Geology and ore deposits of the Alder Gulch area Little Rocky Mountains, Montana
by Robert Leslie Bailey

A thesis submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree of
MASTER OF SCIENCE in Earth Science (Geology Option)
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Abstract:
In the Little Rocky Mountains, Montana, stock-like Tertiary intrusives, consisting of syenite and trachyte porphyries to quartz-rich (alaskite) syenite porphyries domed the Paleozoic and Mesozoic sedimentary rocks. Orthoclase, sodium-rich plagioclase, hornblende and quartz are common constituents of the Tertiary intrusives. Quarts and plagioclase are more abundant at depth.
Post-intrusive erosion has exposed the Tertiary intrusives and the sedimentary rocks dipping away from it. The main intrusive is at least 2400 feet thick and is evidently floorless despite the presence of a few small intrusive domes which show concordance along their contacts with overlying Cambrian rocks and underlying Precambrian metamorphic rocks.

Planes of weakness and/or faulting confined to the Precambrian basement rocks could have facilitated doming of the sedimentary rocks and emplacement of the intrusive body. Ring faulting along the contact between the Tertiary intrusives and the sedimentary rocks indicates post-intrusive uplift probably due to renewed intrusive activity at depth.

Gold deposits in the Little Rocky Mountains are in shear zones in the Tertiary intrusive rocks and were mined between 1884 and 1950 producing gold worth nearly ten million dollars. Silicified, pyritized rock halos enclose the nearly vertical shear zones and also contain secondary-orthoclase, flourite, calcite, and sericite. Hydrothermal solutions moving througt the channelways in the heavily fractured rock, characteristic of the shear zones, apparently introduced and/or concentrated the gold and alteration minerals present. Other base metals such as copper, molybdenum and silver are weakly anomalous in the shear zone halos but not in amounts economically significant at the present time.

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Date May 22, 1974

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ABSTRACT

In the Little Rocky Mountains, Montana, stock-like Tertiary intrusives, consisting of syenite and trachyte porphyries to quartz-rich (alaskite) syenite porphyries domed the Paleozoic and Mesozoic sedimentary rocks. Orthoclase, sodium-rich plagioclase, hornblende and quartz are common constituents of the Tertiary intrusives. Quartz and plagioclase are more abundant at depth. Post-intrusive erosion has exposed the Tertiary intrusives and the sedimentary rocks dipping away from it. The main intrusive is at least 2400 feet thick and is evidently floorless despite the presence of a few small intrusive domes which show concordance along their contacts with overlying Cambrian rocks and underlying Precambrian metamorphic rocks.

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I. INTRODUCTION

Geographic Setting

The Alder Gulch area, consisting of 2.5 square miles, is located in the southeast part of the Little Rocky Mountains, Montana, approximately 100 miles northeast of Lewistown, Montana and 100 miles southeast of Havre, Montana (see Plate I).

The Little Rocky Mountains, rising abruptly 3,000 feet above the surrounding plains, are elliptical in shape, occupy nearly 100 square miles, and are isolated from any major mountain chains. Maximum elevation in the Little Rocky Mountains is 5,800 feet above sea level.

The map area is bounded on the north by Antone Ridge, on the west by a north-south line through the peak of Regal Mountain, on the south by the drainage of Cowboy Gulch and on the east by a north-south line through the peak of Carter Butte (see Plate XIII).

The area is drained by small seasonally dry streams which form a radial pattern. Most of these streams flow in sharp V-shaped canyons.

Climate in the area is semi-arid, but the mountains have more precipitation than the surrounding plains. Average annual rainfall in the surrounding plains is 17 inches, half of which falls in the months of May, June and July. Summers are warm but temperatures seldom reach 90° F. Winters are cold; subzero temperatures are common.

Purpose of Study

The purpose of this study is to attempt to understand the general geology of the Alder Gulch area, Little Rocky Mountains, Montana and in particular to understand the origin and character of the mineralization and alteration.

Previous Geologic Investigations in the Little Rocky Mountains

Earliest geologic work in the Little Rocky Mountains was a study of the general geology by Weed and Pirsson (1896). Weed thought that the mountains had been formed by the intrusion of a laccolith. The floor of the laccolith was thought to be represented by the Precambrian metamorphic rocks seen in the gulches. More recent mapping has revealed that the Precambrian metamorphic exposures are inclusions which occur throughout the intrusive (Brockunier, 1936; Dyson, 1939; Knechtel, 1959). Pirsson studued the petrography of the igneous rocks in the Little Rocky Mountains and concluded that they belong to an alkalic-granite-syenite series. A short account of the ore deposits was included in his report.

Emmons (1908), Corry (1933), and Bryant (1953) describe the ore deposits and the history of production of the gold mines in the Little Rocky Mountains.

Dyson (1939) described the Ruby Gulch ore deposits (see Plate I) and summarized the general geology of the mountains. His structural model for the mountains is a stock-like intrusion which shows concordance with the overlying sedimentary strata in some areas.

Larsen (1940) included the Little Rocky Mountains in his analysis of the petrographic province of Central Montana.

Knechtel (1959), mapped in detail the sedimentary rocks of Paleozoic and Mesozoic age in the Little Rocky Mountains and included the Precambrian (pre-Belt age) metamorphic rocks and Cenozoic intrusive rocks as undifferentiated units.

Collier (1915), Collier and Cathcart (1922), Gries (1953), and Lochman (1953), conducted geologic studues of the Paleozoic and Mesozoic rocks in the Little Rocky Mountains.

The only detailed geologic work in the Alder Gulch area was conducted by Sawyer R. Brockunier in a Ph.D. thesis study (1936). In this paper, he discussed the geology of the Little Rocky Mountains outward to the surrounding plains. The igneous rocks of the Alder Gulch area were described from oldest to youngest as "Antone syenite porphyry, Sullivan trachyte porphyry, and syenite porphyry dikes". Precambrian rocks were described as gneisses and schists but were undifferentiated on the map. Scale of the mapping was at 1:48,000. Brockunier was a strong proponent of a laccolithic model for the origin and configuration of the Little Rocky Mountains. He discussed at length the possible shapes and modes of intrusion of the laccoliths.

II. REGIONAL GEOLOGY

Petrographic Province of Central Montana

The Little Rocky Mountains are located in the northeast corner of what is termed the petrographic province of Central Montana (Pirsson, 1905; Larsen, 1940). This Tertiary province includes igneous rocks near the eastern flanks of the Rocky Mountains extending nearly 400 miles from Yellowstone National Park on the south to the Canadian boundary on the north (see Plate II).

The mountains whose igneous rocks make up the province are the Little Rocky Mountains, Bearpaw Mountains, Adel Mountains Volcanics (Big Belt Mountains), Sweetgrass Hills, Highwood Mountains, Moccasin Mountains, Judith Mountains, Little Belt Mountains, Castle Mountains, Crazy Mountains, Yellowstone National Park Area and the Absaroka Range (including the Gallatin Range). Age-date determinations are as follows: Bearpaw Mountain intrusives, 68 million years; Bearpaw Mountain extrusives, Eocene (40-60 million years); Adel Mountain Volcanics, late Cretaceous (70-80 million years); Sweetgrass Hills, Neogene (30-70 million years); (all from Gilluly, 1965), and Absaroka-Gallatin ranges, Wasatchian to Oligocene (with radioactive age dates 49.0 to 53.0 million years), (Chadwick, 1970). Gilluly (1965) postulates that since the Little Rocky Mountains are similar in mineralogy and occurrence to the Bearpaw Mountains they are probably nearly the same age (68 million

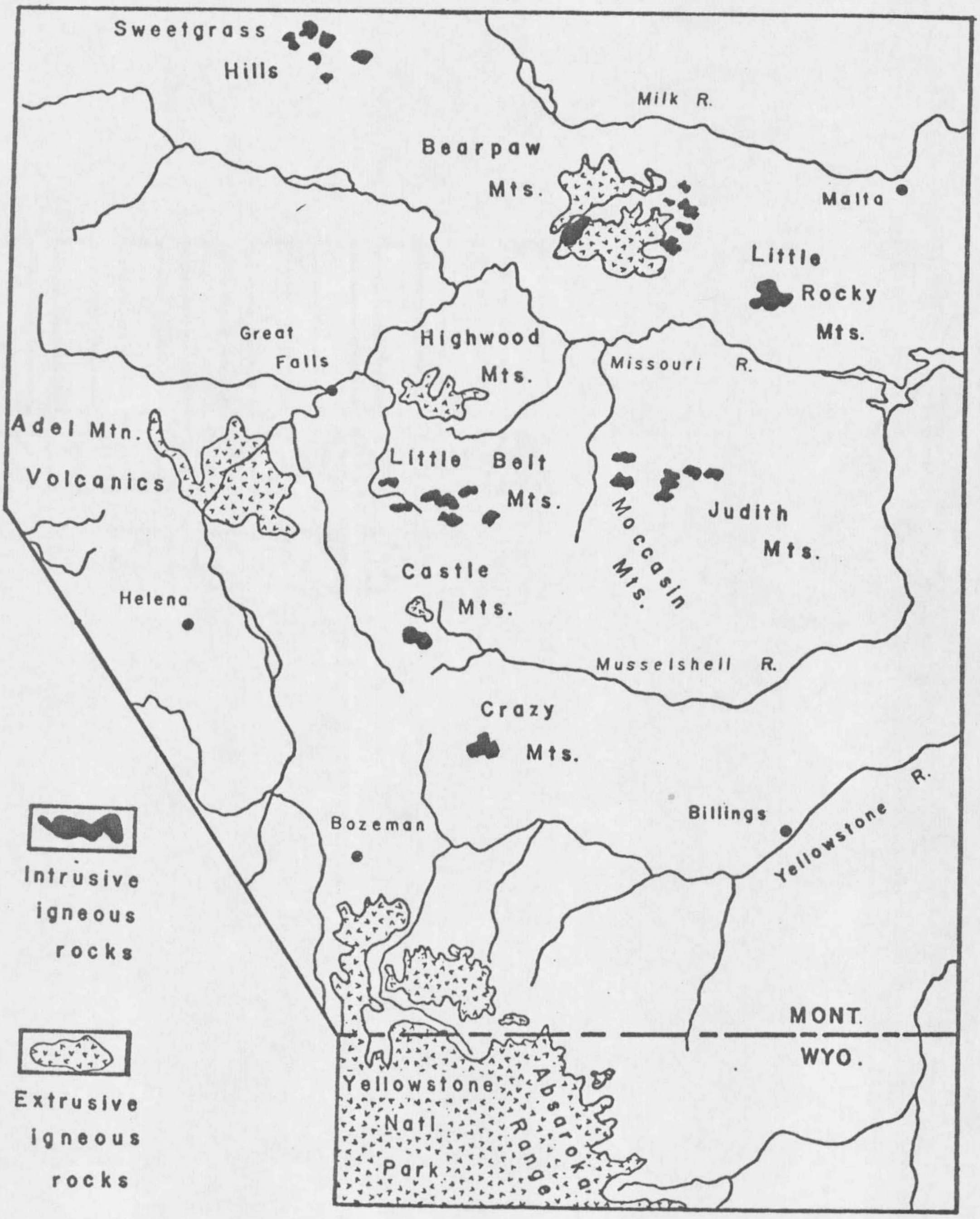


Plate II. Map of the Central Montana petrographic province.

years).

Larsen (1940) found that each of the twelve large mountain masses is made up of one or more subprovinces of igneous rock which vary from mafic to felsic but as part of a smooth variation curve. A mineral and chemical characteristic of the province is that the mafic rocks of each subprovince differ chemically from those of other subprovinces more than do the felsic rocks of each subprovince (Larsen, 1940).

Chemically, the rocks range from lime-alkalic rocks to soda and potash-rich plagioclase-poor rocks. Rock types recorded in the province range from rhyolites, andesites and their phaneritic equivalents to potash and soda-rich rocks such as shonkonites, nepheline syenites, and syenites (Pirsson, 1905; Larsen, 1940). Age relationships show the older rocks are commonly lime-alkalic and the younger alkalic rocks commonly show a cycle of eruptions from mafic to felsic with time (Larsen, 1940). These rocks take the form of flows, stocks, dikes and laccoliths. In general, stocks and radiating dikes may be either lime-alkalic or alkalic but the laccoliths are alkalic (Larsen, 1940).

The structural setting and method of emplacement vary from the northwest-trending zones of volcanic centers in the Absaroka-Gallatin ranges to the localized intrusives of the Little Rocky, Judith and Moccasin mountains. Larsen (1940) contends that since the rocks of this province show a clear chemical relationship, they must have been derived from a common parent magma by a rather simple process of differentiation and/or contamination. This process of differentiation involves two episodes;

1. Deep seated differentiation to yield the primary magma of each subprovince, which is believed to be represented by the most mafic rock.
2. Shallow differentiation of primary magmas to yield the various rocks of each subprovince. This differentiation would consist of crystal settling and assimilation of granitic material to give the various rocks of each subprovince.

To form the alkalic rocks of the northern part of the province, a long time of differentiation would be required to allow for removal of most of the calcium, iron and magnesium. The relatively undisturbed Cretaceous rocks underlying the northern Montana plains suggest that differentiation was allowed to go undisturbed (Larsen, 1940).

Little Rocky Mountains

The Little Rocky Mountains are an alkalic subprovince of the Central Montana petrographic province (Larsen, 1940). Stock-like intrusions of syenite porphyry during Tertiary time domed the Paleozoic and Mesozoic strata in an area occupying nearly 100 square miles leaving the surrounding plains relatively undisturbed. Most of the sedimentary rocks have been eroded from the crest of the range leaving steeply dipping extensively faulted strata surrounding the igneous intrusive (see Plate I).

The oldest rocks in the Little Rocky Mountains are Precambrian gneisses and schists which are exposed throughout the intrusive as roof pendants and along the margin of the intrusive beneath the Paleozoics.

Overlying these oldest rocks is a series of sedimentary rocks ranging in age from Middle Cambrian to Upper Cretaceous (Knechtel, 1959). The sedimentary rocks of Paleozoic age exposed in the Little Rocky Mountains have an aggregate thickness of nearly 2,700 feet (Knechtel, 1959). The sediments were deposited mainly in a marine environment and are now represented mainly by limestone and dolomite, though sandstone, shale and conglomerate are present. The rocks of Paleozoic age, which unconformably overly the Precambrian rocks, are in ascending order, the Flathead Sandstone of Cambrian age, the Emerson Formation of Cambrian and Early Ordovician age, the Bighorn Dolomite of Late Ordovician age, the Maywood Formation and Jefferson Limestone of Late Devonian age, the Three Forks Shale (?) of Devonian and Mississippian age, and the Madison Group of Mississippian age (Knechtel, 1959).

Sedimentary formations of Mesozoic age which crop out in the Little Rocky Mountains have an aggregate thickness of approximately 4,000 feet (Knechtel, 1959). These rocks include strata of marine and nonmarine origin. Shales are the most common rock type, but interbedded sandstone as well as small amounts of conglomerate and limestone are present. Strata of Mesozoic age which unconformably overlie the rocks of the Madison Group are in ascending order, the Rierdon, Swift, and Morrison formations of Jurassic age and the Kootenai Formation, the First Cat

Creek sand (of drillers), the Thermopolis Shale, Mowry Shale, Warm Creek Shale, and the Montana Group of Cretaceous age (Knechtel, 1959). The intrusive contact is locally concordant with Cambrian strata but most contacts between the intrusive and the sedimentary rocks are fault contacts (Knechtel, 1959).

