Morgan Formation		350'	Limestone, gray, cherty. Green nodular shale and red limestone near top.
	Mississippian	Ch	Humbug Formation		750'	Limestone, black, cherty; large corals near top. Limestone, black, buff when weathered, argillaceous. Black shale. Limestone, gray to buff, interbedded with calcareous shale and sandstone.
		Cd	Deseret Limestone		900'	Limestone, dark blue to white, not much chert. Limestone and dolomite, dark, very cherty. Dolomite, whitish, crinoidal, large lumps of pale chert. Dolomite and magnesian limestone, very cherty, black shaly beds at base.
		Cm	Madison Limestone		450'	Limestone, partly magnesian free from chert; blue altering to blue and white; highly fossiliferous.

System	Series		Formation	Section	Thickness	Kind of Rock
Dev.		Dj	Jefferson Dolomite		150'	Dolomitic, thick bedded; flaggy and buggy layers.
Cambrian	Upper Cambrian	€m	Maxfield Limestone		570'	Dolomite, gray mottled. Limestone, gray to buff. Dolomite and limestone, mottled, buff and gray. Dolomite, white sandy. Dolomite, gray, oolitic.
	Middle Cambrian	€o	Ophir Shale		420'	Shale, partly calcareous, greenish gray, yellowish brown when weathered. Limestone, nodular, mottled. Shale, dark micaceous.
	Lower Cambrian	€tq	Tintic Quartzite		800'	Quartzite, light-colored, conglomeratic near base.
		€t	Tillite		0 to 1000'	Tillite, interbedded with varved shale; dark colored, weathering rusty.
Precambrian		pre-€			400'	White quartzite. Light-colored quartzite interbedded with purple shale.
					100'	Argillite, dark purple.
					200'	Quartzite, rusty purple.
					500'	Argillite, with slaty cleavage; dark gray, stained with ocher on weathered surface
					1000'	Quartzite, whitish to red or dull purple.

STRATIGRAPHY

General Statement

The area is composed of rocks ranging from Precambrian to Quaternary. Precambrian rocks are represented by the Big Cottonwood series of quartzite and shale, and are unconformably overlain by the Cambrian Tintic Quartzite and Ophir Shale. Ordovician and Silurian rocks are lacking in the area.

Carboniferous formations are the dominant sedimentary rocks in the area, both in thickness and surface exposure. The Mississippian Deseret Limestone and Humbug Formation have been intensely metamorphosed by the intrusive stock. Pennsylvanian rocks consist of an intercalated series of limestone and quartzite of the Morgan Formation and Weber Quartzite. The Mississippian-Pennsylvanian depositional contact is not exposed but is found to be transitional in nature in the area studied by Butler (1943, p. 28).

No Mesozoic rocks are represented in the area although they are present a few miles to the northeast. The Tertiary is represented by the Eocene Wasatch Conglomerate. Quaternary deposits of the area include glacial deposits, talus and alluvium.

The stratigraphic section shown on Plate III is taken from Butler (1943, Plate V), and is modified by the addition of the Eocene Wasatch Conglomerate. Only portions of the section occur in the area because of faults and erosion. Formations that are exposed in the area are discussed in the following section.

Precambrian Rocks

Big Cottonwood Series

Precambrian rocks are spectacularly exposed on the steep slopes of Twin Peaks and at the head of Silver Fork (Plate II). They occupy the major portion of the eastern marginal contact of the Little Cottonwood Stock. Resistant rocks of the series form the highest topographic features in the area. They strike approximately north 45 degrees east and dip from 25 to 55 degrees to the southeast.

Precambrian rocks in the area consist of over 2,000 feet of argillite and quartzite of the Big Cottonwood series. The series received their name from the excellent exposures of these rocks in Big Cottonwood Canyon where their total thickness has been estimated to exceed 12,000 feet (Walcott, 1886).

The rocks have undergone a moderate degree of metamorphism due to their contact with intrusive rocks. Their original coloration and textures have generally been destroyed, which makes it difficult to correlate them with Precambrian rocks in nearby areas. The quartzites are generally white to gray with tinges of yellow and purple. The argillites and shales range in color from black to tan with occasional tinges of purple.

Striking exposures of the series occur at the head of Silver Fork, where they can be seen overlying intrusive rocks to the west and underlying Cambrian quartzites to the east (Plate II).

The lowest Precambrian strata exposed in the area consists of approximately 1,000 feet of dark brown to black argillite and shale with some beds approaching quartzite in composition. At Twin Peaks, the argillites and shales are overlain by about 400 feet of quartzite. This quartzite forms the western peak of Twin Peaks. It is white to light gray in color and is of a fine texture. The quartzite underlies 100 feet of dark brown shale with tinges of purple.

The Precambrian-Cambrian contact along the east side of Silver Fork one mile south of Twin Peaks consists of Cambrian quartzite unconformably overlying Precambrian quartzite. The two quartzites are very similar in places and have approximately identical strikes; the Precambrian quartzite dips several degrees steeper to the southeast than the Cambrian quartzite. The tillite so common at the base of the Cambrian in surrounding areas is not present. The Precambrian quartzite below the contact is whitish with a tinge of yellow on weathered surfaces, and of fine texture. Underlying about 50 feet of this quartzite is several hundred feet of dark gray, purple tinged quartzite with a few layers of interbedded argillite. Below the dark quartzite is a section a couple of hundred feet thick of homogeneous white quartzite, being exposed in broad relief on the west side of the canyon. This white quartzite may be equal to the white quartzite at Twin Peaks. The exact measurement of the Precambrian section was not possible due to the lenticular nature of various units and complications produced by metamorphism and faulting.

The series seems to be somewhat similar to the relatively unaltered Precambrian rocks exposed to the east of the area. Butler (1943, p. 8) reported the following section of Precambrian rocks in Mary Ellen Gulch, approximately one mile east of Silver Fork.

Bed	Description	Estimated Thickness
5	Quartzite: light colored with purple tinges, some interbedded purple shale. Upper 50 feet of quartzite is whitish.	400 feet
4	Argillite: dull, dark purple with green bands.	100 feet
3	Quartzite: rusty purple.	200 feet
2	Argillite: dark gray, stained with ocher, slaty cleavage.	500 feet
1	Quartzites: whitish to red or dull purple, upper beds white and fine grained.	1, 000+ feet
	Total Feet	2, 200+ feet

It has been suggested that a lack of close correspondance between the various exposures of Precambrian rocks in different places may be due in part to the lenticular nature of thet hick strata of shale and quartzite and in part to an unconformity at the base of the Cambrian (Butler, 1943, p. 9).

Cambrian System

Tintic Quartzite

Cambrian quartzite is located in the northeastern part of the mapped area where it forms steep slopes on both sides of Silver Fork (Plate IX). The quartzite comprises the major portion of the conspicuous hill east of Silver Fork, where it forms an exposure which covers a horizontal area measuring six-tenths by eight-tenths miles. The quartzite strikes north 40 degrees east and dips 45 degrees to the southeast.

The formation consists of approximately 800 feet of fairly homogeneous white quartzite of medium texture. On weathered surfaces the quartzite is flesh colored to brown with joints stained

dark brown with iron oxide. The bedding planes are almost indistinguishable when viewed in small outcrop. Cross-bedding occurs commonly throughout the formation. Beds of pebbles are found in the formation, and are most common near its base; the pebble beds consist mainly of well rounded to subrounded white to pink quartz.

No fossils were found in the Cambrian quartzite itself, but marine fossils are common in the overlying shale into which the quartzites grade. The quartzite represents an ancient salt-water beach deposit as evidenced by the presence of cross bedding, rounded quartz grains, and by marine fossils in overlying transitional shales.

Ophir Shale

The Ophir Shale is found in the east-central section of the area where it is exposed on the south end of the prominant quartzite hill east of Silver Lake (Plate IX). Approximately 100 feet of the soft shale is exposed and strikes north 45 degrees east and dips 45 degrees southwest.

The shale is dark brownish green to brownish gray in color with weathered surfaces of tan to brown. It is highly micaceous and fissile in places. The bedding surfaces are wavey and occasionally show both rain drop depressions and ripple marks.

The base of the formation is transitional with the underlying Tintic Quartzite as shown at the exposure adjacent to the most southern tunnel of the Ontario Mine.

Butler (1943) describes the following section of Ophir Shale from the area immediately to the east.

Bed	Description	Estimated Thickness
3	Shale: greenish gray, yellowish brown when weathered, partly calcareous.	100 feet
2	Limestone: light blue-gray, nodular and mottled.	80 feet
1	Shale: dark, micaceous.	240 feet
	Total Feet	420 feet

Marine fossils are common in the area and include linguloids, trilobite fragments, and wormlike forms (Plate IX, location 66). The shale is correlated with the Ophir Shale of the Ophir District. Butler (1943, p. 14) considers the formation as equivalent to the Pioche Shale.

Carboniferous System

Deseret Limestone and Humbug Formation (Undifferentiated)

Mississippian strata comprise the major portion of the sedimentary rocks in the area and form the southern aureole of the intrusive rocks of the Little Cottonwood Stock. They occur as a relatively thin mantle over the intrusive rocks as shown in Plate II. The strata have an exposure north of Deer Creek which covers an area approximately one mile wide and two miles long. The rocks have undergone various degrees of contact metamorphism due to the effects produced by the intrusion of the stock. The strata generally strike between north 50 degrees east and north 70 degrees east with dips between 30 degrees and 65 degrees southeast.

The strata consist of silicious limestone with subordinate sandstone and shale. Limestone showing only slight metamorphism occurs in the southeastern part of the area, west of Silver Lake Flat. It is dark gray to black in color with white stringers of calcite and contains a few scattered lenses and nodules of chert.

The Mississippian exposure in the area has a thickness estimated to be over 1000 feet. Limestone comprises roughly two-thirds of the rocks while sandstone and shale make up the remainder. A bed of medium-grained, buff sandstone over 100 feet thick occurs near the top of the formation. The argillaceous beds are dark brown to black in color and are up to 100 feet in thickness.

