



Geology of the Moose Creek stock, Highland Mountains, Montana
by Daniel B Andretta

A Thesis Submitted to the Graduate Faculty in Partial Fulfillment of the Requirements For the Degree
of Master of Science in Applied Science at Montana State College

Montana State University

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Abstract:

An area 50 miles south of Butte, Montana provides excellent opportunity to observe Precambrian through Cretaceous sedimentary exposures typically metamorphosed by the Late Cretaceous to early Tertiary Boulder batholith and its apophysis, the Moose Creek stock. Although some related sills and irregular bodies are diabasic, the predominant magma was quartz monzonitic. The general effect has been to convert carbonate units to marble, shale and silt-stone units to dense cordierite hornfels, and chert or sandstone units to quartzite. Although moderate, metamorphism has destroyed enough of the original distinctive lithologies so that formations can be identified only by stratigraphic position or microscope examination. Mineralogy of diabasic sills has also been changed to a low-to medium metamorphic characteristic.

Late Cretaceous to early Tertiary "Laramide" forces produced some folding and faulting of the sediments and basic sills; faulting south of the area resulted in uplift and tilting of the entire rock assemblage to the north.

The quartz monzonite stock and batholith show some variation in texture, color and mineralogy but appear to be closely related. Forceful injection of these intrusives accentuated pre-existing folds and developed complex systems of small scale high angle shear and tensional faults.

Coarse stream deposited, conglomeratic Tertiary sediments in the western part of the area, derived from eastern sources, have been tilted eastward, probably by movement along a postulated normal fault.

Gradational stream processes formed pediment or fan surfaces in Late Cenozoic time which have been dissected by intermittent streams in the present rejuvenated erosion cycle.

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STOCK, HIGHLAND MOUNTAINS

MONTANA

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in

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GEOLOGY OF THE MOOSE CREEK STOCK, HIGHLAND MOUNTAINS, MONTANA

INTRODUCTION

Purpose

The major purpose of this work is to gain a greater understanding of field and petrographic relations in an igneous-metamorphic area.

The work also is presented as a thesis in partial fulfillment for the degree of Master of Applied Science with a major in Geology at Montana State College.

Location and Extent

The mapped area, approximately seven miles square, is located in the western part of the Butte Highlands in Silverbow County, Montana and includes the area between $45^{\circ} 42' 30''$ and $45^{\circ} 50' 00''$ latitude and $112^{\circ} 32' 30''$ and $112^{\circ} 42' 30''$ longitude. Section lines were not plotted on the base map used.

The western border of the area approximately parallels U. S. Highway 91 between Butte and Dillon, Montana. The town of Divide is located on this highway approximately $1\frac{1}{2}$ miles north of the southwest corner of the map area, and the abandoned settlement of Moosetown lies midway on the eastern border. Burton Park occupies the northeast extremity of the area and the Moosetown Road, originating from Highway 91 at Beaudines, runs approximately along the northern border (See Figure 1).

