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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ROBERT LESLIE BAILEY

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Approved:

Milton J. Edie
Head, Major Department

Robert A. Chadwick
Chairman, Examining Committee

Henry L. Parsons
Graduate Dean

MONTANA STATE UNIVERSITY
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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

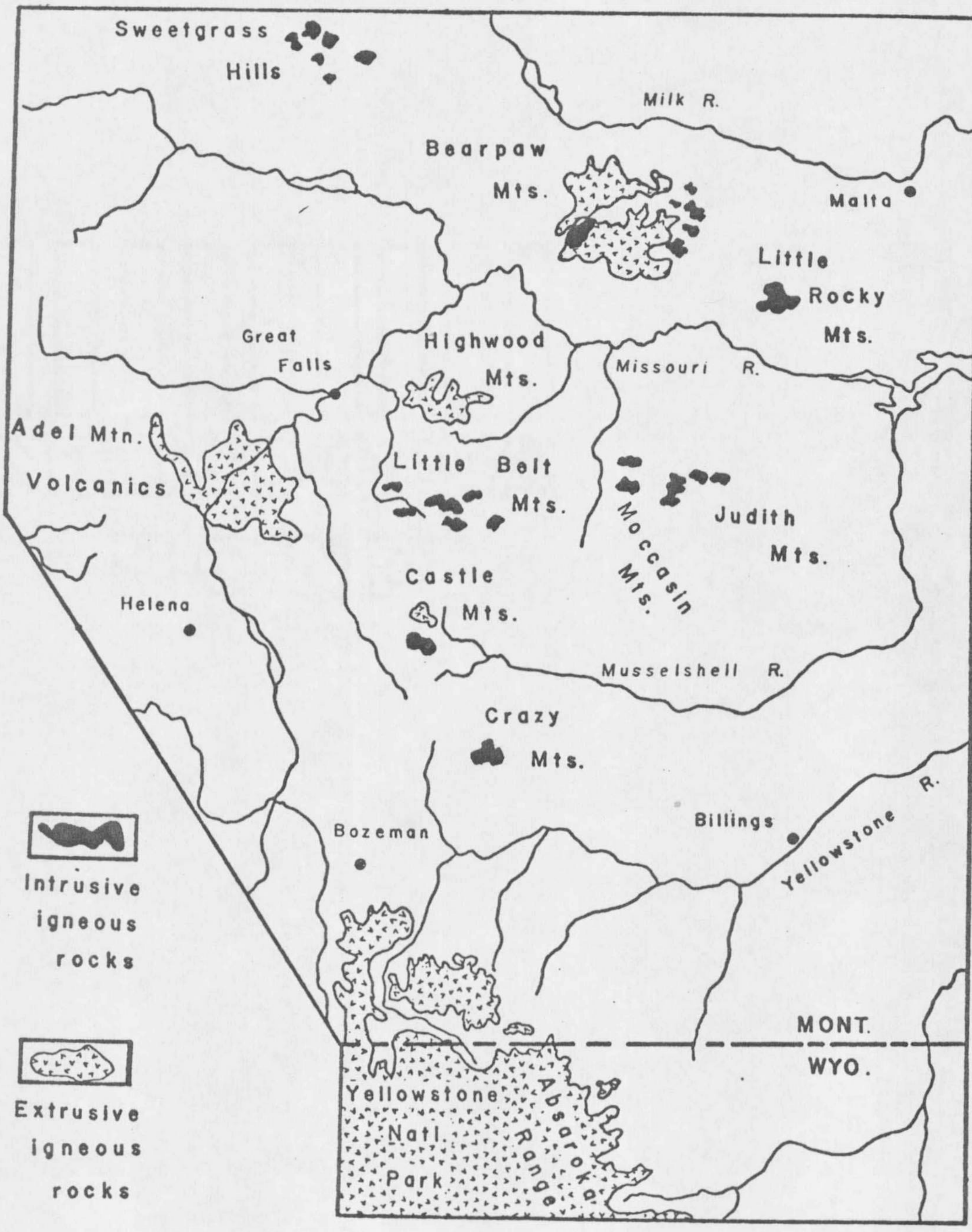

Plate II. Map of the Central Montana petrographic province.

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