Fossils are abundant, but poorly preserved due to metamorphism. On the ridge on the western margin of Silver Lake Flat the following fossils were collected from gray, slightly metamorphosed limestone (Plate IX, location 64):

- *Syringopora* sp.
- *Fenestella* sp.
- *Productus* sp.
- Crinoid
- *Caninia* sp. ? (Large tetracorals up to 10 inches in length)

On the basis of paleontology and lithology the metamorphosed strata are questionably assigned to the Deseret Limestone and the Humbug Formation. The separation or estimation of relative abundance of the two formations is complicated by the destruction of original lithologic features and fossils by metamorphism.

An excellent exposure of the Mississippian strata in contact with underlying intrusive rock occurs west of Silver Lake (Plate II). The contact dips approximately 50 degrees to the southeast.

The generalized sections of the Deseret Limestone and Humbug Formation as they occur to the northeast are as follows (Butler, 1943):

Deseret Limestone

Bed	Description	Thickness
4	Limestone: dark blue to whitish, little chert.	300 feet
3	Limestone and Dolomite: dark cherty.	200 feet
2	Dolomite: whitish, lumps of chert, crinoidal.	100 feet
1	Dolomite and limestone: cherty, black shaley beds at base.	300 feet
	Total Feet	900 feet

Humbug Formation

Bed	Description	Estimated Thickness
4	Limestone, black cherty, large corals and other fossils near top.	
3	Limestone, black, weathering to buff, argillaceous.	
2	Shale, black.	
1	Limestone, gray to buff, interbedded calcarious shale and sandstone.	
	Estimated Total	750 ± feet

The relative abundance of shale and sandstone in the Mississippian strata in the area suggests that a large part of the strata may belong to the Humbug Formation. The large corals that Butler describes in the black limestone near the top of the formation (See Bed 4 above) are tentatively correlated with the large cone corals found by the author in the dark Mississippian limestone west of Silver Lake Flat (Plate IX, location 64).

Morgan Formation and Weber Quartzite (Undifferentiated)

Formations of Pennsylvanian age are represented in the area by the Morgan Formation and the Weber Quartzite. They crop out on the southside of Deer Creek Canyon where they make a wedge shape exposure with the border of the map (Plate IX). The strata represent the north flank of an anticline and have strikes averaging east-west with dips from 30 degrees to 40 degrees toward the north. The strata are terminated on the north by a fault which strikes down Deer Creek. The best exposures of the strata crop out near the top of Box Elder Mountain about one half mile south of the area (Plate IV, figure 1). A section of the Pennsylvanian strata exposed south of Box Elder would exceed 1,000 feet. Because the strata essentially form a dip slope in the mapped area, the thickness of their exposure measures only 2 or 3 hundred feet.

The lowest beds of the Pennsylvanian strata exposed in the area consist of blue-gray limestone and buff calcarious sandstone. Higher beds of the Pennsylvanian strata give way to tan quartzites. The strata consists of approximately equal amounts of sandstone and limestone within the mapped area.

Butler (1943, p. 28) found that in the Cottonwood-American Fork area the Morgan Formation overlies the Humbug Formation with a slight angular unconformity. This contact was not observed in the area studied. Butler also found that the top of the Morgan Formation is transitional to the base of the Weber Quartzite. By local usage (Butler, 1943, p. 28) the Morgan Formation designates the gray limestone with lenses of red sandstone that underlie the lowest quartzitic beds of the Weber Quartzite.

Butler (1943, p. 29) listed 350 feet of Morgan Formation and 1,350 feet of Weber Quartzite as occurring in the Cottonwood-American Fork area.

Pennsylvanian rocks exposed south of Deer Creek can be considered to be Weber Quartzite with a possible thin section of the Morgan

Formation. Quartzitic beds representing the base of the Weber Quartzite may exist below the gray limestone exposed along the base of the southern wall of Deer Creek Canyon, and would delete the presence of the Morgan Formation.

Fossils are moderately abundant in the limestone members of the Pennsylvanian strata; they are highly silicified and poorly preserved. The only fossils that could be identified by the author are crinoid fragments and Spirifer sp. (Plate IX, location 90).

Butler (1943) suggests that the beds assigned to the Morgan Formation in the Cottonwood-American Fork area might be equivalent to the lowest part of the Oquirrh Formation of the Ophir District. The Weber Quartzite is equivalent to part of the Oquirrh Formation. The term Weber Quartzite is preferred only because of established local usage.

Tertiary System

Wasatch Conglomerate

The Wasatch Conglomerate occurs in the southeastern corner of the mapped area where it crops out on the ridge between Silver Lake Flat and Deer Creek (Plate IV, figure 3) where the exposure is approximately 100 feet thick and covers an area less than 200 feet square. The conglomerate strikes north 55 degrees west, and dips 48 degrees northeast.

It is composed of sub-angular to sub-rounded pebbles of gray quartzite and white quartz, with the quartzite being far more abundant than the quartz. The quartzite pebbles resemble those found in the Weber Quartzite. The pebbles generally range from one-fourth to one inch across and the boulders range from one to three feet across. Beds of soft tan shale 2 to 4 inches in width occur throughout the outcrop and are deeply eroded, exposing the bedding surfaces of the fairly resistant conglomerate.

No contact with the underlying rocks is visible although Mississippian rocks crop out a few hundred feet to the north. The conglomerate appears to be terminated to the north by a fault.

The conglomerate exposed in the area seems to represent a northern extension to the Wasatch Conglomerate mapped by Stillman (1928) along American Fork Canyon, approximately one mile southeast of the mapped area.

Quaternary System

Quaternary deposits in the area include glacial deposits, talus and alluvium.

The glacial deposits of the area have been described and mapped by Atwood (1909) and were not remapped by the present writer.

A large glacial moraine extends south from Silver Lake Flat into American Fork Canyon, just off the southeastern edge of the mapped area. A pebble count made of the material showed it to be composed of 12 per cent quartz monzonite, 64 per cent quartzite, and 32 per cent phyllite. The material counted is from 2 to 6 inches in size. The quartz monzonite is badly weathered while the quartzite and phyllite are very well preserved. The phyllite is commonly faceted and deeply striated. Large boulders of quartz monzonite over 3 feet across are abundant. The deposit represents the terminal moraine of a large glacier that once extended up Silver Creek and Silver Fork (Plate IV, figure 2).

Atwood (1909, p. 76) described a section through glacial drift into underlying material cut by a tributary of Deer Creek as follows:

> "At the surface 4 to 6 inches of soil formed since the east retreat of ice; below the surface soil a sheet of till 8 to 10 feet thick, composed of fresh or unweathered granite; beneath the drift an old soil 6 to 18 inches thick; below the buried soil ancient stream alluvium. The buried soil is black, from an abundance of humus, and is so disturbed that at places it bulges up and appears to be crushed. These phenomena appear to be due to the advance of the debris-laden ice, for on the stoss side of each little fold there is lodged a great boulder. The alluvium examined was exposed to a depth of 20 feet and throughout that depth had a dark red color, which set it off in sharp contrast to the white granite drift above."

Large deposits of talus have accumulated at the base of the cliffs and steep slopes in the area. It is especially abundant near the divide between Little Cottonwood Canyon and American Fork Canyon in the highly jointed intrusive rocks of the stock. Only the larger bodies of talus were mapped. The talus represents the largest Quaternary deposits in the area with single bodies extending for over a mile.

A limited amount of alluvium is deposited along the floor of the canyons. The high relief of the area has restricted the accumulation of alluvium. Silver Lake Flat appears to have been formed by the deposition of alluvium in a depression behind a glacial terminal moraine.

An old alluvial deposit is exposed along Deer Creek, where erosion has cut through a mantal of alluvium and glacial drift. The pre-glacial alluvium is red in color, roughly stratified and poorly sorted. The red color is probably due to the erosion of Wasatch Conglomerate.

PLATE IV

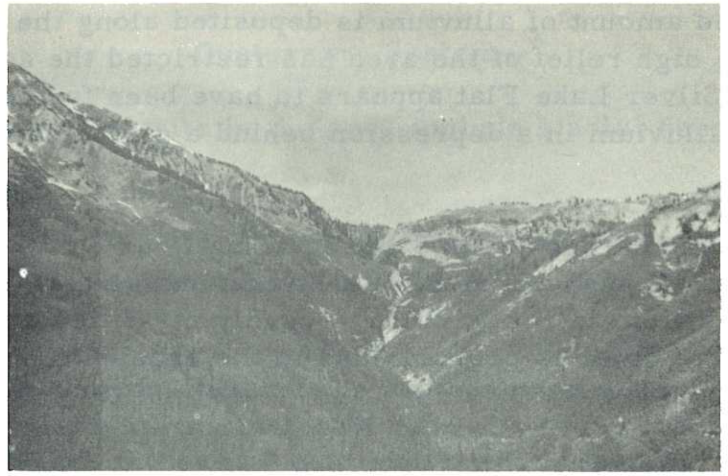


Figure 1. Looking west up Deer Creek.

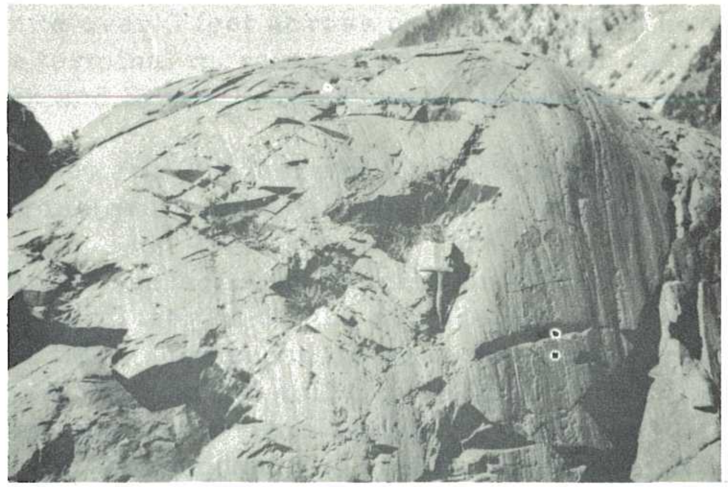


Figure 2. Glacial action at the head of Silver Fork.