The igneous rocks of the Little Rocky Mountains are alkalic with a low lime, iron and magnesia content and a high potash content typical of the alkalic subprovinces. Rocks in some areas are characterized by a high silica content which is mainly post-magmatic. Commonly the intrusive occurs as a light gray to white syenite porphyry with phenocrysts attaining lengths of 25 mm. The even-grained groundmass is made up of feldspar and the phenocrysts are plagioclase and orthoclase and locally quartz. The various porphyries grade into each other throughout the area. Dikes are sparse and are commonly very similar mineralogically to the main intrusive body. No contact-metamorphism of the country rock is present in the Little rocky Mountains.

In gross structural aspect, the northeast trending Little Rockies anticline, approximately 40 miles in width, lies between the northwest trending Blood Creek syncline on the south and the east-west trending Coburg syncline on the north (Brockunier, 1936). Many post-intrusive low angle thrust faults were mapped by Reeves (1924) between the Little Rocky Mountains and the Bearpaw Mountains to the northwest.

Two of these thrust faults cut across the northwestern part of the Little Rockies area but are shallow, extending no deeper than the Upper Cretaceous (Dyson, 1939). These faults have been explained by Reeves (1924) as related to the extrusive activity in the Bearpaws which resulted in "overloading" and "flow" of material away from the Bearpaw Mountains. Ring faulting and other high angle faulting related to the domal structures in the Little Rocky Mountains is younger than the intrusives, which are cut by the faults throughout the area (Knechtel, 1959).

The syenite porphyry has been explained by many writers as a laccolith or laccoliths (Weed and Pirsson, 1896; Corry, 1933; Brockunier, 1936) while others contend that it forms a stock-like body (Dyson, 1939). Evidence in favor of a laccolith-type intrusion is as follows (Weed and Pirsson, 1896; Brockunier, 1936):

1. The large number of dome shaped intrusions (22)
2. Symmetry of the domes
3. Multiple occurrence of circular domes
4. Feeble nature of contact metamorphism
5. Porphyritic texture of the igneous rocks
6. Presence of one domical intrusive with a floor.

Evidence in favor of a stock-like intrusion is as follows (Brockunier, 1936; Dyson, 1939; Knechtel, 1959; Corry, 1933):

1. Lack of a visible floor of the main intrusive in the mine workings or on the surface
2. The presence of discordant intrusives
3. Resemblance of the intrusives to cupolas on a batholith
4. Mineralogic similarity of the prophyry in adjacent domes suggesting one stock-like intrusive rather than many small laccoliths

The evidence cited above is inconclusive in proving either hypothesis. Neither rock on the surface nor in vertical drill holes no. 1 (2,000 feet) and no. 2 (1,070 feet) provide conclusive proof of the configuration of the intrusive mass at depth (see Plate XIV). The rock type and texture is basically unchanged at depth except for an increase in quartz and a decrease in orthoclase which is normal for intrusive masses without a floor and from a common magma chamber (Barth, 1966). The Ruby mine (see Plate I) and Independent mine areas which were described as conduits by laccolith proponents were mined to depths of 700 and 500 feet respectively without any change in texture or mineralogy. It seems unlikely that the two drill holes would also be located on conduits. Most intrusives with a known floor such as the Shonkin sag laccolith near the Highwood Mountains and some of the Henry Mountain intrusives in Utah exhibit horizontal layering of the rock types due to fractional crystallization. The evidence suggests that the Little Rockies represent a stock-like central intrusive which has spread or branched out into the surrounding area forming small laccolithic bodies. This explanation satisfies the inconsistencies in both theories. Circular dome-shape intrusives could result from an increase in viscosity of a stock-like body of magma as it intruded and domed up the sediments overlying the Precambrian rocks. A change in viscosity along with a loss of volatiles may also explain the lack of contact-metamorphism.

Economic Geology

Petrographic Province of Central Montana

The precious metals and base metals which are common to the subprovinces of the petrographic province of Central Montana are gold, silver, copper, lead and zinc. Many other metals occur in the various subprovinces, but this discussion will be limited to include only those metals which have been mined.

Gold and silver have been mined in the following seven subprovinces: Little Rocky Mountains, Judith Mountains (Warm Springs District), North Moccasin Mountains (Kendall District), Little Belt Mountains (Neihart District), Castle Mountains, and Absaroka Range (Cooke City District), (Mineral and Water Resources of Montana, 1963).

Recorded metal production in the various districts of the petrographic province of Central Montana is shown on Table 1 (Winters, 1968; Robertson, 1950; Koscman and Bergendahl, 1968; McCarthy and Lakin, 1956). The districts are listed in the order of the value of their

Table 1. Mining districts and production in the Central Montana petrographic province.

SUBPROVINCE (district)	PRODUCTION - (in thousands of dollars)				
	Au	Ag	Cu	Pb-Zn	TOTAL
Little Belt Mountains (Neihart)	1,675	17,000e	X	X	20,000e
Little Rocky Mountains	9,800	200			10,000
Moccasin Mtns. (Kendall)	9,094	36	X	1	9,100
Judith Mtns. (Warm Springs)	4,547	108	6	22	4,700
Castle Mtns.		1,826	5	1,696	3,500
Absaroka Range (New World)	1,650	X	X	X	1,800
(Emigrant)	400				400
TOTAL					49,500

X - value of production (unrecorded)
e - estimated value of production

recorded production. Although gold was the metal common to most districts, silver was the most abundant metal mined in the Neihart District, the richest district in the province. Total value of metal production in the petrographic province of Central Montana to 1966 is 50.5 million dollars which is approximately 1 percent of the estimated 5 billion dollars worth of metals produced in the state up to 1966 (Perry, 1962; Minerals Yearbook, 1966).

The metals in the districts mentioned above occur as replacement deposits in limestone and dolomite, deposits along the intrusive contact, disseminations in the intrusives, contact metamorphic deposits, and fracture-fillings in the intrusive and country rock. Replacement deposits in limestone and dolomite, fracture filling deposits, and deposits along the intrusive contact are common throughout the petrographic province of Central Montana. Ore disseminated in the intrusive is present only in the Little Rocky Mountains and Little Belt Mountains. The only contact metamorphic deposit is in the Cooke City District.

No distinct metallogenic subprovince or provinces within the petrographic province of Central Montana are indicated by the above mining districts. Metal deposits in and around the Boulder Batholith and related intrusives are similar in type, distribution and occurrence to those in the petrographic province of Central Montana. The number of deposits related to the Boulder Batholith is larger correspoding to the greater extent of igneous activity and larger variety of structural and chemical conditions favorable for the formation of ore deposits.

Little Rocky Mountains

The history of gold and silver production in the Little Rocky Mountain District began as it did in many precious metal districts with the discovery of placer gold in Alder Gulch by Pike Landusky in 1884 (Lyden, 1948; Bryant, 1953). In the rush to the district that followed, pockets of gravel rich in gold were worked throughout the mountains. Weed (1896) reported that a considerable amount of gold was washed out in the first few years after the discovery and that the large low grade gravel bodies remaining could be exploited if water were available in sufficient quanity. Recorded placer gold production in the Little Rocky Mountains since 1904 is 362 fine ounces (Lyden, 1948).

In 1893 Robert Orman discovered the first lode gold deposit and staked the August claim 1.5 miles north of Landusky (Emmons, 1907; Corry, 1933; Bryant,1953). This deposit is similar to most of the others mined later in the Little Rocky Mountains and consists of gold in heavily fractured silicified-pyritized porphyry. Many more claims were staked in the surrounding area shown on Plate I as the Landusky group. The August (Little Ben), and Gold Bug later became the most successful mines of this group.

In the years following 1893 many prospects were worked on a small scale throughout the mountains until 1904 when the Ruby Gulch group of mines became active (Corry, 1933). The Independent, Mint (Ruby) and Alabama are the main mines in this group (see Plate I).

Two other mines in the Little Rocky Mountains which are classed separately are the Beaver Creek and Pole Gulch deposits which are replacement deposits in the Cambrian limestones and adjacent intrusive porphyry.

Lode gold production in the Little Rocky Mountains from 1884 until 1950 was approximately 183,000 ounces worth nearly 10 million dollars. The mines of the groups listed in the above discussion accounted for nearly all the recorded gold production, though many small mines and prospects along with the early placers added many "a day's pay" (Weed, 1896).

The mines in the Little Rocky Mountains contain thousands of feet of underground workings to a maximum depth below the surface of 700 feet in the Ruby mine. Most of the mining was done by the stoping method. In the successful mines such as the Ruby and Independent, stoping of the rich ore continued until the surface was reached producing a glory hole. At the Independent mine the glory hole is approximately 250 feet long, 100 feet wide and 125 feet deep, while the Ruby mine glory hole is approximately 900 feet long, 300 feet in maximum width and nearly 200 feet deep.

Records concerning the milling and metallurgical methods in the Little Rocky Mountains are not complete, but most of the mills consisted of a crusher and a cyanide leaching operation.

In Ruby Gulch three mills operated in the same location since 1905. The first mill was built in 1905 and had a 300 ton per day capacity; the second was built in 1911 after the first burned in 1910 and had a 600 ton per day capacity; the third was built in 1936 with a 300 ton per day capacity after the second mill burned in 1923 (Emmons, 1907; Corry, 1933; Bryant, 1953). The third mill is still intact but has not been workable since 1950. The Goldbug mill which had a 100 ton per day capacity was built in 1902 in Landusky and operated until 1916. There is an old mill near the Goldbug mine which was probably built in the last thirty years although no records were found that mention its operation. The Zortman mill, which had a 100 ton per day capacity, was built in 1902, in Alder Gulch near the intersection with Pole Gulch. During its operation from 1902 until 1907, ore from the Alabama, Ruby, and Pole Gulch mines was treated. The mill did not operate after 1907 and reportedly burned down a few years later. The remnants of a crusher and cyanide leaching plant are located at the Hawkeye mine in the Alder Gulch area (see Plate XIII). The tailings dump is not very large and there is no recorded gold production from the mill.

III. GEOLOGIC UNITS

Precambrian Metamorphic Rocks

Rocks of Precambrian age occur in the Alder Gulch area as xenoliths ranging in exposed area from ½ square inch to ½ square mile. Gneisses and schists are described as separate units, but are not differentiated on the map. Outcrops of Precambrian gneisses and schists which are 100 feet or more in maximum dimension are shown on Plate 1. Although the Precambrian rocks in the Alder Gulch area are enclosed by intrusive porphyry on the surface, they could be continuous downward as part of the basement rocks. In drill hole no. 2, three bodies of gneiss and schist 100-125 feet thick were drilled and are apparently completely enclosed by the intrusive. The distribution of Precambrian rocks in the subsurface is as follows; in drill hole no. 2 from 0 to 125 feet, from 718 to 786 feet and from 922 to 990 feet (see Plate XIV). Xenoliths of gneiss and schist up to six inches in maximum dimension occur on the average of 4 per 10 feet in drill no. 2 and on the average of 2 per 10 feet in drill hole no. 1.

Gneiss

Gneiss occurs throughout the map area but is less abundant in the southwestern part. The gneissic rock is typically white with black bands 2 to 15 mm wide. White bands contain feldspar and quartz while the black bands contain feldspar, quartz and biotite. In highly fractured silicified areas the biotite is completely destoyed due to alteration and the rock is flooded with quartz producing a finely banded pure white gneiss. The silicification of the gneiss is locally confined to individual fractures affecting an area 1 to 2 mm wide while in the heavily fractured zones on the surface and in the subsurface the gneiss is completely silicified for hundreds of feet. The attitude of the foliation was recorded throughout the Alder Gulch area and is shown on Plate XIII. No evident patterns are suggested by the randomly oriented attitudes of the gneissic bands, possibly because most of the Precambrian bodies are xenoliths in the intrusive. The gneissic foliation within the margins of the intrusives generally dips away from the center of the intrusive suggesting concordance with the overlying Paleozoic and Mesozoic strata at depth.

Schist

Black biotite-hornblende schists crop out in the Alder Gulch area and are intercalated with the gneisses in the area. The schist contains hornblende, biotite, feldspar, chlorite and quartz and ranges in composition from hornblende-rich, biotite-poor to biotite-rich, hornblende-poor. Foliation of the schists is locally poor producing a massive appearance. The schist units never exceed 10 feet in thickness on the surface or in the drill holes. The relationship between the foliation in the schist and gneiss could not be determined in the Alder Gulch area because of poor outcrops. Near the Ruby Gulch mine the foliation between the schists and gneisses is parallel.

Most of the small inclusions (1 to 2 inches) in the intrusive rock are schist while the large inclusions are gneiss, possibly because the schist was more easily broken up by intrusive activity.

Schist is more abundant in the southwestern and southeastern parts of the map area but in total makes up only approximately 10 percent of the Precambrian rocks mapped. Alteration of the schist in fractured silicified zones is characterized by chloritization which produces a crumbly dark green rock.

A glistening black amphibolite schist occurs from 780 to 786 feet down in drill hole no. 2 but is not exposed at the surface in the Alder Gulch area. Knechtel (1959) considers the rock to be a metamorphosed Precambrian volcanic rock because of its distribution near the Landusky group of gold mines in the southwestern part of the Little Rockies.

Paleozoic and Mesozoic rocks occur in the Little Rocky Mountains but not in the Alder Gulch area.

Tertiary (Paleocene?) Intrusives

Alkalic intrusive rocks are the predominant rock type exposed in the map area. The distribution of these intrusives outside the Alder Gulch area was mapped by Brockunier (1936). His petrographic model consists of a different rock type for each of the topographic and structural domes in the Little Rockies based on slight mineralogical and textural differences. The domes Brockunier (1936) discusses are topographic in the center of the mountains and are formed by the bowed up sedimentary rocks on the margins of the mountains. These models fit his theory that each of the domes is an individual laccolith. In general his large intrusive bodies can be grouped into two main types, the Antone syenite porphyry which is typified by less than ten percent quartz and the Silvertip porphyry (alaskite) which is typified by greater than ten percent quartz.

Antone Syenite Porphyry

The Antone syenite porphyry is a light gray to tan rock which varies in texture from a porphyry with large orthoclase phenocrysts (20 to 25 mm long) to one with small orthoclase phenocrysts (5 to 10 mm long). The porphyry contains equal amounts of orthoclase and plagioclase phenocrysts up to 25 mm long, hornblende crystals up to 5 mm long and a gray microcrystalline groundmass. Most of the inclusions of Precambrian gneiss and schist discussed above occur in the Antone syenite porphyry. In general this rock type occurs in the central part of the Little Rockies intrusive mass (see Plate I). In the Alder Gulch area this porphyry is the most common rock type at the surface. It is exposed over 75 percent of the map area (see Plate XIII) and is present to the bottom of drill hole no. 2 and to 1420 feet in drill hole no. 1. The Antone syenite porphyry is best exposed on the rounded ridges and V-shaped gulches in the map area, whereas the steep mountainsides are talus covered. The Antone porphyry shows very few contact phenomena common to intrusive rocks in general.