Accessibility

The area is accessible by auto along major roads (marked by

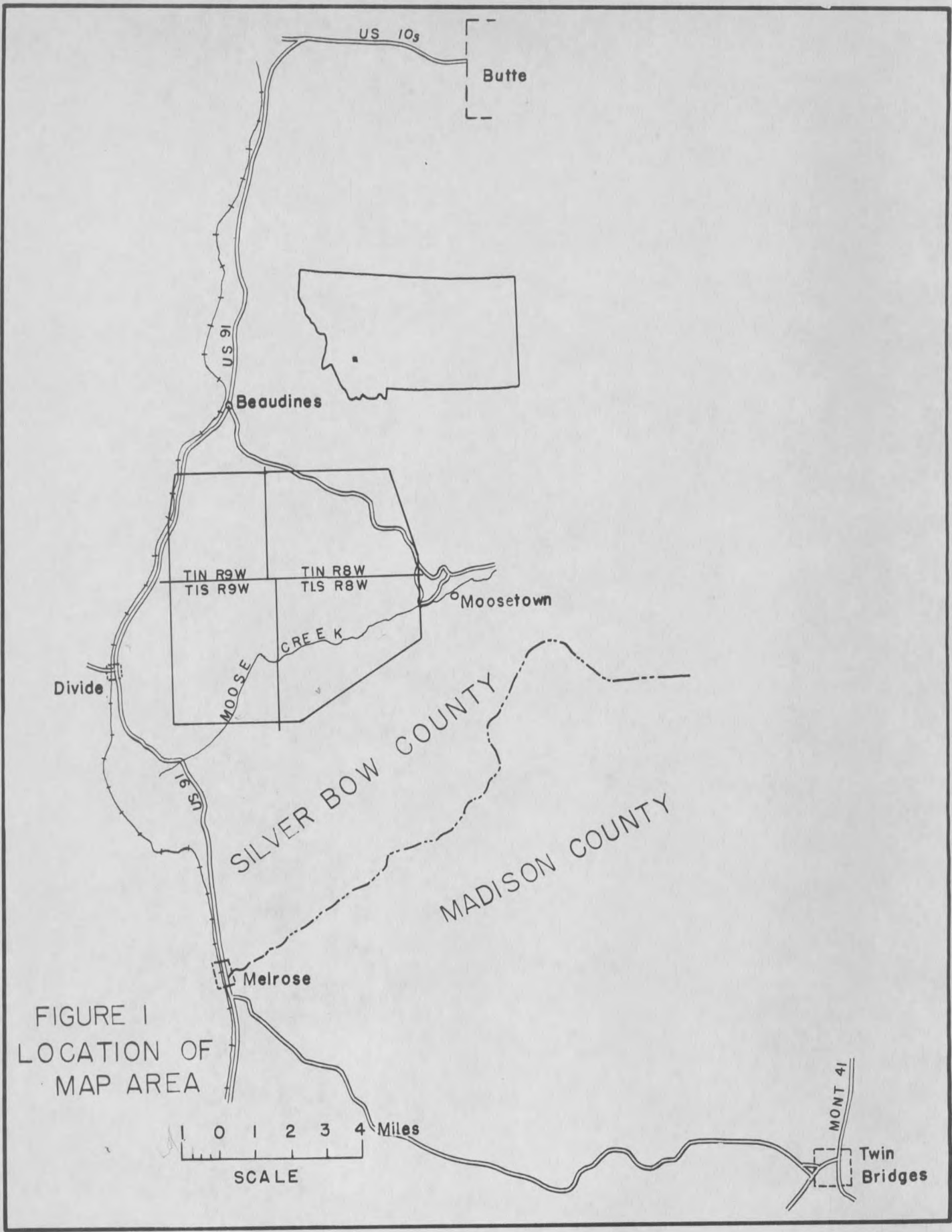


FIGURE 1
LOCATION OF
MAP AREA

1 0 1 2 3 4 Miles
SCALE

MONT 41
Twin
Bridges

solid double lines on Geologic Map), and by jeep along mining roads and secondary roads. The jeep is a feasible means of transportation into some of the broad meadows in the northern part of the area. However, the central part of the area is extremely rugged and foot travel is the only feasible mode of transportation.

Field Time and Methods

Parts of the summers of 1959 and 1960 were spent in the field. Total field time was ten weeks.

The area was mapped on Forest Service air photos, printed in August of 1947, on a scale of approximately three inches equal to one mile. The results were then transferred to U. S. Geological Survey preliminary topographic sheets of the area.

The brunton compass was the only scientific instrument used as a mapping aid. Thicknesses mentioned are either approximate or taken from the literature. In many places outcrops were non-existent and much of the mapping was done on the basis of "float". Thin sections of significant igneous and metamorphic lithologies were prepared and studied under the petrographic microscope.

Previous Work

The area was included in a reconnaissance study of the Highland Mountain by Sahinen (1950). The main purpose in Sahinen's study was to review mineral prospects in the area. The base map in this publication includes the area in T 1 N to T 1 S, R 8 W to R 9 W. Richards and Pardee (1925) also mapped the southwest part of the area, included in the Melrose Quadrangle to the southwest. S. D. Theodosius (1952)

completed a doctorate thesis on the Melrose Area, Beaverhead and Silverbow Counties, which includes some western portions of this map.