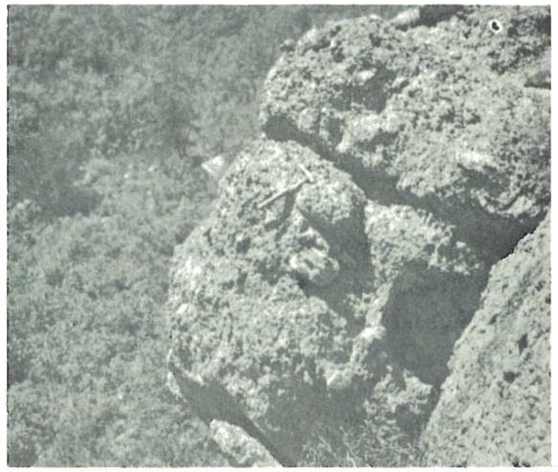


Figure 3. Wasatch Conglomerate.

IGNEOUS ROCKS

Intrusive rocks of the Little Cottonwood Stock cover approximately five square miles in the northwestern part of the mapped area (Plate IX); the exposure represents the southeast portion of the stock. The stock roughly forms a circular exposure covering a total area of approximately 25 square miles, and is one of three large plutonic masses that occur in the Cottonwood-American Fork region. These are aligned in a northeast-southwest direction and consist from west to east of the Little Cottonwood Stock, the Alta Stock, and the Clayton Peak stock. The stocks increase in size of outcrop, coarseness of texture and amount of silica toward the west.

The Little Cottonwood Stock was first considered to be Archean by the Fortieth Parallel Survey (King, 1878, p. 45), but is now believed to be Late Eocene (Crittenden, 1953, p. 18). Radio-active age determinations have placed the age of the stock at approximately 47 million years (Faul, 1954, p. 262).

The Little Cottonwood Stock consists of rocks that range in composition from a granodiorite to a quartz monzonite; the latter is the dominant type. The rocks are light gray in color and have a medium to coarse grain granitic to monzonitic texture. They are commonly porphyritic with phenocrysts of feldspar up to one inch in length; white to pink phenocrysts of feldspar are exposed in moderate relief on weathered surfaces of the rock. Minerals that are readily identified in hand samples of the rock are pink plagioclase, white orthoclase, gray quartz, black biotite, and black hornblende.

The following minerals are identified in thin sections of the material when viewed under a petrographic microscope; they are listed in order of decreasing abundance.

Plagioclase. The average plagioclase composition is about An_{30} as indicated by the extinction angles which range from 1 to 12 degrees. The plagioclase has albite twins and is commonly zoned. Euhedral crystals are abundant and give many of the rocks a typical monzonitic texture. The plagioclase is generally under various stages of alteration to sericite and clay minerals.

Microcline. The microcline occurs as subhedral to euhedral phenocrysts with the characteristic grid pattern produced by the combined polysynthetic albite and pericline twinning. The mineral is commonly altered in part to sericite and clay minerals.

Microperthite. Intergrowths of potassium feldspar and plagioclase are common in some rocks.

Orthoclase. The orthoclase occurs as subhedral to euhedral phenocrysts and as interstites in the ground mass. Carlsbad twinning is common. It is commonly altered to sericite and clay minerals.

Quartz. The quartz is anhedral in form and has a wavey extinction. It shows imperfect rhombohedral cleavage on the edges of the slides.

Biotite. Dark brown biotite occurs as highly pleochroic tabular crystals that often show a hexagonal outline. It contains inclusions of zircon, apatite, and magnetite. It is often in a stage of alteration to green chlorite.

Hornblende. Highly pleochroic hornblende occurs as prisms and grains in the rocks and is most abundant adjacent to the contact.

Additional accessory minerals are magnetite, titanite, apatite, and zircon.

Petrographic analysis made by the author of three samples from the stock are listed as percentages in the following table (See Plate 9 for location of samples).

	No. 22	No. 29	No. 33
Quartz	34	30	30
Orthoclase	15	6	12
Microcline	--	10	24
Microperthite	--	23	20
Plagioclase	30	15	10
Biotite	16	3	2
Hornblende	3	13	--
Magnetite	2	.1	1
Apatite	--	--	.5
Zircon	--	--	.1

The average composition of the intrusive rock is that of a quartz monzonite, as indicated by the petrographic study. The igneous rocks adjacent to the stock-country rock contact contain more biotite and hornblende than those nearer the center of the stock. Samples No. 22 and No. 9 in the above table were located along the contact while sample No. 33Q was located several hundred feet away from the contact.

Butler (1920, p. 239) gave the following chemical percentages for the intrusive body based on a specimen taken along Little Cottonwood Creek:

SiO_2	67.02	Na_2O	3.85	SiO_2	.04
Al_2O_3	15.78	K_2O	3.67	P_2O_5	.26
Fe_2O_3	1.56	H_2O-	.29	S	.03
FeO	2.8	H_2O+	.63	MnO	.02
MgO	1.09	TiO_2	.37	BaO	.13
CaO	3.31				

James Gilluly calculated the norm of the analyzed rock as follows* (Butler, 1943, p. 40):

Quartz	21.60	Hypersthene	5.87
Orthoclase	21.68	Magnetite	2.32
Albite	32.49	Ilmenite	.76
Anorthite	13.90	Apatite	1.01
Corundum	.41		

Dark rounded inclusions ranging 2 inches to 10 feet in diameter occur near the margin of the stock in the mapped area. The material represents remnants of an earlier wall rock that was broken up and distributed within the intrusive body. Phenocrysts of prismatic hornblende are very conspicuous and comprise as much as 30 per cent of many of the inclusions. The petrographic analysis by the author of an inclusion in the quartz monzonite at the head of Deer Creek (Plate IX, location 33) contained the following mineral percentages:

Quartz	Orthoclase	Plagioclase	Hornblende	Chlorite
20	10	30	30	10

Dikes are abundant along the margin of the stock and cut both the intrusive and sedimentary rocks. The dikes cutting the sedimentary

*Cross-Iddings-Pirsson-Washington classification.

rocks in the area are generally 1 to 5 feet thick and of aplitic texture. They have sharp contacts with country rock and persistent strikes.

Small stringers of intrusive rock 1 to 3 inches wide of aplitic texture commonly occur in the sedimentary rock near the contact. An aplite dike located near the crest of the divide north of Deer Creek (Plate IX, location 71) has the following mineral percentages as determined by its thin section study.

Quartz	Orthoclase	Microcline	Plagioclase	Biotite
40	11	18	30	1

A pegmatite dike occurs in the limestone adjacent to the intrusive contact about half way up the slope on the north side of Deer Creek (Plate IX, location 53). The dike is about 5 feet thick and strikes east with an 85 degree dip to the north. The dike grades from a typical pegmatite texture at its center to an aplitic texture at its contact with sedimentary rock. The petrographic analysis of the pegmatite shows a composition of approximately 50 per cent microperthite and 50 per cent quartz. No accessory minerals were seen in the small area of the thin section.

CONTACT METAMORPHISM

Contact metamorphism accompanying the intrusion of the Little Cottonwood Stock produced widely varied effects on the sedimentary rocks of the area. It had little effect on the stable quartzite rocks of Precambrian and Cambrian age. Metamorphism, producing poikilitic grains of cordierite, only moderately affected Precambrian argillaceous rocks. Mississippian limestones occurring as a relatively thin mantle over the intrusive rocks (Plate II), have been highly altered by the effects of contact metamorphism.

A spectacular assortment of metamorphic minerals and rocks was produced in the limestone as a result of the intrusion of the stock; the most striking mineral exposures consist of masses of wollastonite with plumes radiating as much as two feet and bands of garnet several feet in thickness.

The Mississippian limestones on the north side of Deer Creek were divided by the author into four zones of metamorphism on the basis of mineral and rock types present (Plate IX). The chief constituents of the four zones are listed below in order of increasing metamorphic rank: Zone 1 is dark relatively unmetamorphosed limestone; Zone 2 is composed of dark amphibolic limestone; Zone 3 consists of light silicious limestone containing wollastonite, diopside, and idocrase; and Zone 4 consists of silicious limestone with abundant garnet. The zones form concentric bands that closely parallel the contact of the limestone and quartz monzonite. The outcrop pattern of each zone is approximately one mile in a northeast-southwest direction and and four-tenths mile in a northwest-southeast direction.

Zone 1

Zone 1 is represented by a relatively unmetamorphosed slightly dolomitic dark gray limestone with subordinate beds of pink to tan sandstone and dark brown to black shale. The limestone has numerous silicified fossils that include crinoids, corals, brachiopods, and bryozoans. Stringers of white calcite occur throughout the limestone. The line between Zone 1 and Zone 2 is approximately 4000 feet southeast of the contact between the limestone and quartz monzonite.

Zone 2

Zone 2 is represented by a dark gray limestone containing prismatic amphiboles averaging one-eighth inch in length (Plate VI, figure 4). Amphiboles identified in thin sections of the limestone consist primarily of hornblende with some minerals grading into tremolite and actinolite. Amphiboles stand out in moderate relief on weathered surfaces of the limestone and are especially abundant along exposed bedding surfaces. Oriented samples of this rock were collected to determine if the amphiboles had any preferred orientation; the results of the study are discussed under Petrofabric Analysis.

The amphibolic limestones of the zone have as much as 5 per cent graphite which occurs as minute flakes parallel to the bedding, and which cause thin sections of the material to be almost opaque. Gray to green diopside occurs as lenses up to 3 inches across in the limestone of the zone. White calcite stringers generally less than 1 inch in width are scattered through the limestones.

Fossils that could be recognized are tetracoral and Productus sp. Circular carbon inclusions in the limestone may represent crinoid fragments. The boundary between Zone 2 and Zone 3 is approximately one-half mile south of the contact between the limestone and quartz monzonite.

Zone 3

The most common rock types of Zone 3 are marbles of the following varieties: lime, silica, brucite, wollastonite-diopside, wollastonite-diopside-idocrase, wollastonite-diopside-prehnite, forsterite-diopside, and amphibole.

The lime marble consists of a mosaic of equant grains of calcite whereas the marble derived from more dolomitic rocks is composed of mosaic calcite surrounding rounded grains of brucite.