Within twenty feet of the contacts between Antone porphyry and other rock types the porphyry is slightly finer-grained but shows no alignment of phenocrysts. Contact metamorphism of the Paleozoic strata along contacts with the intrusives is slight. Induration of the sedimentary rocks, emphisized by subsequent differential weathering is noticeable within twenty feet of the contacts (Weed and Pirsson, 1896 ; Brockunier, 1936; Dyson, 1939).

Silvertip Porphyry (Alaskite)

Described as an "aberrant" rock type by Brockunier (1936), the Silvertip porphyry is exposed over 20 percent of the Alder Gulch area and is basically a quartz-rich Antone syenite porphyry (see Plate XIII). The snow white color, distinct, large phenocrysts and sugar-like groundmass characterize the texture of the porphyry. Silvertip porphyry is composed of equal amounts of orthoclase and plagioclase phenocrysts 15 to 25 mm long, and quartz phenocrysts up to 7 mm in maximum dimension which make up 10 to 20 percent of the rock. The groundmass is a white microcrystalline mosaic.

Silvertip porphyry occurs mainly in the domes rimming the Little Rocky Mountains (see Plate I), (Brockunier, 1936). In the northeastern part of the Alder Gulch area a body of Silvertip porphyry one-third square mile in area is exposed. In the southeatern part of the area a small sliver of Silvertip porphyry is exposed and is shown on Plate XIII along with a small exposure near the Hawkeye mine.

In drill hole no. 1, Silvertip porphyry is found from 1,420 feet, to the bottom of the hole at 2,004 feet, but is not encountered in drill hole no. 2. The small mass of Silvertip porphyry near the Hawkeye mine probably has a stock-like shape based on its occurrence on the surface and in drill hole no. 1 from 1,420 to 2,000 feet (see Plate XIII). This evidence indicates that the Silvertip porphyry intruded the Antone syenite porphyry. Very few Precambrian metamorphic inclusions are present in the Silvertip porphyry in the Alder Gulch area. There is no topographic relief distinguishing outcrops of Antone syenite porphyry and Silvertip porphyry because they have the same resistence to erosion.

Similarity between the Silvertip and Antone syenite porphyries along with the lack of distinct contact relationships such as alignment of phenocrysts and a chilled border makes mapping the units difficult without thin section studies of the mineralogy. This similarity between the two porphyries suggests a change in the source magma such as assimilation of silica and a short interval in time between intrusions rather than two completely separate intrusions.

Sub-parallel alignment of Silvertip porphyry phenocrysts within fifty feet of the contact with the Antone syenite porphyry is present near the intersection of sections 7, 12, 13 and 18 and also near the intersection of Alder Gulch and sections 13 and 18. This relationship suggests that the Silvertip porphyry is younger than the Antone syenite porphyry.

Sullivan Park Trachyte Porphyry

A Y-shaped dike-like intrusive body 5,000 feet long termed the Sullivan Park trachyte porphyry is exposed in the western part of the Alder Gulch area (see Plate XIII). A smaller dike of Sullivan Park trachyte porphyry which is 250 feet long and 100 feet wide occurs 1,000 feet north to northwest of the Hawkeye mine. Brockunier's terminology is used for this rock unit because he mapped exposures of it during his study of the area.

Sullivan Park trachyte porphyry is very consistent in texture and mineralogy where ever exposed. It is a light gray quartz-deficient rock with distinct flesh-colored orthoclase phenocrysts in a fine-grained groundmass. Phenocrysts are mutually parallel within sixty feet of the contact and subparallel throughout the dike. The Sullivan porphyry does not form prominent ridges or gulches and is affected by erosion to the same degree as are the Antone and Silvertip porphyries. Sullivan trachyte porphyry is younger than Antone syenite porphyry which it intrudes but does not occur in crosscutting relations with the other rock types.

Syenite Porphyry Dikes

Six dikes 300 to 800 feet long and fifty feet wide occur in the east-central part of the map area (see Plate XIII). These dikes are almost identical in mineral composition to the Antone syenite porphyry which they intrude but texturally the dike rock is finer-grained with phenocrysts of orthoclase and plagioclase up to 5 mm long. Lack of fracturing and subsequent lack of hydrothermal alteration has left these dikes very fresh. No alignment of phenocrysts is noted in the dikes. The dikes stand ten to fifty feet above the surrounding rock probably because they erode more slowly than the altered Antone syenite porphyry that they intrude. Contact effects are absent except for a ringing sound given off by the Antone syenite porphyry when struck with a hammer within a few feet of the contact with the dikes. The effect suggests baking of the Antone syenite porphyry by the syenite porphyry dikes during intrusion. The syenite porphyry dikes are younger than the Antone syenite porphyry which they intrude, but do not show crosscutting relationships with the other rock types in the Alder Gulch area.

IV. PETROGRAPHY

Precambrian Rocks

Gneiss

The black and white banded gneiss is composed of orthoclase (35 to 40%), plagioclase (20 to 25%), quartz (15 to 20%), biotite (15 to 20%), sericite (3%), clay minerals (2%) and a trace of magnetite (see Plate III, Figure 1).

The amount of quartz increases to a range of 35 to 40 percent in strongly altered areas (see Plate XIII) along with the occurrence of pyrite, sericite and fluorite. Biotite is absent in strongly altered areas. Orthoclase and plagioclase are uniformly abundant throughout the area.

Quartz occurs as ribbon-like and lenticular composite grains with both smooth and irregular boundaries and slight to strong undulose extinction. Individual grains are elongated parallel to the foliation with a maximum width and length of .5 mm and 5 mm respectively. Quartz veins which fill fractures that are parallel to the foliation are abundant along with a few quartz filled fractures that are oblique to the foliation.

Orthoclase occurs as anhedral to subhedral crystals which show a subparallel alignment with the foliation. Crystals are nearly equidimensional with a maximum length of .5 mm. Most of the orthoclase is moderately sericitized and is characterized by its comparatively low relief in thin section.

Plate III

Figure 1. Precambrian metamorphic gneiss (unaltered)

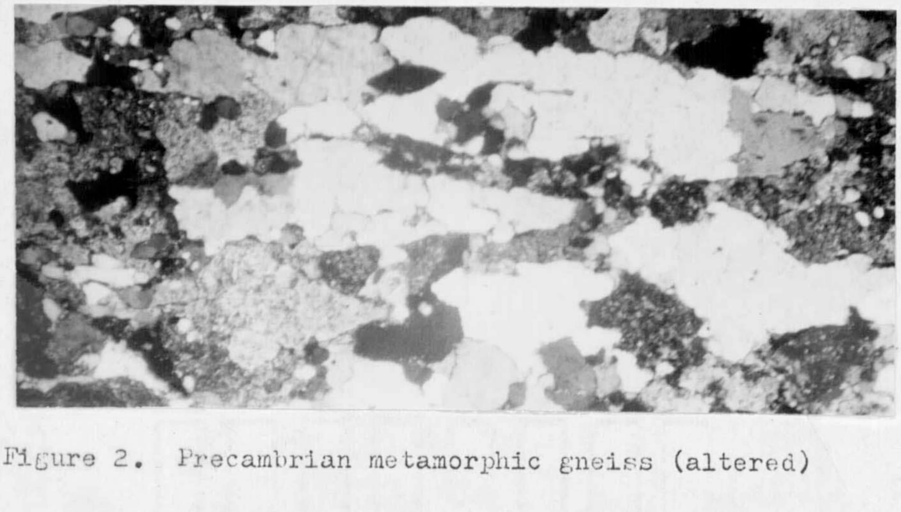


Figure 2. Precambrian metamorphic gneiss (altered)

Plagioclase occurs as subhedral equant crystals up to .5 mm in maximum dimension. Albite and Carlsbad twinning is common but faintly visible due to sericitization. Plagioclase composition probably ranges from albite to oligoclase since in thin section the index of refraction is always less than or equal to that of the Canadian balsalm cement (1.537). Albite and oligoclase have refractive indices of 1.528 to 1.538 and 1.532 to 1.550 respectively (Kerr, 1959).

Subhedral biotite, up to 2 mm long, is commonly bent, and elongated parallel to the foliation. Crystals are rarely unaltered with partial alteration to chlorite common. In strongly altered areas biotite and chlorite are absent due to flooding of the rock with quartz (see Plate III, Figure 2).

Pyrite occurs in crystals up to 3 mm in diameter in the fractures, along with quartz and purple fluorite. Magnetite is scattered sparingly throughout the rock. Sericite and kaolinite occur as alteration products masking the feldspars in strongly altered areas (see Plate III, Figure 2).

Schist

The schists are composed of hornblende (0 to 45%), biotite (0 to 45%), orthoclase (25 to 30%), plagioclase (10 to 20%), chlorite (0 to 15%), quartz (0 to 5%), sericite (0 to 1%) and magnetite (0 to 1%).

The mineralogy of the schist varies both on the surface and in the subsurface with biotite and hornblende locally absent.

Chlorite is more abundant in biotite-rich rocks. Plagioclase is less abundant in biotite-poor schists. Hornblende, chlorite and biotite are the only mineral grains elongated parallel to the schistosity.

Hornblende is always partially altered to chlorite and rimmed by magnetite alteration. Contorted laths of hornblende may reach 2 mm in length. A few grains are seam twinned and a few are replaced by biotite.

Biotite occurs in appreciable amounts in a few of the schist inclusions present in drill hole no. 2. Subhedral to euhedral crystals up to 1 mm long are commonly elongated parallel to the schistosity. In biotite-rich schists most crystals are at least partially altered to chlorite. In biotite-poor schists most crystals are replacement products of hornblende.

Orthoclase has grown as equant subhedral crystals up to .5 mm in maximum dimension. Most of the orthoclase is weakly sericitized showing alteration only along cleavage planes and fractures.

Plagioclase forms subhedral laths up to .5 mm in maximum dimension. Albite and Carlsbad twinning of plagioclase is present in all the schists examined. Composition of the plagioclase by the Michel-Levy method is approximately andesine (An_{44}).

Quartz is present as scattered equant crystals up to 1 mm in maximum dimension. Chlorite forms as anhedral masses replacing hornblende and biotite. Magnetite rims hornblende and is in places seen throughout hornblende crystals. Sericite occurs as a replacement of the feldspars.

Tertiary Intrusives

Antone Syenite Porphyry

This rock contains phenocrysts of flesh-colored orthoclase and gray plagioclase ranging from 5 to 25 mm in length. These phenocrysts make up about 50 percent of the rock. The groundmass is made up of orthoclase and quartz.

Average mineral percentages are: orthoclase (45 to 55), plagioclase (30 to 35), hornblende (5 to 10), augite (2 to 3), aegerine-augite (1 to 2), biotite (1 to 2), and magnetite (0 to 1), (see Plate IV, Figure 1). The secondary minerals quartz (0 to 20%), fluorite (0 to 1%), pyrite (0 to 2%) and sericite (0 to 1%) form in veins and are also disseminated throughout the rock.

Equidimensional subhedral to euhedral orthoclase phenocrysts 10 to 25 mm in maximum dimension locally show Carlsbad twinning and commonly show concentric zoning. Some phenocrysts occur as orthoclase envelops enclosing a central crystal core of plagioclase (see Plate IV, Figure 1). A few composite phenocrysts of orthoclase contain inclusions of augite, aegerine-augite and hornblende and are rimmed by plagioclase crystals (see Plate V, Figure 1). The composite orthoclase phenocrysts are unaltered suggesting a secondary origin (see Ch. VI) but no inclusions of groundmass within orthoclase phenocrysts were noted in any of the sections examined.

Euhedral to subhedral plagioclase phenocrysts ranging from 4 to 12 mm long are present as unoriented laths.

Plate IV

Figure 1. Antone syenite porphyry

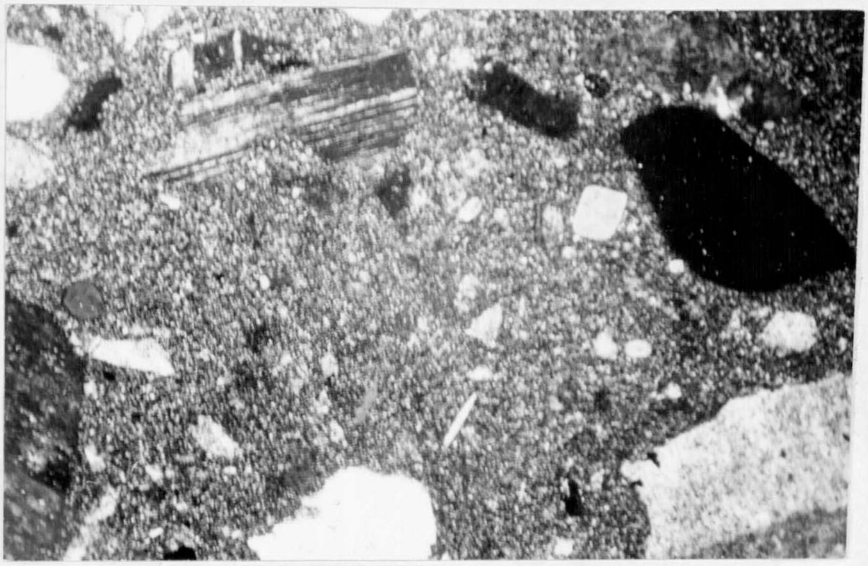


Figure 2. Silvertip porphyry

Plate V

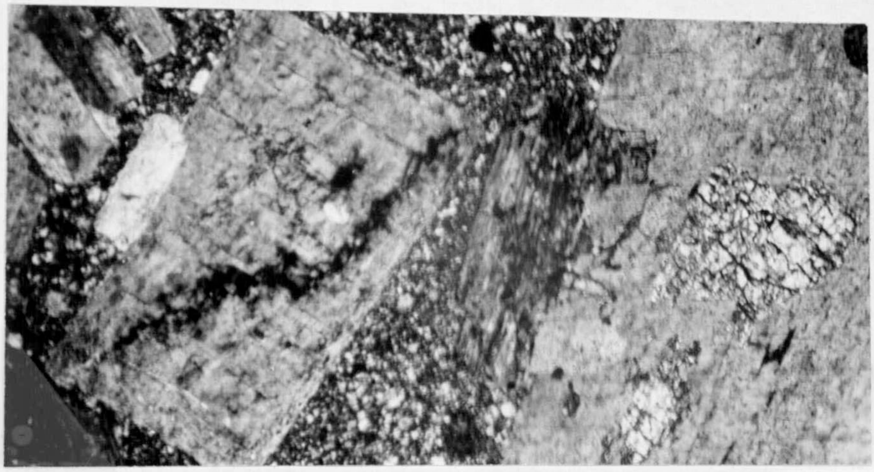


Figure 1. Antone syenite porphyry showing large fresh orthoclase phenocryst and inclusions of plagioclase, aegerine-augite and hornblende.

Elongate crystals found as inclusions in orthoclase phenocrysts are oriented parallel to the cleavage planes. Albite, Carlsbad and albite-Carlsbad twinning are common features. Composition determined by the Michel-Levy method and by oil immersion studies is albite (An_6) and oligoclase (An_{20}) with the latter more abundant. Sericitization is present in all sections examined and clouds the optical properties.

Elongate euhedral hornblende phenocrysts 4 to 6 mm long are locally present but are generally partially to completely replaced by biotite and pyrite (see Plate V, Figure 1). Magnetite forms along the rim of hornblende phenocrysts. Most crystals are pleochroic in shades of green, a few are seam twinned.