Acknowledgements

The writer particularly wishes to acknowledge aid received in the field from Dr. Harry Smedes of the U. S. Geological Survey and Dr. William J. McMannis of Montana State College. A National Science Foundation grant awarded to Dr. McMannis for his study of Belt stratigraphy financed the first summer of field work. Guidance in writing of this report given by Dr. John de la Montagne of Montana State College is greatly appreciated and assistance in petrologic work by Dr. Robert J. Foster of Montana State College is also acknowledged. Carol Mifflin and Lois Pohto typed the manuscript.

GEOGRAPHY

Surface Features

The area, in general, can be divided into two broad topographic types: Those sectors underlain by the Boulder batholith and the related Moose Creek stock are youthful in topographic expression. With few exceptions, the rest of the area is generally mature.

The places underlain by the igneous rocks are dominated by an abundance of needle-like peaks of quartz monzonite sharply jutting as much as 200 feet above surrounding topography. These areas as a whole are extremely rugged and sharp-ridged.

Geomorphic expression of regions surrounding these igneous bodies are described separately. To the west, where maximum relief is 200 feet, the topography is gentle and flat, being underlain by relatively flat lying Tertiary sediments.

The area to the north consists of a series of broad meadows and



Fig. 2. - View looking north to Mt. Humbug across Moose Creek. Mature topography is illustrated. The timbered ridge is underlain by the Quadrant formation.

rounded hills. The relief is greater, up to 2,000 feet between the Tucker Creek Valley and the top of Mt. Humbug, which, at 8,255 feet, is the highest point in the area.

Areas to the east and south are much the same as to the north; broad steep meadows and valleys, and rounded hills with high relief. All these areas are mature.

Drainage

Major drainage is to the west with both Moose Creek and Tucker Creek flowing in that direction.

Drainage in the stock has a general radial pattern with the exception of Moose Creek which traverses the stock from east to west. The streams generally occupy steep canyons in the stock and broader valleys in the surrounding country. An exception is Tucker Creek which, near its head, is entrenched in a steep canyon.



Fig. 3. - Looking east into the Tucker Creek Canyon. Note canyon's steep, youthful appearance in contrast with mature topography in Fig. 2. Outcrops to the left are the Dinwoody and Kootenai formations.

Most of these west flowing streams are tributary to the south flowing Big Hole River, the regional master stream just beyond the west border of the map area.

STRATIGRAPHY

Sedimentary rocks of the region range in age from Precambrian to Recent. All sedimentary rocks have been metamorphosed so that the lithology is quite different from the normal unmetamorphosed equivalents of these rocks. The rock units as they appear in the area are described below and their expectable unmetamorphosed lithology is mentioned for comparison.

Due to northward regional dip, oldest beds are restricted in exposure to the southern part of the area and the section becomes progressively younger to the north.

PLATE I



Fig. 4. - Looking west along Moose Creek into the stock. Note abrupt change in topography. Foreground is on alluvium.



Fig. 5. - Looking east across part of the Boulder batholith in the northern part of the area. Note dense timber on the igneous rocks and the sudden change of topography: Steep where underlain by the batholith, gentle where underlain by meta-sediments.

Precambrian

Belt Series - Sediments of the Belt series occupy the extreme southern part of the area. W. J. McMannis (1960, personal communication) presently studying Belt stratigraphy, has generally described the Belt in this area to the writer.

The Belt section to the east of the map area, in the vicinity of the Highland Mt. peaks, is over 15,000 feet thick and is generally depicted in the following table:

UNIT	APPROXIMATE THICKNESS	LITHOLOGY
Cambrian Flathead ss.		
1	1000 ft.	clean quartzites and interbedded argillites.
2	1500 ft.	lime silicates.
3	500 ft.	coarsely micaceous siltites.
4	2000 ft.	green siltites intbed. with quartzites.
5	6000 ft.	dark gray to black argillites and siltites.
6	750 ft.	clean quartzites.
7	600 ft.	gray argillites and carbonates.
8	3000 ft.	feldspar rich graywacke.
	15,350 ft.	

Pre-Beltian metamorphics

TABLE I.

General stratigraphic section of the Belt series in the Highland Mountains.

To the west, the section is truncated by the Flathead sandstone, and, at Soap Gulch, just to the south of the map area, the Flathead rests on Unit 5.