Idocrase occurs as prisms up to one inch in length and as stringers through the metamorphic rock. Prehnite occurs as interstitial radial aggregates between prismatic wollastonite and coarse granular diopside. Masses of white fibrous tremolite are present throughout the zone, but it is far less abundant than the wollastonite. Hornblende occurs as small prisms in isolated patches of dark gray limestone.

Zone 4

Zone 4 is characterized by the addition of garnetiferous rocks and intrusive dikes. Bands several feet thick of brownish to greenish garnet of the grossularite-andradite series both follow and cut across bedding. The large bands of garnet are adjacent to intrusive dikes or to the contact with the stock. Small stringers of aplite are abundant in many of the garnetiferous bands.

Minerals differentiating this zone from Zone 3 are garnet, olivine, zoisite, microcline, and serpentine. Selected samples of the garnetiferous rock contain as much as 3 per cent scheelite.

Metamorphic Conclusions

Plate V lists the zonal distribution and relative abundance of the more important minerals found in the metamorphosed limestone. The minerals are listed in order, left to right, of decreasing horizontal distance from the contact between the quartz monzonite and limestone.

The four most significant factors which governed the formation of the various metamorphic minerals in the different zones are (1) temperature, (2) pressure, (3) original composition of the limestone, and (4) introduction of chemically active fluids into the limestone. The maximum temperature of the aureole, based on the approximate temperature of formation of wollastonite from quartz and calcite at high pressure, is placed by the author at approximately 1,000 ^{o} C. Wollastonite represents a good temperature indicator because of its abundance in the two zones nearest to the contact and because of its well known temperature of formation as calculated by Goldschmidt, Bowen, and others.

The original composition of the various beds in the metamorphosed limestone is assumed to be similar to that of the dark gray limestone of Zone 1. The amphibolic limestone of Zone 2 represents a simple rearrangement of the elements existing in the pre-metamorphosed limestone.

Large quantities of silica have been metasomatically introduced into Zones 3 and 4 as indicated by the abundance of chert, silicious limestones, and silicate minerals. Moderate amounts of aluminum, magnesium, and iron were introduced into the inner two zones as indicated by the abundance of minerals containing these elements. The carbon which is so conspicuous in the form of graphite in Zone 2 is almost completely removed from Zones 3 and 4.

Space for the introduction of new material was created by the formation of denser minerals and the loss of carbonate as carbon dioxide. The loss and gain of material probably took place approximately volume for volume.

There is a marked change in atomic structure of the various minerals toward the contact between quartz monzonite and limestone. Increasing grades of metamorphism produced minerals with more open atomic structures as indicated by the predominance of the double chain inosilicate structure (amphibole) in Zone 2, the single chain inosilicate structure (pyroxene) in Zone 3 and the independant tetrahedral orthosilicate structure (garnet) in Zone 4.

The more common mineral assemblages found within the various metamorphic zones are listed in the following table in order of increasing metamorphism and are correlated on the basis of mineralogy with the metamorphic facies of Eskola.

Zones	Characteristic Mineral Assemblage	Facies
I	Calcite-quartz	Amphibolite
II	Calcite-tremolite	Amphibolite
	Calcite-hornblende	"
	Calcite-diopside	"
III	Calcite-wollastonite-diopside	Pyroxene-hornfels
	Calcite-wollastonite-diopside-idocrase	"
IV	Wollastonite-grossularite-idocrase	Pyroxene-hornfels
	Wollastonite-grossularite-forsterite	"
	Calcite-wollastonite	"
	Microcline	"
	Wollastonite-quartz	Sanadine

ZONAL DISTRIBUTION
AND
ABUNDANCE OF METAMORPHIC MINERALS

PLATE V

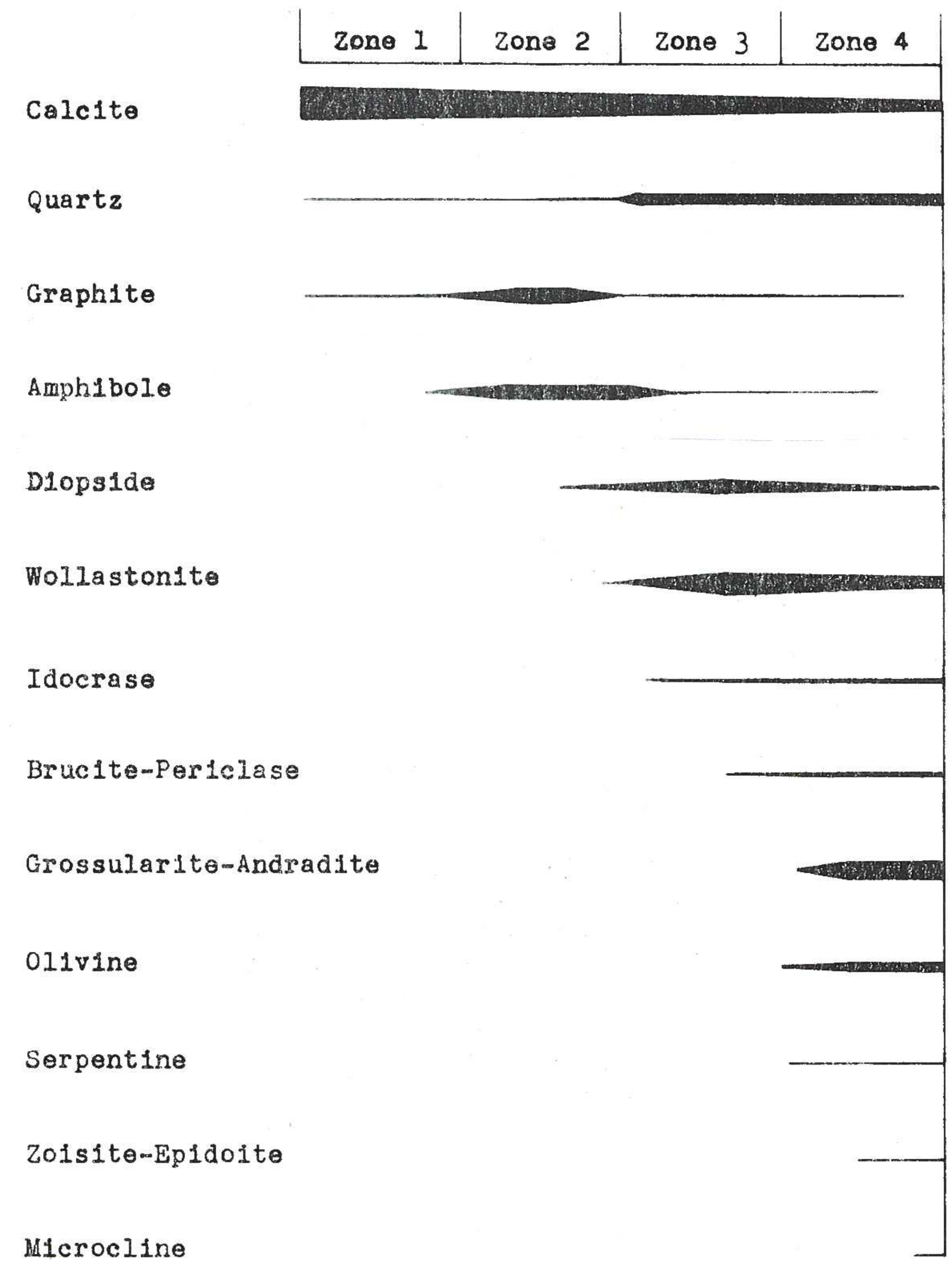


PLATE VI

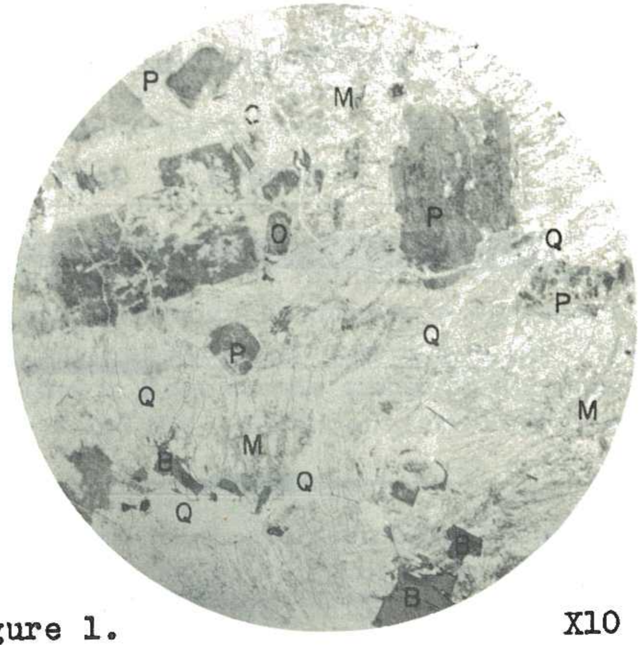


Figure 1. X10

Sample 33Q. Quartz monzonite of the Little Cottonwood Stock. Microperthite (M), quartz (Q), plagioclase (P), orthoclase (O), and biotite (B). Feldspars are partly altered to sericite and clay minerals.

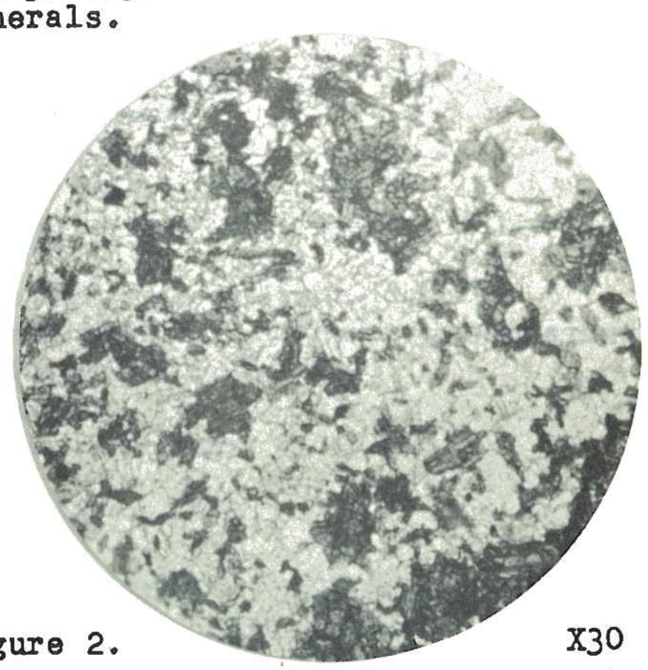


Figure 2. X30

Sample 33. Xenolith in the Little Cottonwood Stock. Dark prisms of hornblende with plagioclase, orthoclase and quartz.