Augite occurs as subhedral crystals of prismatic habit up to 2 mm in maximum dimension and are often partially replaced by hornblende. Pleochroism is weak to absent and is commonly masked by alteration of augite to magnetite and pyrite.

Elongate anhedral crystals of aegerine-augite up to 1 mm long are present as inclusions in orthoclase phenocrysts (see Plate V, Figure 1). Biotite occurs as a replacement of hornblende and is commonly absent. Magnetite rims and is included in augite and hornblende.

Pyrite is a secondary mineral which is commonly found replacing augite. The secondary minerals pyrite, quartz, sericite, calcite and fluorite occur as fracture fillings and as disseminated grains in the groundmass and will be discussed in the chapter dealing with alteration and mineralization (see Ch. VI).

<u>Silvertip Porphyry</u> (Alaskite)

Silvertip porphyry is composed of plagioclase (30 to 50%), orthoclase (25 to 40%), quartz (15 to 25%), magnetite (0 to 1%) and secondary quartz (0 to 10%), calcite (0 to 3%), pyrite (0 to 2%), sericite (0 to 2%), and clay (0 to 1%), (see Plate IV, Figure 2).

Phenocrysts of orthoclase are commonly more abundant than plagioclase. In orthoclase-poor sections the rock approaches a quartz monzonite porphyry in composition although no dark-colored minerals are present. The groundmass makes up approximately 50 percent of the rock and contains orthoclase and quartz.

The plagioclase occurs as unoriented anhedral to subhedral laths up to 5 mm long. Crystals are commonly masked by sericite alteration and have corroded margins and a pitted appearance accompanied by calcite alteration. Carlsbad, albite, pericline and combined Carlsbad-albite twinning is present in all sections of the rock examined. Composition of the phenocrysts determined by the Michel-Levy method and by oil immersion studies is oligoclase (An_{28}).

Anhedral to euhedral equant crystals of orthoclase occur from 4 to 25 mm in maximum dimension. The larger phenocrysts are subhedral to euhedral and contain plagioclase inclusions which are aligned parallel with the cleavage planes. Crystals commonly have pitted surfaces which contain calcite and sericite. The smaller phenocrysts of orthoclase and plagioclase are more altered by calcite, sericite, fluorite and pyrite than are the larger (10 to 25 mm) phenocrysts of orthoclase.

Equant quartz phenocrysts are interstitial and are from 2 to 7 mm in maximum dimension. Most grains have rounded irregular boundaries. Approximately one-half of the quartz present is interstitial in the groundmass. Crystals are unaltered except for sericite alteration along fractures. A few grains contain inclusions of the groundmass suggesting contemporaneous crystallization.

The secondary minerals pyrite, quartz, sericite, calcite and fluorite occur as fracture fillings and as disseminated grains in the groundmass and will be discussed in the chapter dealing with alteration and mineralization (see Ch. VI).

Sullivan Park Trachyte Porphyry

The texture of the Sullivan Park trachyte porphyry is characterized by well aligned phenocrysts and alignment of microlites in the groundmass. Phenocrysts make up from 55 to 80 percent of the rock. The groundmass is made up of orthoclase and quartz.

Range of mineral percentages are: orthoclase (75 to 85), plagioclase (8 to 12), quartz (2 to 5), aegerine (1 to 2), and secondary minerals magnetite (0 to 1), pyrite (0 to 1) and clay minerals (1 to 3). Euhedral orthoclase phenocrysts, which are from 5 to 30 mm long and tubular shaped commonly show Carlsbad twinning. Most grains are only faintly clouded by sericite alteration. Subhedral to euhedral laths of plagioclase are present up to 8 mm long. Composition is An_{24}, (oligoclase) by the Michel-Levy and oil immersion methods. Most crystals are partially altered to sericite and clay minerals (halloysite?). Carlsbad, albite, pericline and combined Carlsbad-albite twinning are present in all of the sections examined.

Euhedral aegerine crystals up to 2 mm long are scattered throughout the rock. Partial alteration to clay minerals and magnetite obscures the optical properties, but a slight yellowish-green pleochroism is present.

Quartz is restricted to the groundmass and is characterized by the lack of alteration affects. Pyrite is found as fracture fillings and as a few grains disseminated throughout the groundmass in strongly mineralized areas (see Ch. VI).

Syenite Porphyry Dikes

The dikes are less porphyritic than the other intrusive rocks and consist of orthoclase (50 to 60%), plagioclase (25 to 35%), quartz (2 to 4%), augite (1 to 3%), and secondary minerals magnetite (1%), sericite (0 to 2%) and clay minerals (0 to 1%).

Equant orthoclase phenocrysts from 2 to 5 mm in maximum dimension are anhedral to subhedral. A few grains are clouded by sericite alteration and a few are pitted and corroded on their margins. Subhedral laths of plagioclase up to 4 mm long, have a composition of An_{24}, oligoclase by the Michel-Levy method. Anhedral augite up to 2 mm in maximum dimension is partially altered to sericite, clay minerals and magnetite. The phenocrysts grade in size into the groundmass which consists of quartz, orthoclase and plagioclase.

V. LOCAL STRUCTURE

Shear Zones

Shear zones in the Little Rocky Mountains have been cited by many geologists as the main factor controlling the configuration of the gold deposits (Weed and Pirsson, 1896; Corry, 1933; Brockunier, 1936; Dyson, 1939; and Bryant, 1953). The reason for this localization is that the strong fracturing of the rock in the shear zones provided channelways for the hydrothermal solutions which deposited the gold and other minerals. The Landusky group (see Plate I) of gold mines in the western part of the Little Rocky Mountains is located along nearly vertical northeast striking shear zones (Emmons, 1907; Corry, 1933; Dyson, 1939). In the eastern part of the Little Rocky Mountains, the Ruby Gulch group of gold mines is aligned along nearly vertical northwest striking shear zones (Emmons, 1907; Dyson, 1939). Displacement along the shear zones probably ranges from a few feet up to a maximum of two hundred feet based on the offset of bisected Precambrian metamorphic rock xenoliths (Brockunier, 1936; Knechtel, 1959). The shear zone five hundred feet east of the Hawkeye mine is mapped as a major fault because of the presence along its strike of breccia, abundant slickensides, displacement of small gulches and the topographic saddles formed along it near the Hawkeye mine and on the next ridge to the south. The small amount of displacement along the gulches, is detectable only on the air photo and is probably a young feature indicating continued movement along a pre-existing fault. In the Alder Gulch area the mineralization is distributed along the trace of nearly vertical shear zones (see Plate XIII). Northeastward across the Alder Gulch area, the most prominent group of parallel shear zones trend N35°W near the Hawkeye mine and N40-50°W near the Alabama mine. Other minor shear zones in the Alder Gulch area show no parallelism with adjacent shear zones or any consistency in trend and commonly intersect the main shear zones. Such intersecting shear zones in the Alder Gulch area produce the largest masses of secondary (quartz-pyrite-sericite) mineralization (see Plate XIII), in particular at the Hawkeye mine and the mineralized area in Alder Gulch in the western part of section 18. Breccias near these two mineralized areas may be the result of the strong fracturing along two directions. Another factor to be considered is the intrusion of the Silvertip porphyry into the Antone syenite porphyry (see Ch. III for discussion of order of intrusion). Contacts between the two porphries are located near the breccias in the Alder Gulch area suggesting that the breccia formed due to stress caused by the intrusion of Silvertip porphyry into the Antone porphyry.

Breccias

The breccia in the Hawkeye mine contains unoriented angular, equidimensional fragments of Antone syenite porphyry up to 12 inches in maximum dimension in a matrix of fine-grained quartz and pyrite (see Plate XII, Figure 2). In a few parts of the breccia the matrix consists of a fine-grained rock flour consisting of crushed Antone porphyry.

In drill hole no. 1 six feet of the breccia was encountered at depths from 445 to 451 feet. The breccia zone is exposed only in one corner of the Hawkeye pit.

The breccia in Alder Gulch and directly north of the Hawkeye mine is in a fault zone (see Plate XIII). The breccia extends for 200 feet and varies in width from 25 to 60 feet. This breccia is similar to the one at the Hawkeye mine except that it has a sparse amount of secondary quartz and pyrite in the matrix. In the outcrop the breccia resembles a sedimentary conglomerate because of its subrounded fragments which project from the rock flour matrix. The conglomeratic appearance is caused by spalling off of the corners of the breccia fragments which erode slower than the matrix.

The largest area of brecciated Antone syenite porphyry is in tributaries of Alder Gulch in the eastern part of the map area (see Plate XIII). The main breccia extends for 1,100 feet along the bottom of a tributary of Alder Gulch in a shear zone. The brecciated rock can be traced continuously for up to 300 feet as it branches, pinches and swells. Individual branches never exceed fifty feet in width. Breccia also occurs 500 and 1,000 feet farther west and within 100 feet of Alder Gulch. Fifty percent of the matrix of the breccia in the eastern part of the Alder Gulch area has been completely silicified and pyritized while the remaining matrix is unaltered rock flour.

All of the breccias in the Alder Gulch area contain some angular, equidimensional unaltered fragments of Precambrian rock up to six inches in maximum dimension, suggesting that the breccia zones are intrusive pipes related to magmatic activity at depth, but the following discussion tends to refute this theory. The planar shape of two of the breccia units, alignment of the breccias along shear zones, and the lack of flow structures in the breccia matrix suggest that the brecciation originated by physical fracturing.

A probable sequence of formation of the breccias is as follows:

1. Intrusion of the Silvertip porphyry into the Antone syenite porphyry causing mechanical brecciation of the Antone syenite porphyry near the contact. The brecciation may have been localized by pre-existing planes of weakness.

2. Silicification, pyritization and introduction of the other secondary minerals into the breccia. The crushed rock flour matrix was more easily and completely altered and replaced than were the breccia fragments because of the increased porosity and the lack of interlocking crystalline structure in the former.

Another possibility is that the brecciation took place along shear zones after the Antone and Silvertip bodies had been emplaced. However this hypothesis seems less likely because the breccia is confined to one host rock type throughout the Alder Gulch area and is generally localized near the contact between the Antone and Silvertip porphyries.

Joint Patterns

Fracturing of the rock in the map area is not confined to the shear zones, but rather the shear zones are prominent because the rock in them is more heavily fractured than average for the area and the wall rock shows evidence of displacement. Brockunier (1936, p. 38), noted that; "The porphyry throughout the area is so fractured that each blow of the hammer merely reveals another rust stained surface, and a fresh hand specimen is a desideratum rarely realized."

The trend of joint sets was recorded throughout the map area to determine if a prominent joint system exists. In any one outcrop the fracturing trends in many different directions, so to make the study valid only the trend of joint sets (a group of parallel joints, Billings, 1954; p. 108) were recorded at each of the stations. On Plate XIII the 96 recordings of the trends of joint sets are represented by five rosettes. Each rosette portrays 18 to 22 individual readings of the trend in approximately a quarter section. Individual joints vary from 1 to 2 inches apart and weren't considered a set unless 10 to 12 joints in an outcrop were consistent in trend. The rosettes don't reveal any obvious structural patterns in the Little Rocky Mountains but suggest the following:

1. The joint system in the map area consists of primary sets of N25-45°W, N55-75°E and secondary sets of N10-20°E and E-W.

2. The joint sets echo the patterns of the shear zones in each of the five areas represented by the rosettes. In areas where there are only a few narrow shear zones which are primarily striking in one direction, the joint sets are fairly simple, for example in the southwest corner of section 13 (see Plate XIII). Where the shear zones are closer together and intersecting, the rosette shows a greater scatter of the fracture directions, for example in the western part of section 18.

A Schmidt equal area projection plot (lower hemisphere) of all the fractures or joint trends is shown on Plate VI. The pole normal to the fracture planes is plotted to give a point diagram which in turn is contoured by using a Kalsbeck counting grid. The counting grid consists of overlapping hexagons each making up one percent of the total projection plot area. The contours represent 7, 5, 3, and 2 percent of the total points. This plot refines the measurements of trends of the joint system present in the Alder Gulch area. Primary sets are N10°E, N65°E and N35°W, and secondary sets are N45°E, and E-W (see Plate VI).

Origin of Structures

In general, the prominent trend of joint sets in the southwestern part of the Alder Gulch area and the southwestern part of the Little Rocky Mountains is N65°E; the prominent trend in the central and southern part of the Alder Gulch area and the southern part of the Little Rocky Mountains is N10°E; and the prominent trend in the northern part of the Alder Gulch area and the northern part of the Little Rocky Mountains is N45°W. The origin and control of the fractures and shear zones in the Little Rocky Mountains has been explained by geologists in the following ways:

1. Compressive forces caused the shearing, brecciation, and discontinuity of the gold deposits (Emmons, 1907).
2. Uplift (caused by the intrusives) produced the structures, which radiate from this center of uplift especially near the contact between

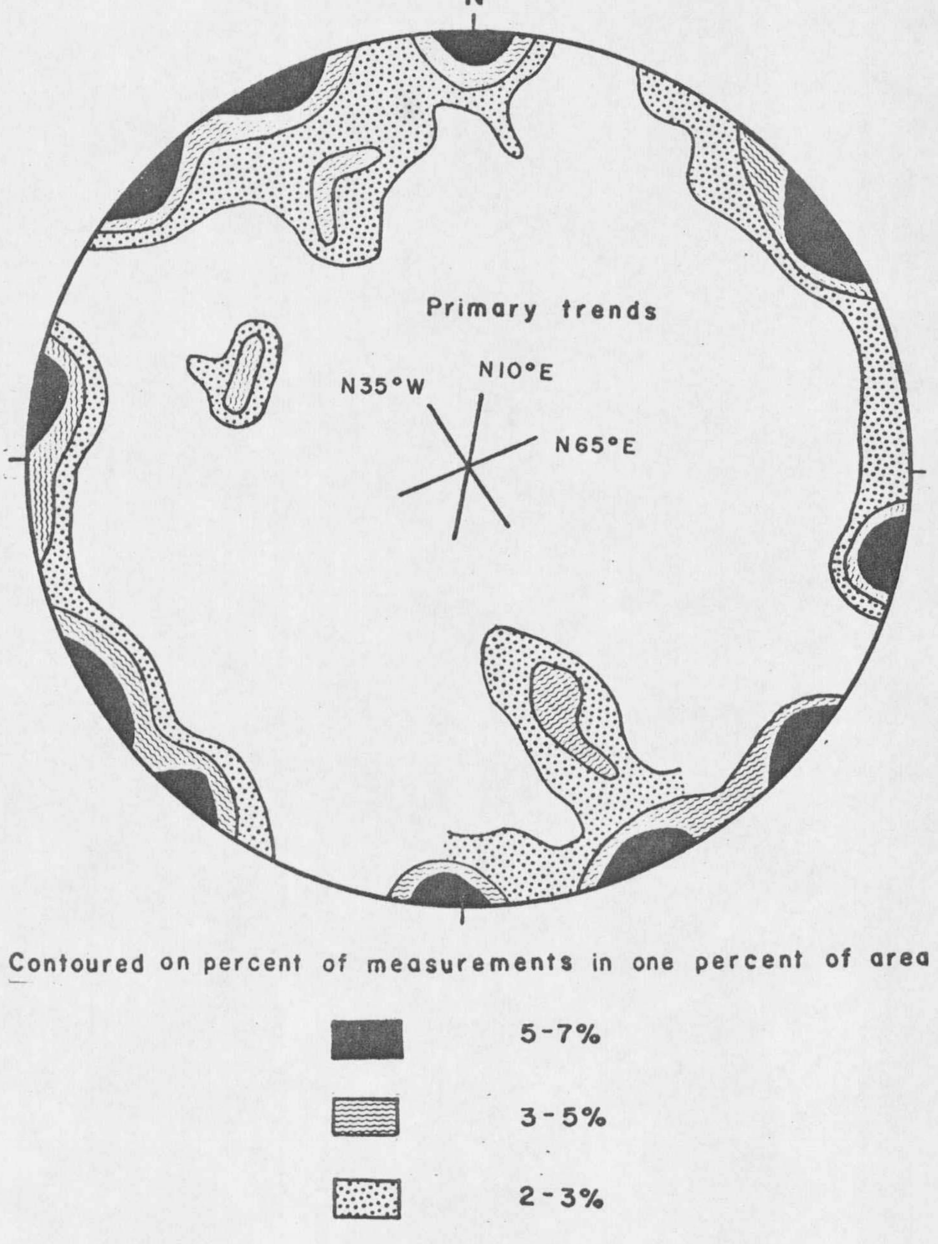


Plate VI. Schmidt equal area projection plot (lower hemisphere) of 96 joint trend measurements in the Alder Gulch area.

intrusive and host rocks (Corry, 1933).

3. The conduits feeding the laccoliths caused localization of strong fissuring above them (Brockunier, 1936).
4. Consolidation of an underlying intrusive later than the Little Rockies intrusive caused shearing (Brockunier, 1936).
5. Relaxation and shrinkage of the intrusive after its consolidation caused the shearing (Dyson, 1939).

Each of the above mechanisms has probably contributed to the fracturing and shearing in the Little Rockies except no. 3. Each laccolith conduit should be characterized by a radial fracture pattern in the intrusive rocks above it to fit model no. 3. This is not the case. In analyzing the structure of any intrusive, Hills (1936) suggests considering the pre-existing regional trends and planes of weakness along with the joint sets directly related to the intrusive. In the Little Rocky Mountains and Alder Gulch area, the main northwest and northeast shear zones are similar in trend to regional directions of fracturing in the main Rocky Mountains to the west where strong northwest and northeast fault, fold, and joint trends are attributed to compressive forces. On the other hand, the trend of shear zones in the Little Rocky Mountains appears to fit the pattern of Hills (1963) in which granite intrusives display two sets of fractures which are nearly perpendicular to each other. One of Hill's fracture sets, however, commonly dips at a 45 degree angle unlike the vertical fractures in the Little Rockies. It is likely that the fracture trends in the Little Rockies cannot be explained by any one hypothesis as is true in many localities. The following factors probably influence the structural trends in the Little Rocky Mountains:

1. Regional structural patterns existing before intrusive activity in the Little Rockies.
2. Forceful intrusion and consolidation of the porphyries.
3. Post-intrusive regional uplift.
4. Shrinkage and relaxation after intrusive activity had ceased.
5. Recent normal faulting.

Many of the large anticlines and synclines in Central Montana possibly were synclines and anticlines respectively before the Laramide orogeny. Pre-Tyler (Mississippian) normal faulting of blocks of basement rock (Precambrian) into grabens formed synclines which controlled Tyler Formation (Mississippian) deposition. But the Tyler Formation is thickest along the axis of present day anticlines in the sedimentary rocks. Cooper (1956) concludes that Laramide reverse movement on the basement faults, caused by east-west compressive forces, formed the anticlines in the sedimentary rocks. If the Little Rocky Mountains were involved in this process, evidently at least part of the uplift of the Paleozoic and Mesozoic strata in the Little Rocky Mountains occurred during the Laramide before intrusive activity. If Cooper's hypothesis applies to the Little Rockies it suggests the presence of planes of weakness due to faulting in the basement rocks below the present Little Rocky Mountains which would facilitate emplacement of the intrusive mass.

Post-intrusive uplift is suggested by the ring faulting peripheral to many domes in the Little Rocky Mountains (see Plate I). Continued intrusion and/or uplift would cause fracturing of the intrusions already emplaced. Forceful intrusion and consolidation of each of the porphyries would cause fracturing of the intrusive bodies already consolidated. Lack of assimilation of the metamorphic and sedimentary rocks by the intrusive and lack of contact metamorphism suggest a forceful, dry and/or viscous intrusion.

Shrinkage and relaxation of an intrusive mass after it is emplaced is common and produces fracturing, shearing and brecciation such as is present in the Little Rockies. Recent normal faulting is suggested by the offset of gulches which is evident on the air photographs.

It is most likely that the five hypothesis discussed are all factors which affected the structure of the Little Rocky Mountains. Evidence of the complex history of shearing and fracturing in the Little Rocky Mountains is the presence of many veins which have been offset, slickensides present along quartz and pyrite veins, and shear zones that transect these major veins.

VI. ALTERATION AND MINERALIZATION (LITTLE ROCKIES)

Some of the previous geologic investigations in the Little Rocky Mountains were primarily concerned with the occurrence of gold deposits (Emmons, 1908; Corry, 1923; Dyson, 1939; and Bryant, 1953). The descriptions of rock alteration and mineralization in the Little Rocky Mountains by all previous investigators (see Ch. 1) were also based around the primary gold ore.

Emmons (1907), Corry (1933), and Dyson (1939) concluded that the alteration associated with the gold deposits in the Little Rockies consists of a sulphide zone and an oxidized zone. Both zones are confined to shear zones similar to those discussed in Chapter VI although pervasive silicification and pyritization of the wall rock beyond those zones is common (Corry, 1933; Dyson, 1939).

The oxidized zone is characterized by the presence of iron oxides, and quartz along with trace amounts of native gold and gold tellurides which increase in abundance with depth. Oxidation of the mineralized shear zones extends to more than 500 feet below the surface in the Ruby mines (Dyson, 1939) but is confined to the fractured areas in the deposit.

The sulphide (hypogene) zone contains abundant quartz and pyrite with smaller amounts of sericite, calcite, fluorite, native gold and gold tellurides.

Indicators of gold ore in the sulphide zone are the presence of fluorite and a decrease in the amount of pyrite (Corry, 1933; Dyson, 1939). In the oxidized zone indicators of ore are manganese oxide and chalcedony (Corry, 1933; Brockunier, 1926).

Replacement deposits also occur in limestone of Cambrian age in Pole Gulch and Beaver Creek (see Plate I) within a few feet of the intrusive contact. Silicification and fluoritization of the limestone along bedding planes and fractures characterizes the replacement deposits (Corry, 1933). The intrusive rock near the replacement deposits is altered and gold-bearing as described above.

Alteration and Mineralization
(Alder Gulch)

The purpose of this discussion of the rock alteration and mineralization in the Alder Gulch area is not solely to facilitate the search for gold in the Little Rocky Mountains or similar geologic environments. An attempt is made to describe both the physical and chemical environment of alteration and mineralization as a contribution to the study of hydrothermal alteration and associated base metals and precious metals.

Mineralization

Ore minerals encountered in the Alder Gulch area are native gold, gold telluride, galena, sphalerite and molybdenite. Native gold intergrown with telluride is found in the Hawkeye mine (Brockunier, 1936). Galena and sphalerite occur in drill hole no. 1 (at 1,195 feet) only in a three inch vein along with pyrite, quartz and sericite.

The galena and sphalerite is accompanied by magnetite and abundant Precambrian metamorphic gneiss inclusions in the Antone syenite porphyry from 1,125 feet to 1,350 feet in drill hole no. 1 (see Plate XIV). Molybdenite is disseminated through a 2 inch quartz vein in drill hole no. 1 at 346 feet.

Eighty-eight rock samples were collected by Robert McNeil (field assistant, 1968) in the map area on a 500 foot grid (see Plate VII and VIII) and analyzed for copper and molybdenum content by geochemical (wet) analysis. For comparative purposes, average content of copper, molybdeum, gold, and silver in parts per million in certain crustal rock types is shown in Table 2 (Turkian and Wedepohl, 1961).

Table 2. Concentration of some metals in granitic and syenitic rocks in the earth's crust (parts per million), (from Turekian and Wedepohl, 1961).

	Granitic	Syenitic
copper	10	5
molybdenum	1.3	.6
gold	.004	.00?
silver	.04	.0?

GEOCHEM MAP - Mo

Key to Plate VII

Contoured on ppm Molybdenum

Rock Sample Location o

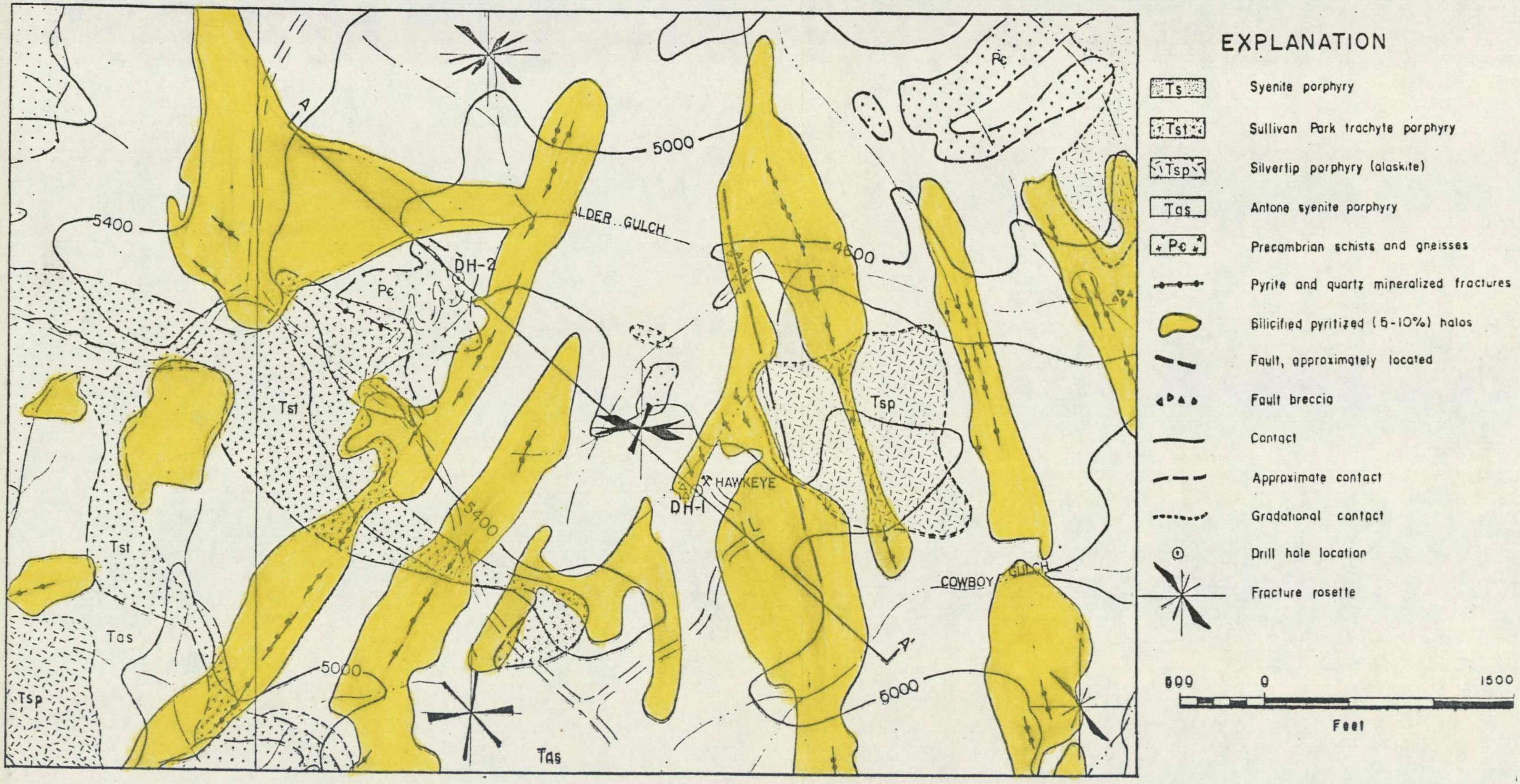
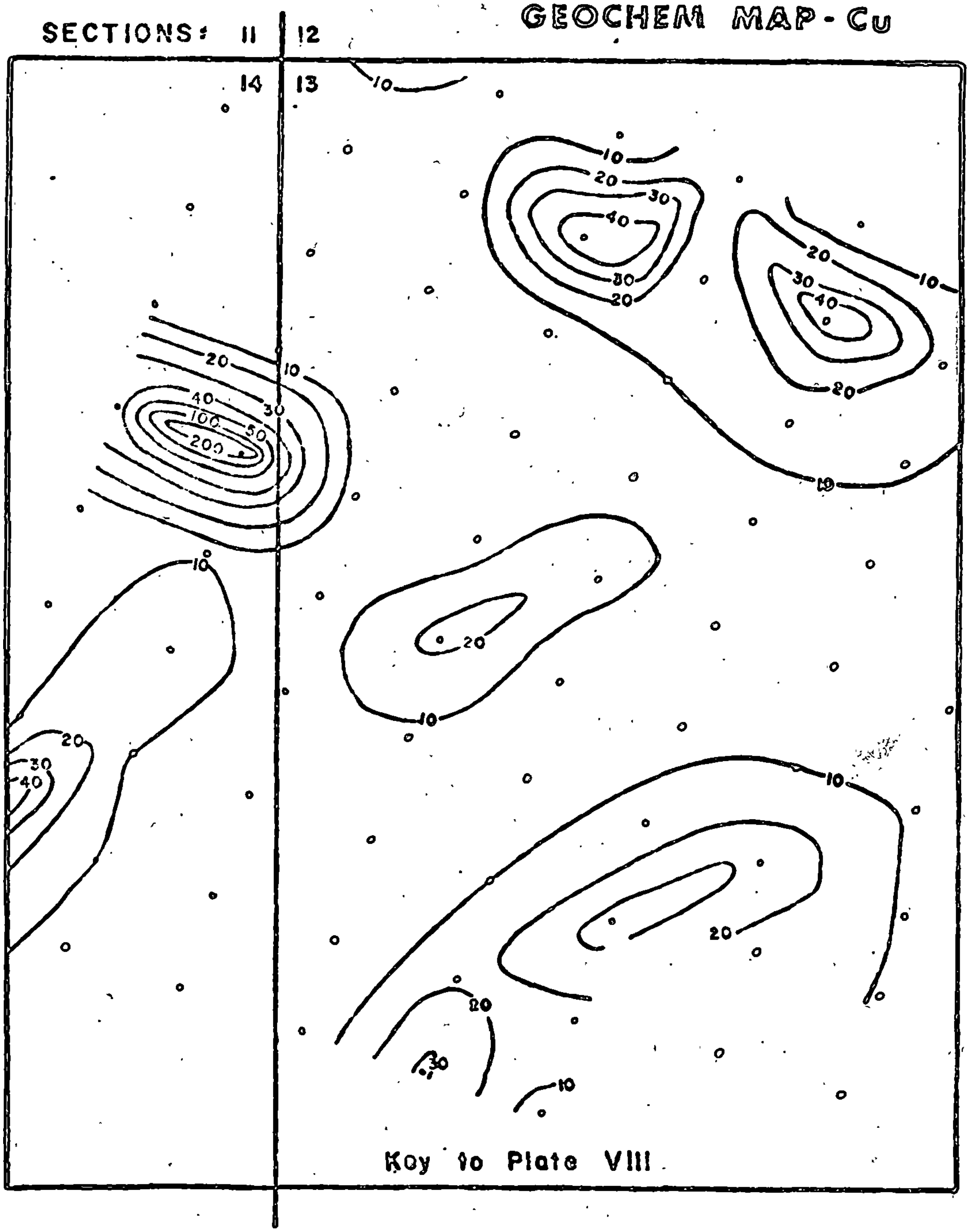


Plate VII. Geologic map of part of the Alder Gulch area (see Pate XIII).