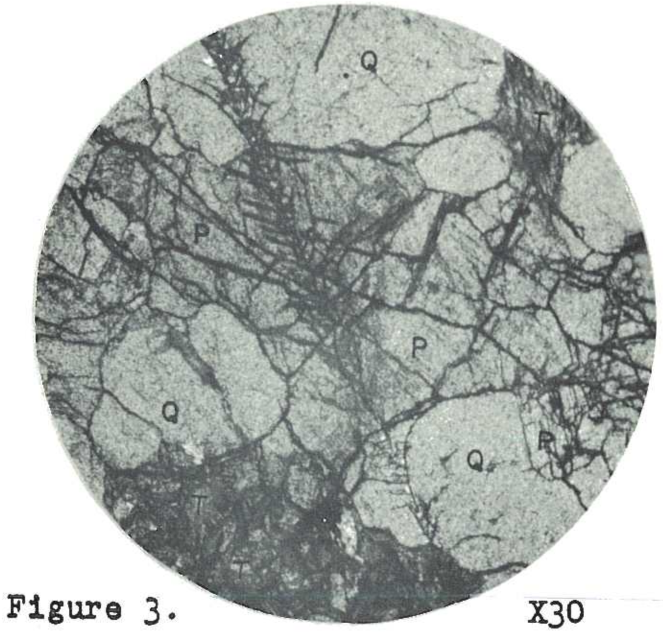


Figure 3. X30

Sample 84. Mineralized quartz monzonite on the contact with limestone. Quartz (Q), plagioclase (P), tremolite (T), and malachite within the fracture.

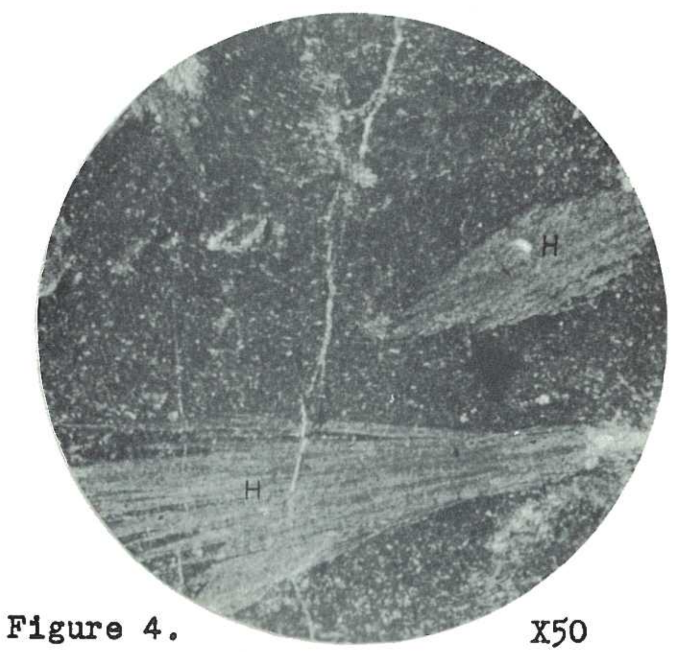


Figure 4. X50

Sample 112. Amphibole limestone. Hornblende (H), opaque flakes of graphite and fine grain calcite.

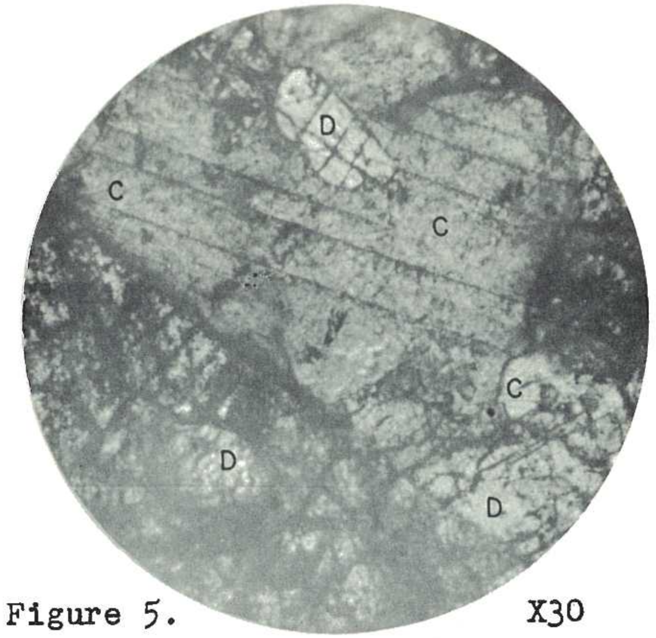


Figure 5. X30

Sample 24. Diopside marble. Diopside (D), and calcite (C).

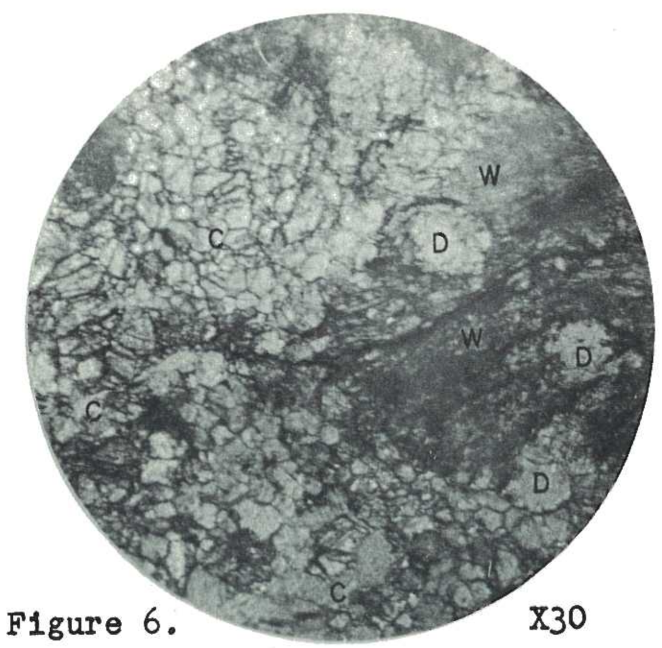


Figure 6. X30

Sample 14. Wollastonite-diopside-idocrase marble. Wollastonite (W), diopside (D), idocrase (I), and calcite (C).

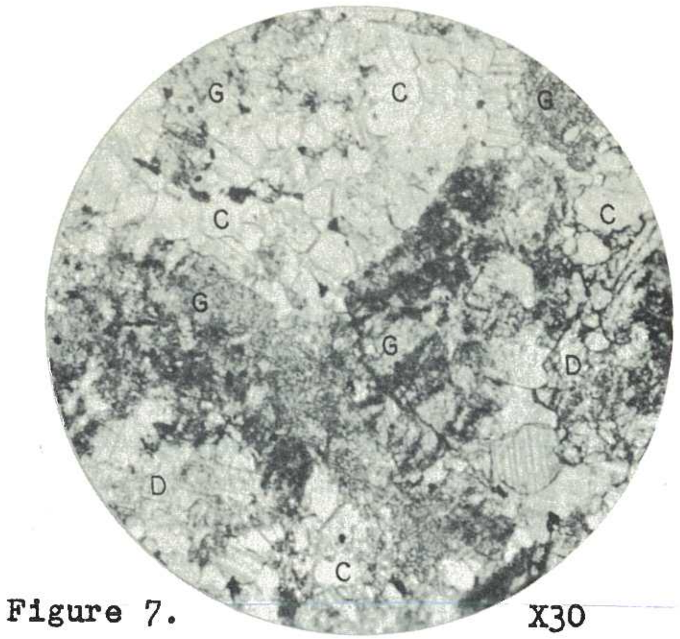


Figure 7. X30

Sample 15. Garnet-diopside marble. Garnet (G), diopside (D), and calcite (C).

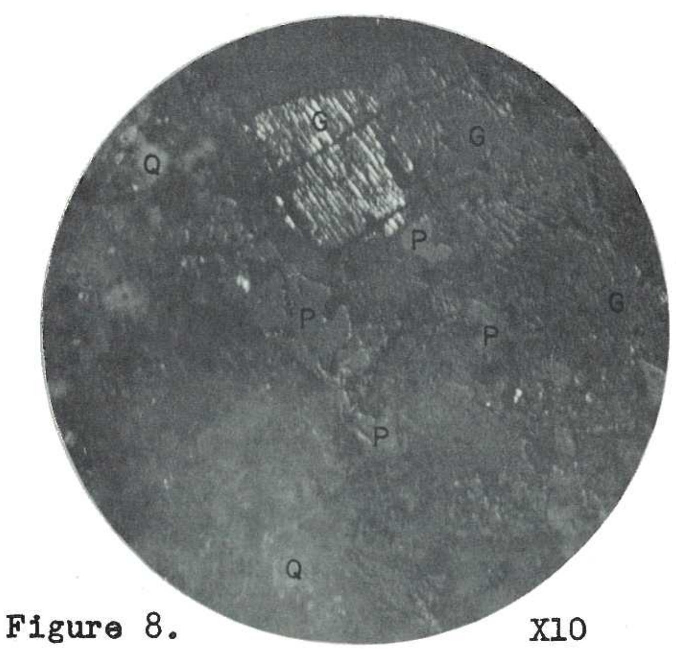


Figure 8. X10

Sample 2. Ore from the Milkmaid mine. Galena (G), pyrite (P), and quartz (Q).

STRUCTURE

Stock

The Little Cottonwood Stock represents the major structural feature within the area. The intrusion of the stock domed and fractured the surrounding strata; the strike of the strata are essentially parallel to the oval contact of the stock as shown on Plate IX. The outward dipping margins of the stock are clearly defined as shown on Plate II.

Folds

The area under consideration lies on the southern flank of the Park City Anticline (Boutwell, 1912, p. 94). The axis of the anticline strikes east-northeast with an eastward pitch, and passes near the northwest corner of the area. The strata within the area form a great homocline, and the north flank of an anticline.

The strata comprising the homocline occur north of Deer Creek where they have an average strike of north 45 degrees east and dip approximately 45 degrees southeast; local variations in strike of the strata range from north 30 degrees to 70 degrees east and their dips range from 20 degrees to 65 degrees southeast.

The strata on the south side of Deer Creek represent the northern flank of an anticline, the axis of which strikes north 55 degrees west through the top of Box Elder Peak, 11, 101 feet elevation, approximately one-half mile south of the mapped area. The strata south of Deer Creek within the area strike nearly east-west and dip from 30 to 40 degrees to the north.

Faults

Thrust faults within the area are indicated by a large thrust sheet of Madison Limestone overlying Ophir Shale on the hill on the east side of Silver Fork, just off the eastern edge of the mapped area (see Plate II). Metamorphosed limestones that form the thin mantle over the quartz monzonite, as shown in Plate II, may represent a westward extention of

the thrust. A study of the complex structural features in the area to the south and east would be valuable in outlining the thrust sheets. At the present time Arthur A. Baker and Max Crittenden of the U. S. G. S. are engaged in a study of the region which will undoubtedly help clarify the complex structural relationships.

High angle faulting which preceeded the intrusion of the stock is represented by the two faults bordering the northeastern and southwestern edges of the prominent quartzite hill east of Silver Lake (Plate IX). The southern fault is located along Silver Creek and strikes approximately north 65 degrees west into the stock. The fault cannot be traced into the stock, which indicates that the fault preceeded the intrusion of the stock. Mississippian limestone has been faulted down to rest adjacent with Cambrian quartzite, showing a stratigraphic displacement of 1,600 feet, assuming that a normal section between the top of the Tintic Quartzite and the base of the Deseret Limestone, as shown on Plate III, has been displaced. If the limestone represents an extension of the thrust sheet overlying the Ophir Shale that exists towards the east, the displacement would be only a few hundred feet. The fault zone which is narrow and shows little brecciation is hidden by alluvium except for a few exposures close to the intrusion.

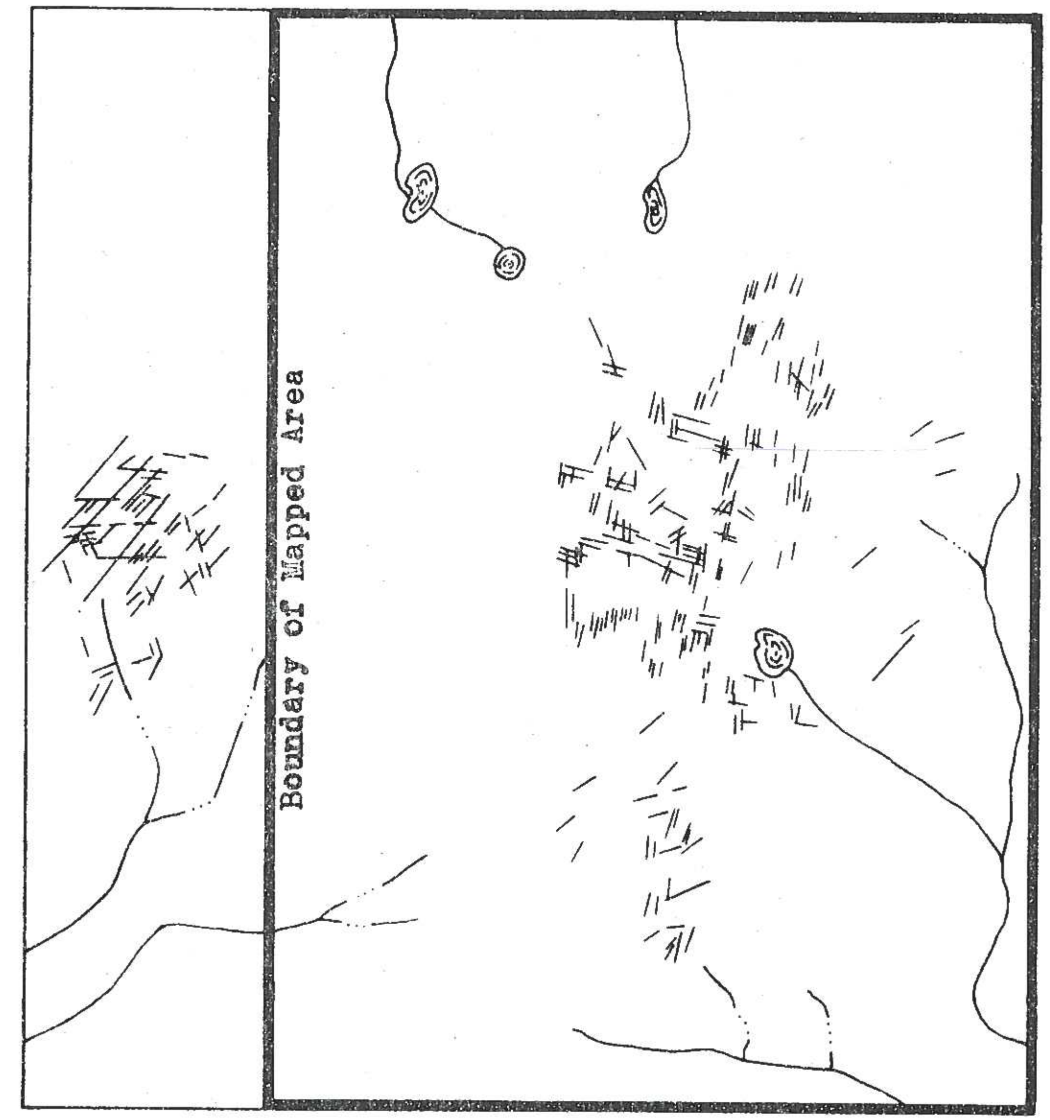
The fault on the northeast side of the quartzite hill strikes approximately north 45 degrees west and separates Precambrian rocks on the north from Cambrian rocks on the south. The stratigraphic displacement measures several hundred feet.

A large post intrusive fault parallels the head waters of Deer Creek. The fault strikes approximately north 70 degrees west and separates unmetamorphosed Pennsylvanian sandstones and limestones on the south from quartz monzonite and highly metamorphosed Mississippian limestones on the north (Plate IV, figure 3). Exposures of the fault occur on the divide between Alpine Canyon on the west and Deer Creek Canyon on the east where unmetamorphosed limestone rests directly adjacent to the quartz monzonite. The stratigraphic displacement is not over a few hundred feet if a normal section is assumed as shown on Plate III. The lack of metamorphism of the southern rocks indicate that they must have undergone more displacement than is shown by the missing section. The effects of metamorphism on the limestone on the north side of the creek were pronounced for a horizontal distance exceeding 4, 000 feet. The Deer Creek fault must have a horizontal slip of at least 3, 000 feet.

A series of northeasterly striking normal faults occur in the area and have dips running from 70 degrees to 80 degrees toward the northwest, and are characterized by having vertical displacements generally less than 100 feet with narrow brecciation zones. Several of the faults have been important as localizers of metallic minerals.

Joints

All of the rocks of the area are jointed to varying degrees. The high degree of jointing in the quartz monzonite, combined with the steep relief resulting from the cutting action of glaciers has been responsible for the accumulations of large bodies of talus near the summit of the main divide. Joint patterns taken from aerial photographs are plotted on Plate VII. Of special interest is the change in direction of the major joints in the stock from west to east. The major joints on the western part of Plate VII strike in a northeast direction, closely paralleling the axis of the Park City Anticline, whereas the major joints on the east strike a few degrees east of north, paralleling the contact between the stock and sedimentary rocks. The western joints probably represent fractures developed by mountain building activities whereas the eastern joints represent fractures due to tensional stresses produced in the cooling stock. Joints in the sedimentary rocks have similar directional trends with those of thewestern part of the intrusion as shown on Plate VII.



THE JOINT AND FAULT SYSTEM OF SILVER LAKE FLAT

(Taken from the U.S.D.A. Aerial Photos COH-1-73, 125.)

PETROFABRIC ANALYSIS

A petrofabric study was made of the amphibolic limestones of metamorphic Zone 2, exposed along a northern tributary of Deer Creek. A dozen oriented samples of the rock were taken at approximately 100 feet intervals. (Plate IX, samples 101-112). The dark gray limestone contains prismatic amphiboles one-sixteenth to one-quarter inch in length that stand out on weathered surfaces in moderate relief. Thin sections of the material show that at least 70 per cent of the long axes of the amphiboles are located parallel or closely parallel to the plane of bedding. The high graphite content of some of the samples make their thin sections almost opaque. The graphite, probably derived from carbon in organic material converted by metamorphism, occurs as small flakes that also parallel the bedding of the limestone.

The various orientations of the long axes of the amphiboles are plotted on Plate VIII. The axes pass through the center of a sphere and intercept the surface of the sphere's bottom half. Points near the center approach vertical dips and those near the circumference approach horizontal dips. The contours on the lower half of Plate VIII represent the relative concentrations of the amphiboles' long axes at various orientations. The dark area includes nearly 50 per cent of the measured prisms. From 50 to 100 prism axes were oriented on each of the 12 samples.

The enclosed area on the upper part of the Plate VIII represents the projection of poles normal to the various planes of bedding of the samples. The poles are plotted as passing through the center of the sphere and cutting the sphere's bottom surface. The line drawn at right angles to the center of the enclosed area represents the average strike of the various bedding planes. The purpose of these projections is to show the average strike and dip of the samples and the varied orientation that might be caused by difference in particular strikes and dips.

A study of Plate VIII shows a preferred orientation of amphiboles along the bedding planes of the samples with directions closely paralleling the strike and at right angles to the strike. The greatest concentration was at right angles to the strike at approximately north 20 degrees west.

A logical explanation for the preferred mineral orientation in the samples is that the metamorphic effects created by the intrusion of the

stock produced the graphite and amphiboles whereas the stresses accompanying the intrusion produced their orientation.