GEOCHEM MAP - Cu



Key to Plate VIII

contoured on ppm Copper

Rock Sample Location o

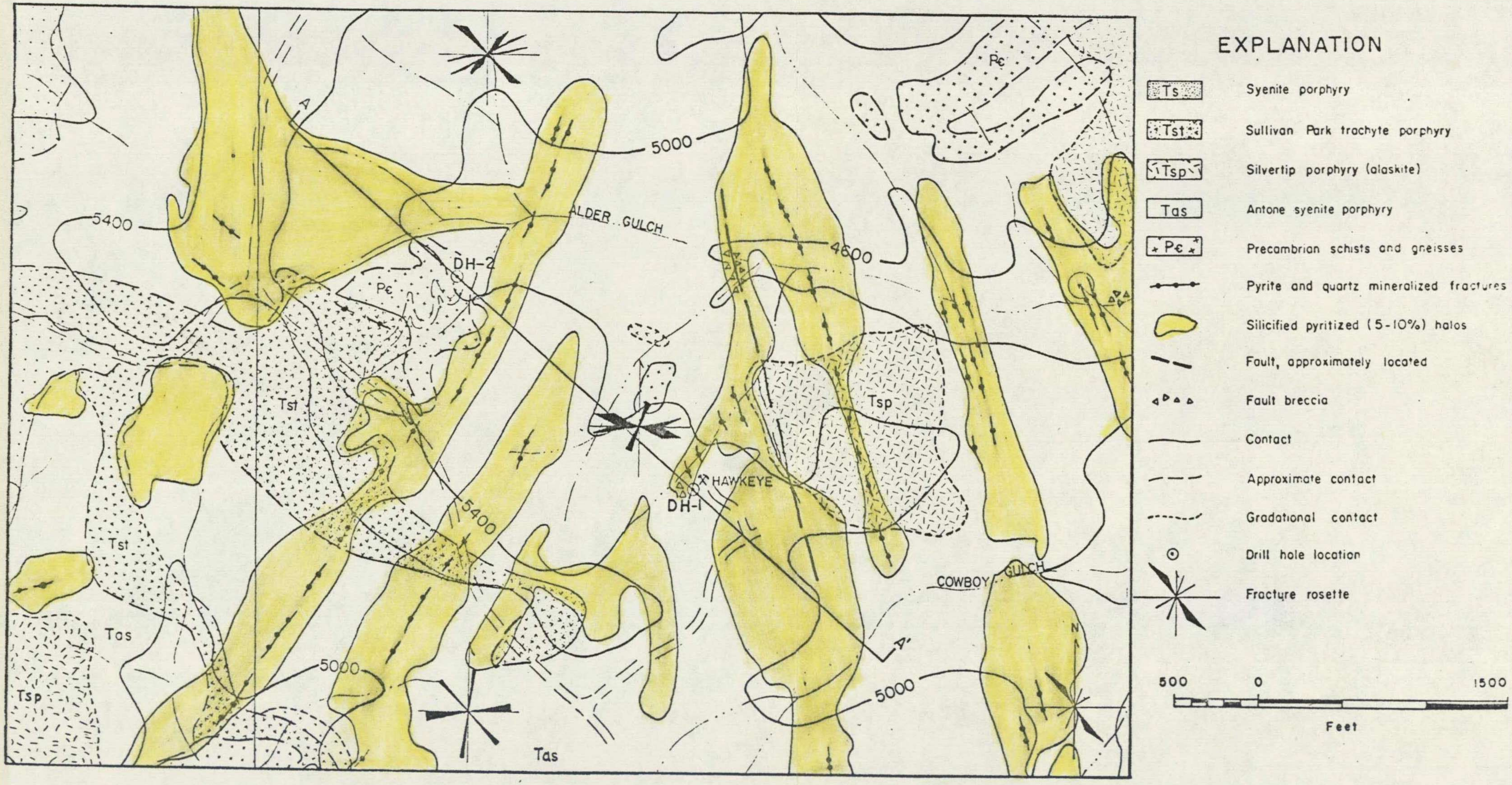


Plate VIII. Geologic map of part of the Alder Gulch area (see Plate XIII).

The results of geochemical analysis of 88 rock samples for molybdenum content are shown in Plate VII. Values range from 0 to 500+ ppm for the rock samples. Plate VII shows that anomalous high molybdenum values exist along the fracture zones and alteration halos in the Alder Gulch area. High molybdenum values adjacent to the Sullivan trachyte porphyry dike in the western part of the area decrease abruptly into the dike. The trachyte porphyry possibly did not react with or transmit the hydrothermal solutions and acted as a dam concentrating the molybdenum. Pressure, temperature and chemical (such as solubility) conditions may have also helped localize molybdenum along the Sullivan trachyte porphry dike. No copper sulphides occur in the Alder Gulch area, but malachite is present northeast of drill hole no. 2 along the fracture zone where it crosses Alder Gulch. The malachite is present as thin coatings along a few fractures. The results of geochemical analysis of 79 rock samples for copper content are shown in Plate VIII. Values range from 2 to 270 ppm for the rock samples which are from the same group of rock samples as those analyzed for molybdenum content. The higher copper values are present within the alteration halos and seem to be unaffected in magnitude by different rock types (see Plate VIII). Concentrations of copper and molybdenum minerals are too low in the Alder Gulch area to be of economic significance.

Alteration

Alteration minerals in the Alder Gulch area are quartz, orthoclase, pyrite, sericite, fluorite, magnetite and calcite. These minerals don't occur in a distinct zonal arrangement, but are related spatially to the vertical fracture and shear zones producing the elongate alteration patterns shown on Plate XIII. Units of mappable rock alteration are as much as 1,000 feet wide and nearly one mile long. Alteration halos up to a few feet wide, occur throughout the Alder Gulch area around individual fractures, but were not mapped unless they were a part of a major fracture system. The alteration zones are present in the Antone syenite porphyry but pinch down in thickness when passing through other rock types. In the Alder Gulch area hydrothermally altered areas are characterized by the following:

1. A central alteration zone consisting of heavily fractured rock containing pyrite and quartz-filled fractures, quartz flooding of the matrix, disseminated pyrite, sericitized feldspars, and locally, fluorite and manganese oxides.
2. A halo around the central zone characterized by a partially silicified groundmass, disseminated pyrite and locally hairline quartz veins.
3. A zone along the outer edge of the alteration halo characterized by some disseminated pyrite and bleaching of the host rock.

All of the above zones are gradational into one another, and the outer zone is gradational into fresh rock. Alteration is irregular and discontinuous across the area. The central heavily fractured zone is tabular in overall shape, from 6 inches to 25 feet wide and up to hundreds of feet long and deep (see Plate XIII). A grayish white to gray color characterizes the central zone of alteration in an unweathered outcrop, but surface weathering produces a reddish-orange color due to oxidation of pyrite. The outer two zones of alteration were not differentiated in the map area because they are intergradational. The middle zone or halo (see no. 2 above) delineates the extent of quartz flooding of the groundmass while the outer bleached zone (see 3 above) is the outer limit of disseminated pyrite.

Locally the outer bleached zone is not present. Calcite and fluorite are common in the Silvertip porphyry as disseminated minerals and are generally confined to fracture zones in the Antone syenite porphyry. Calcite does not occur on the surface in the Alder Gulch area suggesting a change in chemical composition of the intrusives at depth.

The rock alteration in drill holes no. 1 and no. 2 doesn't reflect the concentric alteration zones described above because the fracture zones are nearly vertical and the drill holes therefore stay in one alteration zone. However, vertical zoning of the alteration minerals controlled by the intrusion of Silvertip porphyry into Antone syenite porphyry is suggested by the mineral relationships in drill hole no. 1 (see Plate XIV). The alteration halo along the intrusive contact between the Silvertip porphyry and the Antone syenite porphyry is the same mineralogically as the halo around the fracture zones.

Within 100 to 300 feet of the contact between the two rock types the groundmass of the Antone syenite porphyry is silicified and pyritized, and contains disseminated calcite and fluorite. The groundmass of the Silvertip porphyry is partially silicified in the fractured zones.

The vertical distribution of alteration minerals in drill hole no. 1 is as follows (see Plate XIV);

SURFACE

1. Silicification and pyritization of the Antone syenite porphyry and fracture filling along channelways proveded by vertical fracture zones extending to the present surface. (These are the fracture zones and alteration halos described earlier in the chapter and shown on Plate XIII).
2. Silicification and pyritization of the Antone syenite porphyry within 100 to 300 feet of the contact with the Silvertip porphyry.
3. Partial silicification and pyritization of the Silvertip porphyry.

BOTTOM OF HOLE

Petrography

Quartz is a widespread alteration mineral in the Alder Gulch area and is present as a replacement of the groundmass of the intrusive rocks and as fracture fillings. Quartz as a replacement of the groundmass forms an anhedral microcrystalline even-textured mosaic (see Plate IX, Figure 1). It is distinguished from the primary

Plate IX

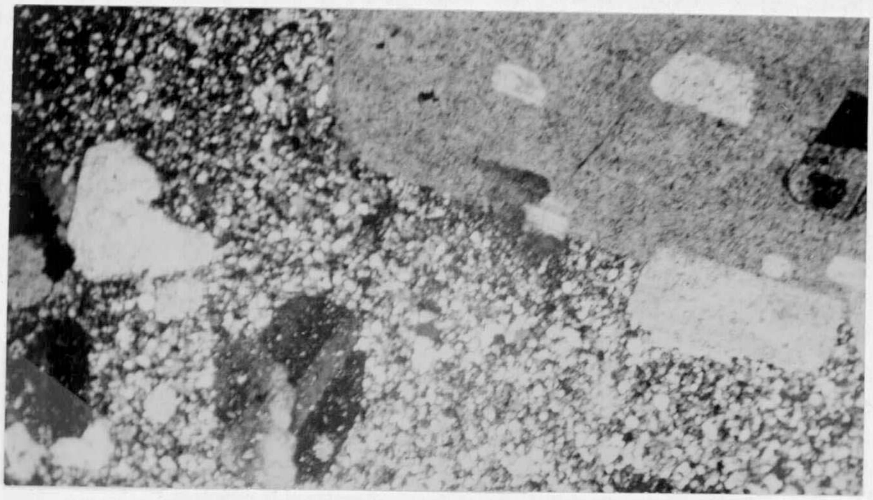


Figure 1. Antone syenite porphyry showing the silicified groundmass.

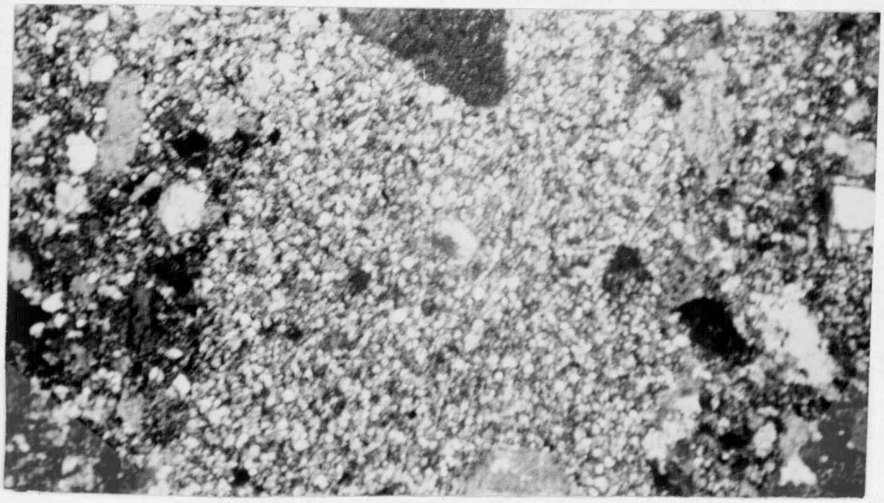


Figure 2. Antone syenite porphyry showing a partially silicified groundmass.

groundmass minerals of the intrusive rocks by its even texture and uniform freshness as seen under the petrographic microscope. A partially silicified groundmass is characterized under the petrographic microscope by irregular lobe shaped masses of secondary quartz which are separated from the original groundmass by a sharply distinct boundary (see Plate IX, Figure 2). Near quartz veins, grains in the silicified groundmass become gradually coarser toward the vein up to 1 mm in maximum dimension. Feldspar phenocrysts exhibit the same type and extent of alteration whether in silicified or unsilicified groundmass. Feldspar phenocryst boundaries are corroded in intrusive rocks which have a silicified groundmass. Quartz phenocrysts in the Silvertip Porphyry commonly have overgrowths beyond their original boundaries. The overgrowths commonly enclose cubic pyrite crystals. Quartz veins in the Alder Gulch area consist of composite grains up to 1.5 mm and contain pyrite, magnetite, molybdenite, native gold, gold tellurides, sericite, fluorite, calcite and secondary orthoclase. Quartz probably occurred both earlier, contemporaneous with, and later than all the minerals except the fluorite and gold tellurides which occur only in the interstices of the veins. Native gold is found both in the interstices of the veins and disseminated throughout the quartz present in the mines in the Little Rocky Mountains (Dyson, 1939).

Pyrite occurs as fracture fillings and disseminated grains in the matrix of the intrusive rock.

It is common throughout the Alder Gulch area and is usually less abundant than quartz as a fracture filling, but locally fractures up to 3 inches wide contain pyrite in the absence of quartz. Disseminated pyrite is present as individual crystals and as clusters of cubic crystals. Locally pyrite is present as cubic crystals within the pseudomorphs remaining after augite and hornblende is altered to chlorite and sericite. Pyrite is present in cubic crystals as inclusions in secondary calcite in drill hole no. 2 at depths from 1,420 to 2,000 feet (see Plate X, Figure 1).

Magnetite is present as anhedral grains on the rims of hornblende phenocrysts, as a massive vein mineral and as anhedral grains in the groundmass of the intrusive rocks in the Alder Gulch area. Disseminated and vein magnetite occurs in intrusive rock which contains abundant Precambrian rock inclusions. Drill hole no. 1 at depths from 1,125 to 1,350 feet contains Precambrian schist and gneiss inclusions ($\frac{1}{2}$ to 2 inches in maximum dimension) up to 5 in number per foot of core. The Antone syenite porphyry from 1,125 to 1,350 feet is a darker color than normal due to the hornblende, augite, and magnetite present. In this same interval veins commonly contain massive magnetite with pyrite and calcite (in the interstices).