The injection of the stock domed the surrounding rocks. The bedding planes acted as slip planes over which movement occurred. Compressive stresses were produced in a line radiating away from the intrusion and resulted in slippage along the bedding planes, producing the north 20 west orientation.

Tensional stresses developed at right angles to the compressive stresses producing secondary slippage along the strike of the beds. The slippage orientated the amphiboles along the bedding plane, closely parallel with the strike.

MINERALOGY

Minerals that are found in the area are listed in the following section with their locations and natures of occurrence. The numbers following certain minerals represent locations of the more notable occurrences as plotted on Plate IX. The metamorphic zones referred to are plotted on Plate IX and are discussed in detail under metamorphism. The number of minerals found may have been increased if it were not for the many caved or extremely dangerous mines and prospects the author was unable to enter. The minerals are arranged in the order followed in Dana's "System of Mineralogy."

Native Elements

Graphite (1). Graphite is common in the amphibolic limestones of metamorphic Zone 2 where it occurs as microscopic flakes. Certain analyzed rocks contained as much as 5% graphite.

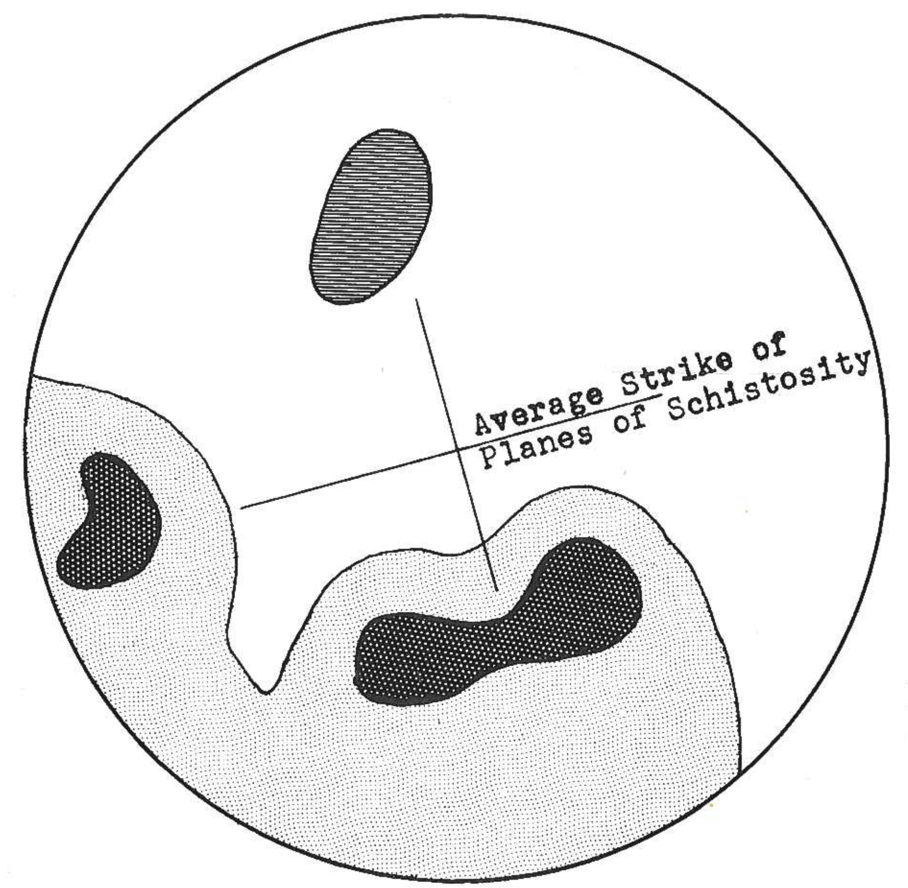
Gold. Traces of gold are found in the ores of both the Milkmaid and the Ontario mines (located in the Tintic Quartzite west of Silver Fork). It is associated with galena and pyrite. The occurrence of gold has been reported in several prospects along Deer Creek, where it occurs in hydrothermal veins in metamorphic limestone.

Sulfides

Molybdenite (3). Molybdenite occurs in minor amounts in quartz veins at several prospects near the head of Deer Creek. Small amounts of the mineral are found within the north-eastern striking joints in the western portion of the intrusive stock as shown on Plate VII.

Galena (2, 4). Galena is the common ore mineral at both the Milkmaid and Ontario mines. It occurs in hydrothermal fissure deposits along fractured quartzite. It is found associated with sphalerite, pyrite, chalcopyrite and argentite. Common gangue minerals of the ore consist of quartz, barite, and actinolite. In the upper oxidized zones galena is altered to cerussite and anglesite. Galena was found in several prospects in quartz gangue on the northern side of Deer Creek.

PETROFABRIC ANALYSIS OF AMPHIBOLIC LIMESTONE



(a) Contours of projections of 50 to 100 long axes of amphiboles in each of 12 samples of amphibolic limestone.

10-20% 20-30% 40-50%

(b) Contour of projections normal to planes of schistosity of the 12 samples of amphibolic limestone.

100%

Argentite (2, 4). Argentite occurs as microscopic intergrowths in the galena ores of the area and has been of major economic importance.

Bornite (2). Traces of Bornite were identified in the ores of the Milkmaid mine.

Pyrite. Pyrite is common in all hydrothermal mineral deposits of the area.

Sulfo Salts

Tetrahedrite. Tetrahedrite occurs as minute intergrowths in the galena of the Milkmaid and Ontario mines.

Oxides

Quartz. Quartz is abundant in most of the rocks in the area. It is a common gangue mineral associated with hydrothermal activity, and a major constituent of the intrusive rocks. Quartz occurs in the cryptocrystalline variety as chert throughout the metamorphic limestone.

Periclase. Periclase occurs in minor amounts in the metamorphosed Zones 3 and 4, where it occurs as microscopic grains commonly altering to brucite.

Hematite (5). Hematite is common in all the ores of the area. It occurs as earthy masses of material in several prospects north of Deer Creek.

Brucite. Brucite occurs in limited amounts as an alteration product of periclase in the metamorphosed limestone Zones 3 and 4.

Magnetite (6). Magnetite is abundant in the prospect in the Tintic Quartzite, east of Silver Lake. It is found as stringers and pods up to one foot thick in an actinolite and quartz gangue. It is a common accessory mineral in the intrusive rock.

Psilomelane (7). Psilomelane occurs in the area as a black stain or earthy material in many of the mineralized zones. The earthy variety is abundant in a prospect north of Deer Creek where it is associated with hematite.

Limonite. Limonite is common as the oxidized alteration of pyrite and magnetite at all hydrothermally mineralized zones. It commonly forms coatings on the joint surfaces of the quartzites and argillaceous rocks in the area.

Carbonates

Calcite. Calcite is the main constituent of the limestones. It is also present as a gangue mineral associated with quartz in hydrothermal mineral zones.

Dolomite. Dolomite occurs in minor amounts in the limestones of the area.

Siderite (8). Siderite is abundant in the prospects along the western contact of the metamorphosed limestone and the Little Cottonwood Stock. It occurs in bands several inches wide in the prospects.

Cerussite (2, 4). Cerussite occurs as fine crystals and as white alteration masses in the galena ores of the Milkmaid and Ontario mines.

Malachite (9). Malachite occurs in minor amounts in several prospects along the western contact of the metamorphosed limestone with the stock where it is found in minute fractures in quartz monzonite (Plate VI, figure 3).

Silicates

Orthoclase. Orthoclase is a major constituent of the intrusive rocks.

Microcline. Microcline is a major constituent of the intrusive rocks. It also occurs as a minor product of contact metamorphism in the metamorphic limestone of Zone 4.

Plagioclase group. Plagioclase feldspars are common constituents of the intrusive rocks of the area.

Pyroxene group. Diopside (10) Wollastonite (11) Pyroxene group minerals form the most spectacular mineral displays in the area. Diopside is found as nodules and lenses in the metamorphosed limestones of Zone 2 and as coarse granular grains in the diopside-wollastonite hornfels of the more highly metamorphosed limestones of Zones 3 and

4. Wollastonite is the most abundant mineral produced by metamorphism in the area. Solid masses of wollastonite with radiating plumes 3 feet long are common throughout the highly metamorphosed Zones 3 and 4. Augite is a common constituent of the intrusive rocks.

Amphibole group (12). Tremolite occurs in large radiating masses in the metamorphic limestones of Zone 2 and Zone 3. Hornblende is a common constituent of the intrusive rocks and of the metamorphosed limestones of Zone 2, where it occurs as prisms up to one-fourth inch in length.

Cordierite. Cordierite is common in some of the highly metamorphosed argillaceous rocks of the Precambrian series.

Prehnite. Prehnite occurs in minor amounts as radial interstitial aggregates in wollastonite and diopside hornfels in the more highly metamorphosed limestones of Zones 3 and 4.

Garnet group (13). Andradite and grossulerite are abundant in the metamorphosed limestones of Zone 4. Large bands of garnetiferous rock several feet wide are common in the zone.

Olivine group. Forsterite is only moderately abundant as small granules in the highly metamorphosed limestones of Zone 4. It is commonly under various stages of alteration to serpentine.

Idocrase (14). Idocrase occurs in prisms up to 1 inch long and in bands up to 1 inch wide in highly metamorphosed limestone belonging to Zones 3 and 4.

Zircon. Zircon is a minor accessory in the quartz monzonite of the intrusive.

Epidote. Epidote occurs as a minor mineral in the metamorphosed limestones of Zone 4.

Muscovite. Muscovite is abundant along the bedding planes of the Ophir Shale. The variety sericite is common as the alteration product of the feldspars and micas of the intrusive rocks. Sericite is a common gangue mineral in the Milkmaid mine.

Biotite. Biotite is a common accessory mineral in the intrusive rocks.

Serpentine. Serpentine is common as the alteration product of forsterite in Zone 4. It also occurs along the zone associated with the Deer Creek fault.

Titanosilicates

Titanite. Titanite occurs as a minor accessory mineral in the quartz monzonite of the intrusive.

Phosphates

Apatite. Apatite is a common accessory in the quartz monzonite.

Sulfates

Barite (4). Barite is a common gangue mineral at the Ontario mine.