Sericite is abundant in the Alder Gulch area as an alteration product of feldspar phenocrysts and feldspar groundmass. Most thin sections examined contained at least a film of sericite on the

Plate X

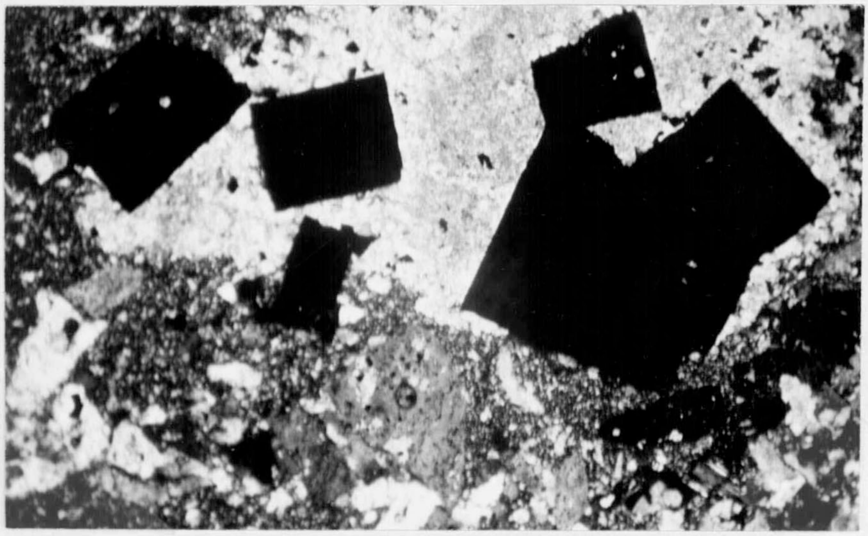


Figure 1. Silvertip porphyry showing calcite and pyrite disseminated throughout the groundmass.

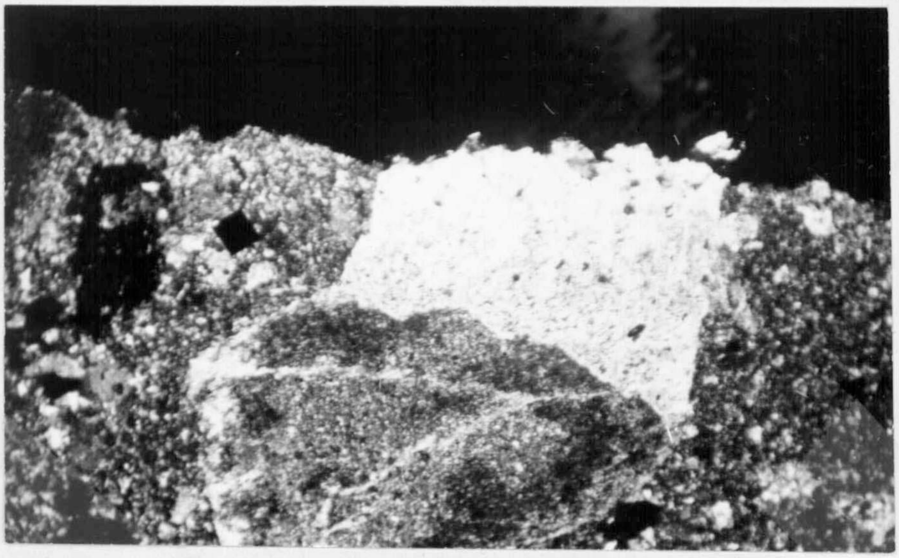


Figure 2. Secondary orthoclase? adjacent to sericitized orthoclase phenocrysts, also bounded by a pyrite vein.

feldspars. In the heavily silicified and pyritized fractured zones in the Alder Gulch area, the feldspars are partially to completely sericitized. Sericite is sparse or absent as a vein mineral.

Calcite is not present on the surface in the Alder Gulch area but is found in both drill hole no. 1 and no. 2 (see Plate XIV). Veined and disseminated calcite occur at depths from 500 to 2,000 feet (bottom of hole) in drill hole no. 1 and from 500 to 1,070 feet in drill hole no. 2. Disseminated calcite is present as pseudomorphs of feldspar phenocrysts and in the groundmass. Pyrite and fluorite inclusions (locally), probably formed earlier than the calcite. Small shreds of sericite are commonly interspersed with calcite suggesting that calcite formed as a replacement of sericite (see Eq. 6.3).

Purple fluorite is present in veins in the Alder Gulch area and disseminated in the groundmass along with calcite in the Silvertip porphyry in drill hole no. 1 (see Plate XIV). Fluorite appears in veins in the heavily fractured, strongly altered zones and is contained in all the gold deposits in the Little Rocky Mountains. It is a late alteration mineral common in rocks which show evidence of post-alteration fracturing such as offset veins, abundant vugs and slickensided pyrite and quartz veins. In thin section fluorite is characterized by its purple color in plane light, cubic crystals, and isotropic nature.

Secondary orthoclase is difficult to distinguish from primary because the mineral is a common constituent of the Antone and Silvertip porphyries. Criteria which suggest the presence of secondary orthoclase in the intrusive rock in the Alder Gulch area are:

1. Large (up to 25 mm) unaltered orthoclase phenocrysts which contain inclusions of all the other constituents in the rock (see Plate V, Figure I).
2. Fresh and sericitized phenocrysts in the same thin-section (see Plate X, Figure 2).
3. Overgrowths of unaltered orthoclase on sericitized orthoclase phenocrysts and on fractured orthoclase phenocrysts (see Plate XI, Figure I).
4. High percentages of K_2O in heavily fractured, silicified-pyritized zones.

The percentage of orthoclase present in the fresh rock in the Alder Gulch area varies considerably (see Ch. IV) which possibly accounts for some of the high K_2O percentages. The variation in the size, alteration, and inclusions in the orthoclase phenocrysts cam be explained as a late magmatic or deuteric product. Despite the difficulty in distinguishing secondary orthoclase, it is probably present based on the criteria listed above.

In the discussion of the alteration zones, the central veined zone was described as mainly fracture filling whereas replacement minerals are present in the outer alteration halo. This discontinuity of alteration type does not suggest two stages or types of alteration in

Plate XI

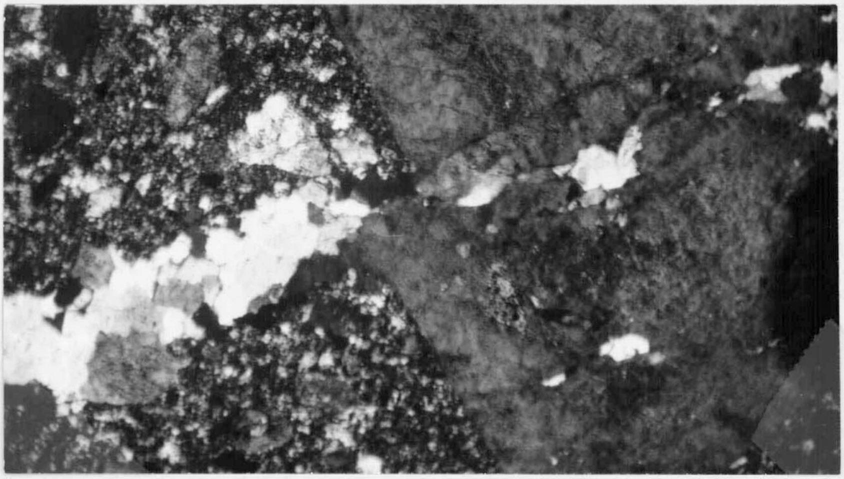


Figure 1. A quartz vein cutting the groundmass of the Antone syenite porphyry changing to secondary orthoclase as it passes through a fractured orthoclase phenocryst.

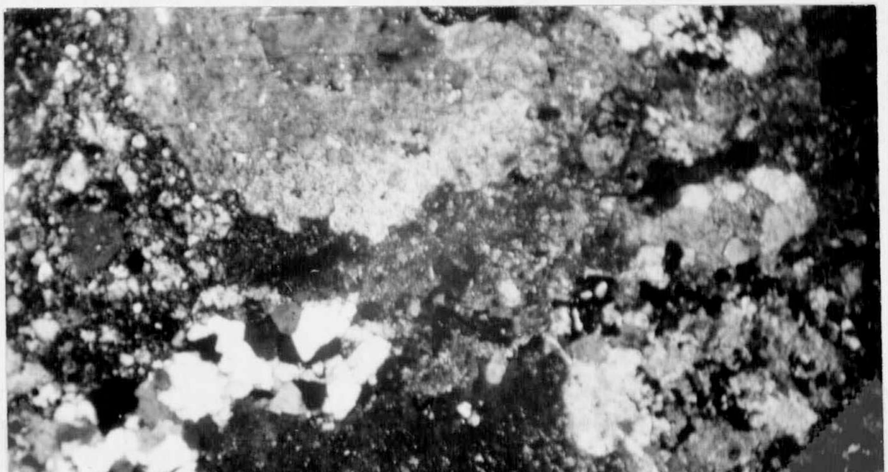


Figure 2. A quartz vein cuts Antone syenite porphyry then changes to a calcite vein as it passes through a Precambrian inclusion.

Plate XII

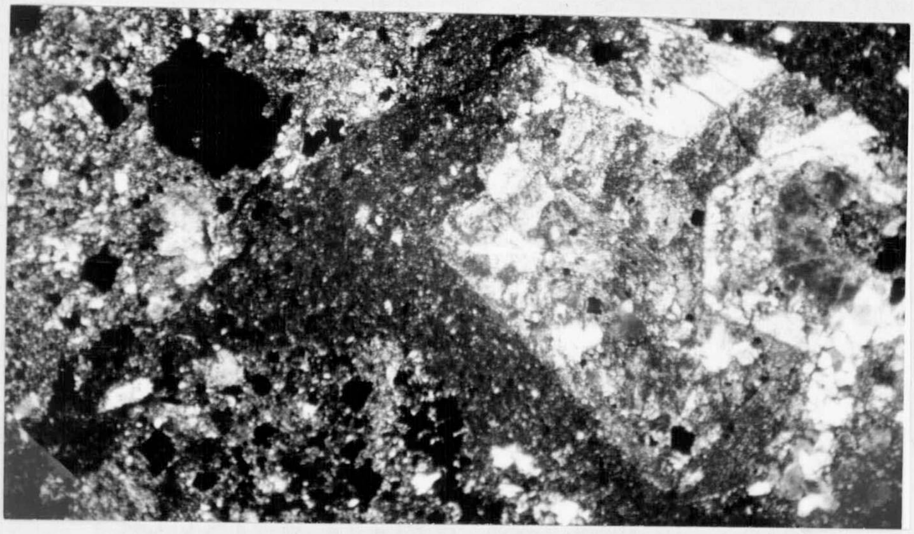


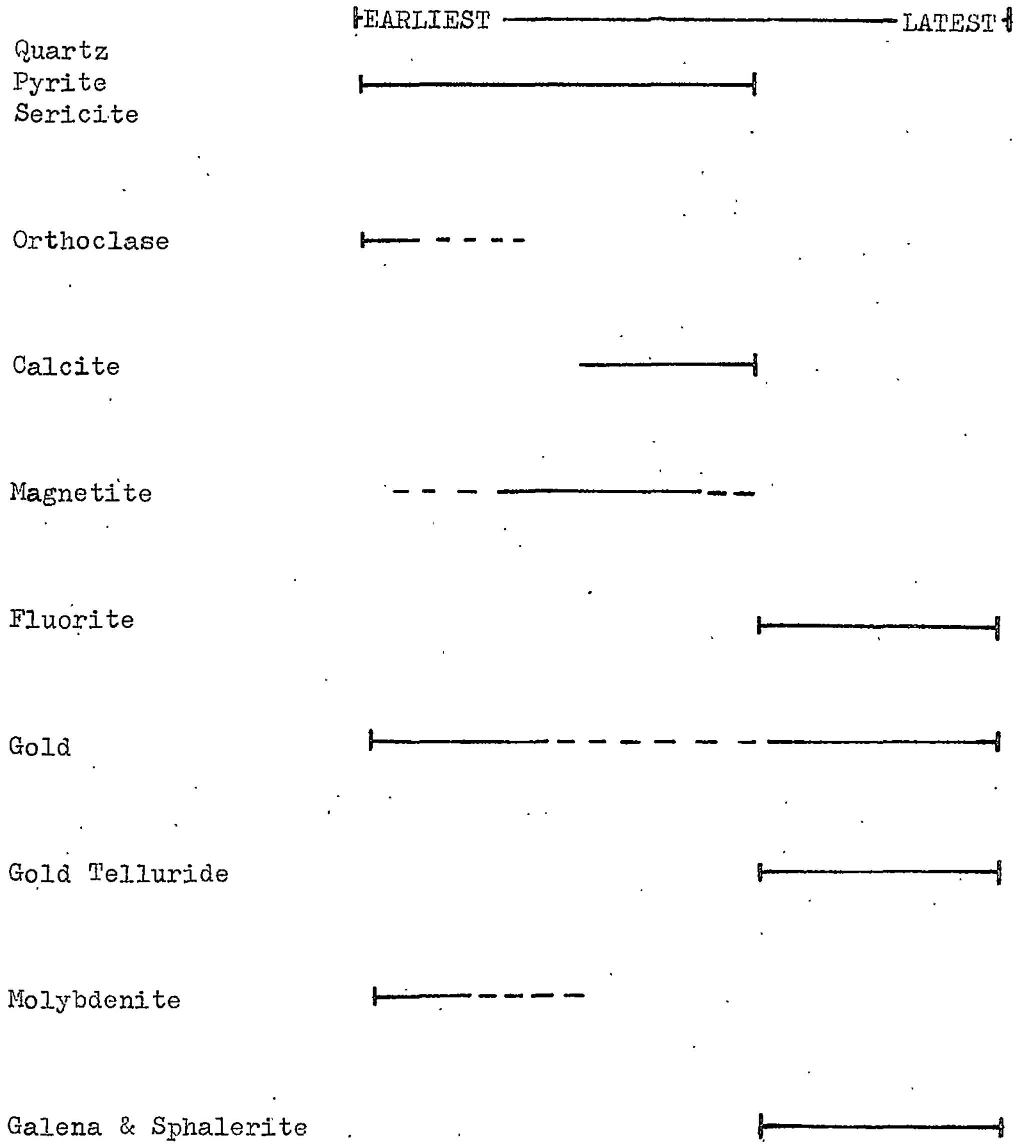
Figure 1. Brecciated Antone syenite porphyry

Figure 2. Brecciated Antone syenite porphry near the Hawkeye mine

the Alder Gulch area. Evidence will be discussed which suggests that chemical activity between the hydrothermal solutions and wall rock was a factor controlling fracture filling. In thin section, quartz veins commonly grade into the fine-grained silicified groundmass rather than being separated by a sharp boundary as in fracture filling. Some quartz veins change into calcite, sericite and pyrite veins where they pass through Precambrian inclusions which are rich in hornblende (see Plate XI, Figure 2). These features suggest that the chemical composition of the host rock was a controlling factor in the deposition of the alteration minerals and the fracture fillings were partially a replacement deposit.