Anglesite (2, 4). Anglesite was formed as an oxidized alteration product of the galena ores in the Milkmaid and Ontarion mines. It was of major economic importance in the mines in the past.

Tungstates

Sheelite (2, 15). Scheelite is common in the garnetiferous tactite zones of the highly metamorphosed limestones of Zone 4. Some tactites have as much as 3% WO_3. It is found in limited amounts in many mineralized zones in both the quartzites and limestones. A porphery dike cut by the Milkmaid mine in Tintic Quartzite contains up to 1 ½% WO_3. Common mineral associations of the scheelite in the dike include quartz, garnet, pyrite, epidote and amphibole.

ECONOMIC GEOLOGY

General Statement

The area surrounding the headwaters of American Fork Canyon was organized into the American Fork District on July 2, 1870 (Butler, 1943). The district extends from Silver Fork on the west to Snake Creek on the east, and from the first high ridge south of the main canyon to the divide on the north. The district covers an area approximately 10 miles on a side. Few mineral locations were made in the canyon prior to the Fall of 1870. The Miller mine was discovered 3 miles east of Silver Fork, in September, 1870. The mine sold for $190, 000 in 1872. It was the major early producer in the canyon.

The area to thew est of the American Fork District was organized into the Silver Lake District on January 28, 1871. The district included most of the area mapped in this report. The exact boundaries are unknown by the author, but probably extended westerly from Silver Fork to the divide between Deer Creek and Alpine Canyon, and from the Bullion divide on the north to American Fork Canyon on the south. The district has generally been considered as part of the American Fork District. Production figures of American Fork District in the past included the production of the Silver Lake District.

There were 260 locations made in the area prior to 1880 of which only 10 of the original locations were retained. Numerous claims have been filed over the original locations in more recent years. The important economic ore deposits of the area are located in the metamorphosed limestone north of Deer Creek and in the Tintic Quartzite west of Silver Fork. The mines in the Tintic Quartzite have been the most productive.

The workings are wet, and many have a considerable outflow of water. The tunnels close to the canyon floors are often flooded, while working higher up on the slopes are more sufficiently drained.

Tunnels in quartzite are generally in good condition and can be safely entered whereas those in altered limestones are often caved and are extremely dangerous. Most of the examinations of the workings in the limestones were restricted to the inspection of the dumps. Argentiferous galena and sphalerite have been the only ore minerals profitably mined in the past.

The demand for tungsten created by World War II stimulated the prospecting for scheelite deposits. The mineral was found in several locations near the headwaters of Deer Creek on the north side of the canyon. The scheelite was found in metamorphosed limestones containing garnet, idocrase, wollastonite and diopside. Assays in the area show as much as 3 per cent WO_3 in selected samples. As yet no extensive development of the scheelite has been attempted.

Milkmaid Mine

The Milkmaid mine has been the principal producer in the mapped area. The mine is located in the Tintic Quartzite, west of Silver Fork. It was an early producer, having shipped $13,000 in ore prior to 1880. The early ore contained 36 per cent Pb, 58 ounces of Silver, and a trace of gold. The most recent shipment was in 1954 when 25 tons were shipped with a value of $70.16 per ton. The total past production is unknown, but is estimated by James J. O"Brian, present owner, (personal communication) as being between $25,000 and $50,000.

The mine is developed by 3 tunnels having a total length of approximately 2,000 feet. The lower tunnel is terminated by quartz monzonite approximately 600 feet from the portal. The minerals deposited in the mine represent hydrothermal fissure filling and replacement. The mineralized fissure roughly strikes north 50 degrees east and dips about 70 degrees to the northwest.

Argentiferous galena is the chief mineral in the lower 2 tunnels. The ores of the upper tunnel are oxidized and include cerussite, anglesite, and galena. The upper tunnel has been the largest producer running 50 to 60 ounces of silver per ton as compared to 10 to 20 ounces of silver per ton in the lower sulphide ores. The sulphide ores contain up to .3 per cent selenium. The workings cut a 3 foot dike running .5 per cent to 1.5 per cent scheelite. Minerals from the dike recognized in hand sample included quartz, pyrite, epidote, garnet, and amphibole. No lead-silver ore is directly connected with the dike. The dike rock looks surprisingly similar to certain rocks found in the metamorphosed limestone north of Deer Creek.

Tunnel roofs are continually dripping water, yellow with iron oxide and high in arsenic. Considerable quantities of the water flow out of the lower tunnel's portal. The middle tunnel was flooded at the time of the author's visit.

The mine is presently inactive, although plans are being made to erect a small mill on the site and resume mining activities in the future.

Ontario Mine

The Ontario mine is located immediately south of the Milkmaid mine. The workings develope north-east striking fissure in Tintic Quartzite. The mines past production has been estimated by James J. O'Brian, present owner, (personal communication) as being between $25,000 and $50,000 in ore.

Most of the old workings are presently inaccessible due to water and caving. The amount of material on the three conspicuous dumps on the property shows that the total length of tunneling must have exceeded 1,000 feet.

The chief ore minerals are argentiferous galena and sphalerite, and the common gangue minerals are quartz and barite.

Future Economic Possibilities

A limited amount of ore still exists in the Ontario and Milkmaid mines. Present economic conditions prohibit the profitable extraction of the ore. Future plans of Mr. Jim O'Brian (personal communication), president of the Silver Lake Mining Co., include the erection of a small capacity mill in Silver Fork to process the ores from the Ontario and Milkmaid mines. Any future plans toward development of the ores depends on a substantial increase in the value of lead and zinc.

A limited amount of undiscovered lead-silver ore may still exist in the area. On the basis of past production and of the geologic conditions of the area, it is unlikely that any large deposits of the metals will be made in the future. Investigations should be made on the selenium known to occur in the area. The scheelite deposits of the area represent a possible future source for tungsten.

Generalizations can be made which might aid any future development of mineral resources in the area. There is little chance of finding economic deposits in the stock itself. Metallizing fluids derived from the stock have been deposited near its borders, primarily along fissures striking north 45-55 degrees east. Tintic Quartzite has been the most favorable producer of the lead-silver ores whereas the metamorphosed Mississippian limestones have been the most favorable scheelite producers. The scheelite is generally found in highly metamorphosed limestones containing garnet, wollastonite, diopside and idocrase. Intrusive dikes are generally adjacent to the richest deposits. There is considerable ground that is yet unprospected due to the lack of rock exposures. An electrical resistivity survey may be of value in locating hidden metallic deposits.

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Geology and Coal Deposits
RAGGED-CHAIR MOUNTAIN AREA
PITKIN and GUNNISON CO'S-COLO.
T. L. Hanks - 1962
R 89 W
SCALE 1:48,000
4000 0 4000 8000 12000 16000 Feet
R 90 W
DH-23 (1400')
DH-13 (1400')
DH-8
Area not mapped in detail
Geology taken from areal photographs
PLACITA MINE
Placita
McClure Pass
COLLGATE MINE
DH-3
DH-4
DH-5
DH-6
Eagle Nest Peak
PITKIN CO.
GUNNISON CO.
ELK MTN.
LILY LAKE
GALLOWAY PROSPECT
CENTER MINE
MARBLE
McINTIRE PROSPECT
SHEEP MTN
SPATAFORE No. I
CHAIR MTN.
Anthracite Pass
RAGGED MTN.
Bark Basin
McLAUGHLIN No. I
BEAR PROSPECT
Springhouse Park
North Slope MARCELLINA MTN
South Rim of Coal Basin and Placita Area
Composite section
FEET
COAL Thickness - Range
Anthracite, Munsey and South Muddy Creeks Area
Composite section
FEET
COAL Thickness - Range
EOCENE
Wasatch ("Ruby") formation
Ohio Creek conglomerate
UPPER CRETACEOUS
Mesaverde formation
Undifferentiated member
Paonia member
Upper sandstone unit
Middle sandstone unit
Bowie member
Rollins sandstone member
Mancos shale
COVER
Number of thin coal beds - Exact stratigraphic position not known
EXPLANATION
Sandstone
Shale
Sandstone and shale interbedded
Conglomerate
Quartzite
Coquina
Coal and/or boney coal
INDEX MAP
DENVER
COLO.
MAP AREA
ASPEN
PITKIN Co.
MARBLE
CRESTED BUTTE
GUNNISON Co.
GUNNISON
SOURCES of BASE MAP
Enlarged from U.S. FOREST SERVICE MAP
Enlarged from USGS MT. GUNNISON (15 min. Topog. Quad.)
Compiled by JACK AMMANN Photogrammetric Engineers
Advance Proof USGS SNOWMASS MTN. SW (7.5 min. Topog. Quad.)
Advance Proof USGS ANTHRACITE NW (7.5 min. Topog. Quad.)
EXPLANATION
SEDIMENTARY ROCKS
Qal
Alluvium
Recent
QUATERNARY
Tw
Wasatch ("Ruby") formation
Variegated shales, sandstones and conglomerates
UNCONFORMITY
Toc
Ohio Creek conglomerate
Friable conglomeratic sandstone
Eocene
TERTIARY
UNCONFORMITY
Kmvu
Undifferentiated member
Massive sandstones separated by sandy shales
Kmvp
Paonia member
Shale and sandstone (Coal-bearing)
Kmvb
Bowie member
Shale with middle and upper sandstone units (Major coal-bearing strata)
Kmvr
Rollins sandstone member
White, coarse-grained, massive sandstone
MESAVERDE FORMATION
Upper Cretaceous
CRETACEOUS
Km
Mancos shale
Dark-gray, sandy shale
Pu
Undifferentiated
Undifferentiated
PALEOZOIC & MESOZOIC
IGNEOUS ROCKS
Ti
Quartz monzonite porphyry and related rocks
Trg
Rock glaciers
Resulting from porphyry talus
Tis
Porphyry sill
Tgd
Granodiorite
Tid
Diabase dike and related rocks
TERTIARY
Contacts
Definite
Approximate
Concealed
Faults
Synclinal axis
Drill holes
Gas well
Diamond drill
Coal prospects
Adit
Trace of geologic section
Detailed coal section and sample
Detailed coal section only
6000 Structure contour (Top Rollins sandstone)