A summary of the paragenesis of the alteration and mineralization is shown in Table 3. Quartz, pyrite and sericite are the most common minerals in the area and are persistent throughout the development of the alteration zones. Calcite, which is possibly a replacement of sericite, exists deeper in the intrusive and is later than some of the quartz and pyrite. Pyrite deposition extends in time both earlier and later than magnetite in the same vein. Secondary orthoclase is difficult to identify but probably formed at the time the porphyry groundmass was silicified. Fluorite is later than the quartz-sericite-pyrite alteration because it fills fractures which cut quartz veins. Native gold occurs with the quartz and is also present in post-vein fractures along with fluorite (Dyson, 1939). Gold tellurides are

Table 3. Paragenesis of alteration minerals and ore minerals.



contained in fractures that post-date the quartz veins. Molybdenite is present in a quartz vein in drill hole no. 1. Galena and sphalerite occur in drill hole no. 1 and are later than the quartz-pyrite-sericite alteration.

Chemical Interchanges

In calculating chemical interchanges semiquantitatively, constant-volume is assumed before and after the rock is altered unless there is evidence to the contrary (Barnes, 1967; Nilsson, 1968; Nielson, 1968; Hemley and Jones, 1964). In the Alder Gulch area no processes such as metamorphism or extreme weathering have affected the intrusive rocks, so for this study constant-volume is assumed.

Reporting chemical gains and losses in terms of gram equivalents rather than grams is the more meaningful method because it accounts for differences in atomic weight between elements. In this study bulk densities of the rocks in the Alder Gulch area were not measured but because of the similarity in texture and composition of the two main types - Antone syenite porphyry and Silvertip porphyry - it is assumed a constant. To compute grams/volume or gram equivalents/volume, the bulk densities are multiplied by the weight percent which in this study is a constant, so chemical gains and losses will be discussed as weight percent. Total rock chemical analyses were not made, so the method of comparing weight percents of oxides is used and can be compared to many similar alteration studies. This method is a rough estimate and is as accurate as the data available.

In the Alder Gulch area 53 samples of intrusive rock were taken on the same grid as that shown in Plate VII and analyzed for Na_2O, CaO, and K_2O in weight percent. Fourteen of the samples taken were in altered zones and thirty-nine in unaltered zones (see Plate XIII). Averages and percent change are shown in Table 4.

Table 4. Average percent and average percent change in K_2O, Na_2O and CaO in 53 samples of intrusive rock taken in the Alder Gulch area.

	Unaltered	Altered	% Change
CaO	.48	.25	- 48%
Na_2O	4.70	3.90	- 17%
K_2O	6.30	7.10	+ 12%

CaO is depleted by 48 percent on the surface but was not abundant in the unaltered intrusive rock. The abundance of calcite in both drill holes at depth (below 500 feet) as an alteration product requires a source of Ca such as migration from the limestones which ring the intrusive or emanations from a calcium-rich magma at depth. Another possibility is that calcite was deposited in the depth zone of steam loss and rising pH which is due to pressure and temperature changes and is common in many hydrothermal areas (Barnes, 1967). The rising pH causes a lower solubility of Ca.

Na_2O is depleted in the altered zones by 17 percent probably due to sericitization of plagioclase. K_2O is richer in the altered zones by 12 percent probably due to the formation of secondary orthoclase and sericite. The possibility that the depletions and additions are controlled by weathering is not likely because sericitization and secondary orthoclase are present in both drill holes no. 1 and no. 2 to a depth of 2,000 feet.

The above percentages have an approximate ± 5 percent margin of error due to compositional and textural variations in the fresh intrusive rock. The additions and depletions are consistent with the alteration mapped on Plate XIII and would probably be more distinctive if altered samples had been taken only from the central most heavily fractured and altered zone rather than from a grid system.

The amount of calcium, sodium and potassium being exchanged by hydrothermal alteration processes can be estimated roughly. A rock density of 170 lbs./cu. ft. for a typical syenite porphyry is assumed (McKinstry, 1948). The area within an alteration halo such as the one south of the caption "Cowboy Gulch" on Plate XIII is measured. This particular halo has surface dimensions of 1,100 feet by 600 feet and to a depth of five hundred feet has a volume of 6.6×10^7 cubic feet. Calculating the difference in tonnage of calcium, sodium and potassium oxides in the altered zone compared to unaltered rock gives the following values for the first 500 feet of depth.

1. CaO depleted - 64,515 tons
   Na_2O depleted - 224,400 tons
2. K_2O added - 224,400 tons

Other constituents in the alteration zones were not determined quantitatively by sampling on a grid system. Silica, iron, sulfur, and many additional trace elements were probably added by the hydrothermal solutions, since they occur in greater abundance than would be expected in the ordinary alkalic intrusive rocks in the Alder Gulch area. Based on drill hole information and detailed mapping on the surface, quartz in alteration zones increases by approximately 30 percent over its abundance in unaltered country rock. In the heavily fractured zones, this increase is probably due to the addition of silica by the deuteric phase of the Silvertip porphyry as it intruded the Antone syenite porphyry. Excess silica is also available in hydrothermal systems after feldspars are sericitized and sericite is carbonated (see Eqs. 6.1 and 6.3). Addition of iron in the form of pyrite and magnetite in the altered zones in the Alder Gulch area is assumed because of the scarcity of iron-bearing minerals in the intrusive rocks. Precambrian inclusions contain abundant ferromagnesian minerals such as hornblende and augite, but the distribution and degree of alteration of these inclusions is so variable that no reasonable approximations of chemical exchange can be made.

Sulfur in the form of H_2S is a common constituent of hydrothermal solutions and is evidenced by the abundant pyrite present in the Alder

Gulch area. In the heavily fractured zones pyrite averages 5 percent of the total rock. Assuming a density of approximately 3.0, the amount of sulfur added to the rock is approximately 15 gm/100 cc or nearly 1.0 gram equivalent/100 cc. Carbonation of the rock as at depth in drill holes no. 1 and 2 requires addition of HCO_3 from the hydrothermal solution.

Some of the chemical reactions (from Barnes, 1967) which might have occurred in the Alder Gulch area are as follows:

(Eq. 6.1) The sericitization of orthoclase by mineral hydrolysis.

$$3KAlSi_3O_8 + 2H^+ \longrightarrow KAl_2AlSi_3O_{10}(OH)_2 + 2K^+ + 6SiO_2$$

(Eq. 6.2) Silicification of sericite

$$KAl_2AlSi_3O_{10}(OH)_2 + 3Si(OH)_4 + 10H^+ \longrightarrow 3Al^{3+} + K^+ + 6SiO_2 + 12H_2O$$

(Eq. 6.3) Calcite plus quartz after sericite

$$2Ca^{2+} + 2HCO_3 + KAl\ Si_3O_{10}(OH)_2 + 4H_2O \longrightarrow 3Al(OH)^- + 4H^+ + K^+ + 2CaCO_3 + 3SiO_2$$

(Eq. 6.4) Pyrite formed from sulfur and iron in solution

$$2H_2S + Fe^{++} \qquad FeS_2 + 4H^+ + 2e$$

(pyrite could be formed from many different reactions between iron and sulfur compounds)

Of the many possible reactions suggested by Barnes (1967) and others, Eq. 6.1 thru 6.4 were considered the most likely to fit the pattern of alteration minerals present in the Alder Gulch area. A summary of additions and depletions during rock alteration in the Alder Gulch area is as follows:

1. Additions in altered zones
   Si, K, Fe, F, Cu?, Mo?, Au?, Ag?, H_2S, CO_3
2. Depletions in altered zones
   Ca, Na

Copper, molybdenum, gold and silver are questioned in the list of additions because they could have been reconcentrated from the intrusive rock in the Alder Gulch area or they could have been added from an outside source. The deuteric phase of the Silvertip porphyry could have been comparatively enriched in one or all of the following: copper, molybdenum, gold, and silver. The metals in solution migrated through fracture zones in the Antone syenite porphyry and were deposited as temperature, pressure and chemical conditions permitted. All of the gold deposits examined in the Little Rocky Mountains are in fracture zones in the Antone syenite porphyry. Later fracturing of the rock and continued alteration favorable for reconcentrating gold is a possible explanation for the deposits in the Little Rockies. Concentration of metals in the deuteric phase of an intrusive body can be explained even though the unaltered Silvertip porphyry as a whole is not richer than average in any of the base metals or precious metals. For example to concentrate a sizeable deposit of molybdenum, say 10,000 tons, from a small granitic stock (± 100 Km^3), the average molybdenum content of 1 part per million for the average granite (Turekian and Wedepohl, 1961) would be decreased by only .3 parts per million (Barnes, 1967). To furnish the small amount of metals present in the Little Rocky Mountains (see Plate VII and VIII) a source such as the Antone porphyry and Silvertip porphyry which contained average amounts (see Table 2) of metals would be sufficient. The metals are possibly partially concentrated during the deuteric phase of magmatic activity. Reconcentration of the metals would be facilitated by fracturing and the presence of aqueous solutions rich in sulfur, carbonate, chlorides and acids which are necessary to transport the metals in solution.

A summary of the elements possibly present in the hydrothermal solutions during rock alteration is: water, some form of sulfur, silica, potassium, carbonate (or carbon dioxide), calcium and trace elements including copper, molybdenum, gold, silver and fluorine. A solution saturated in chlorides and fluorides is discussed by many authors as being necessary for the hydrothermal transport of gold (Barnes, 1967; Krauskopf, 1964; Cloke and Kelly, 1964; Corry, 1933 and others). Chlorides are not present in the map area in any of the mineral complexes, but the fluorite associated with the gold deposits as a late alteration product suggests the presence of fluoride salts in the hydrothermal solutions accompanying the gold and gold tellurides deposited as the last phase of mineralization.

VII. GEOLOGIC HISTORY

Precambrian

Pre-Belt rocks exposed in the map area are all foliated. Prior deposition of a quartzo-feldspathic sedimentary sequence is suggested by the intercalated quartz-feldspar gneisses and biotite-hornblende schists. This earliest recordable event in the map area was followed by metamorphism which evidently took place in Precambrian time, since it didn't affect any of the rocks of Paleozoic or Mesozoic ages exposed in the Little Rocky Mountains.

Rocks belonging to the Belt series are not present in the Little Rocky Mountains, and the nearest exposures are approximately 150 miles to the west in the Big Snowy and Little Belt Mountains.

According to E. W. Heinrich (oral communication to Knechtel, 1959) much of the rock of the Precambrian pre-Belt gneisses and schists in the Little Rockies resembles parts of the Cherry Creek group of south-central Montana. The Cherry Creek group rocks underlie the Belt series and overlie the Pony group (Heinrich, 1953). This evidence suggests that the Precambrian rock in the Little Rocky Mountains is at least partly younger than the Pony group (Knechtel, 1959). The Precambrian metamorphic rocks are overlain unconformably by the Flathead Sandstone (Middle Cambrian).

Paleozoic - Mesozoic

Following metamorphism and erosion a sedimentary sequence at least 6,700 feet thick was deposited unconformably on the Precambrian metamorphic rocks (Knechtel, 1959). No sedimentary record is present for early Cambrian, much of the Ordovician, all of the Silurian, parts of the Devonian and Mississippian, all of the Pennsylvanian, and Permian, and Triassic, ~~and~~ Early Jurassic periods. A broad regional uplift in Early Jurassic time resulted in the well-marked hiatus between beds of Mississippian and Middle Jurassic age. The youngest sedimentary formation in the Little Rockies is the Bearpaw shale which is Cretaceous (Montana Group), though formations as young as the Hell Creek formation (Paleocene) are believed to have been present in early Tertiary time (Knechtel, 1959) and if so have been removed by erosion.

Cenozoic

Movements along faults in the basement rock probably took place in several phases from late Cretaceous up to at least early Tertiary. This faulting is probably related to the Laramide orogeny which produced east-west trending compressional forces to the west in the Rocky Mountains. Other evidence suggesting deep seated faulting and/or uplift before emplacement of the intrusives is the large amount of doming on the sedimentary rocks without intense folding. From drill hole information five miles south of the Little Rocky Mountains apparent upward displacement is at least one mile.

During early Tertiary time (68 million years ago, Gilully, 1965) intrusive activity began with emplacement of the Antone syenite porphyry causing continued uplift of the sedimentary rocks. Faulted, uplifted blocks of basement rock provide an environment that explains the areal confinement of the intrusive mass and also explains the extent of uplift of the sedimentary rocks. If the location and configuration of the intrusive and uplift were dependent only on the upward pressure of an intrusive mass, it seems logical that the sedimentary rocks would be forced aside and intensely faulted and folded as they were being intruded. Conversely, the sedimentary rocks have been uplifted at least one mile. The intrusive rocks cut no sedimentary rocks younger than Cambrian except by faulting. Intrusive activity continued with forceful emplacement of the Silvertip porphyry into the Antone syenite porphyry. The older Antone porphyry was popped upward by the later intrusive, causing fracturing as well as ring faulting and hinge faulting along the contact between the intrusive and sedimentary rocks (see Plate I). Magmatic activity ended with the intrusion of the Sullivan trachyte porphry dikes and syenite porphyry dikes (see Plate XIII). Post-intrusive structural adjustments such as subsidence and possibly continued uplift caused shearing and fracturing of the intrusives.

Erosion during the remaining part of the Tertiary period and during the early part of the Quaternary period produced the present topography and established a drainage pattern that was adjusted to the late Tertiary ancestral Missouri River system.

Hydrothermal alteration probably began as the Antone syenite porphyry was being intruded by the Silvertip porphyry. The deuteric phase which concentrated near the roof of the intruding mass was probably rich in silica and hydrothermal constituents such as water, sulfurous compounds (and gases), carbonate, and carbon dioxide. Silicification of the Antone syenite porphyry within 100 up to 300 feet away from the Silvertip porphyry contact is evidence supporting this hypothesis. Fracturing and shearing contemporaneous with intrusive activity provided channelways for circulation of hydrothermal solutions. As pressure and temperature decreased and as the chemical factors such as pH and solubility permitted, minerals were deposited in the fractures and as replacements in the wall rock. Continued structural adjustments due to shrinkage and possibly uplift caused further fracturing of the intrusive mass providing channelways which facilitated concentrating and reconcentrating certain elements. Gold and silver are examples of elements which were probably concentrated and reconcentrated by the hydrothermal solutions. If the solutions contained chloride and fluoride salts or some other constituents which increase the solubility of gold and silver, they could transport the metals in solution to a favorable environment such as a heavily fractured zone. A decrease in pressure and temperature there would probably cause deposition of the salts in the solution along with the gold.

As the intrusive rock in the Little Rocky Mountains was exposed to weathering, oxidation began. Oxidation of the rock below the surface was probably faster along unfilled fractures such as the ones present in the heavily fractured zones. Oxidation at depth along shear zones is evidenced by the oxidized ore present in the Ruby Mine 500 feet below the surface.

Economic Recommendations

The feasibility of finding economic amounts of base metals or precious metals on a large scale in the Little Rocky Mountains would be increased by the following:

1. Mapping of the Antone syenite porphyry and Silvertip porphyry over the entire Little Rockies with emphasis on contact relationships.
2. Detailed mapping and geochemical sampling of the breccias present in the Little Rocky Mountains.
3. Measurement of joint set trends over the entire Little Rocky Mountains and statistical analysis of the trend measurements in order to determine a center or centers of intrusion.

If the criteria listed were followed and favorable base metal targets were revealed, chances are still slim that any further exploration such as drilling would lead to discovery of an economic ore body.

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