Also, to the west the lower part of the section changes. Unit 6, the clean quartzite, ends abruptly, either by pinchout or perhaps by faulting. Unit 7, the argillite and carbonate sequence, also pinches out. The interval below unit 5 is a thick unit of feldspar rich graywacke.

Near Soap Gulch, a lens of argillite appears in the upper part of this unit of feldspar rich graywacke and thickens to the west. Some feldspar rich graywacke is interbedded with the argillite in this lens, but the graywacke overlying this lens becomes more quartzitic to the west.

Only a few original observations of Belt material were made to augment McMannis' general description and the detailed description of random samples of Belt argillite and quartzites by Sahinen (1950, p. 13, 15) which follows:

"The predominant rock of the Belt Series is a grey green to red fine-grained argillite, locally interbedded with grey to black slate, fine-grained quartzite, and quartzite conglomerate. Some of the argillite, although massive, shows irregular banding, which, under the microscope is seen to indicate rough sorting of the fine-grained material. Individual mineral particles are not visible to the naked eye alone, or with the aid of a hand lens. Under a magnification of 400X the rock is seen to be composed of quartz, feldspars, sericite, and clay minerals ranging in size from about 0.01 inches in diameter down to submicroscopic size. Some of the argillite shows very thin bedding in light and dark bands from 0.05 to 0.10 inches thick, and some specimens show a tendency to cleave along this bedding. The light-colored bands are composed mainly of sericite and clay minerals too fine in grain size for positive identification. The dark-colored bands are composed of somewhat coarser material composed principally of quartz and earthy clay minerals. The largest quartz grains measured were but 0.0015 inches in diameter.

"Some of the argillite is still finer grained. A specimen from the vicinity of the Ballarat mine is so fine grained, compact, and lacking in any evidence of bedding, that it resembles purplish-black glassy basalt. It also has the conchoidal fracture of basalt. Individual grains can hardly be recognized under a magnification of less than 80 times. Under higher magnification it shows a mineral composition similar to the normal argillite. Some black fissile shale or slate occurs near the bottom of the series. These slates are best exposed at the junction of Camp and Wickiup Creeks.

"Most of the Beltian quartzites are banded pink and black, and are very fine grained with particles about 0.02 of an inch or less in diameter. Some of the quartz shows minute inclusions of needle-like crystals and shredded sericite, and has been recrystallized into interlocking grains like a mosaic. In many places, the quartzite is conglomeratic with four-inch quartzite pebbles in a quartzite matrix, usually pinkish in color, but streaked with black. Usually, the Belt quartzites can be distinguished from those of the Paleozoic series because they nearly always show dark colored irregular bands or streaks which do not occur in the Paleozoic quartzites."

Random samples of Belt units within the map area were examined in thin section under the petrographic microscope. One sample shows evidence of baking, as the rock is extremely dense and dark and is recrystallized to a very fine-grained quartzite, yet retains a relict bedding revealed by concentrations of limonite in parallel bands. This rock was probably originally an argillite, with affinity to unit 5.

Samples collected at greater distances from the igneous bodies are less affected by baking. Some of the minerals such as horn-blende are altered, but rocks from such locations tend to be calcareous graywacke.

Cambrian

Flathead Formation - Exposures of the Flathead formation are restricted to the southernmost part of the area. The thickness averages about 125 feet (Sahinen, 1952, p. 15).

The Flathead, in this part of Montana, consists primarily of dense, hard quartzites and sandstones. Here, after metamorphism, the sandstones of the Flathead are thoroughly fused and recrystallized to form a very hard, massive, pink to tan, dense, fine-to medium-grained quartzite. Cross bedding and other common secondary features of Flathead lithology have been mostly obliterated by metamorphism and the rock now displays extreme jointing and is very brittle in nature. This jointing consists of, or is characterized by, a series of fractures at random angles to the bedding and with no orderly orientation. The joints are closely spaced and are planes of

weakness, which make the rock susceptible to rapid erosion. The brittleness allows the Flathead to be broken up relatively easily, and in many places the surface of the ground which is underlain by Flathead is talus. The jointing obscures bedding, and attitudes are difficult to measure. The Flathead closely resembles the Quadrant and Phosphoria quartzites in hand specimen.

Wolsey Formation - The Wolsey shale is nowhere well exposed in the map area and was mapped on the basis of float. The Wolsey is restricted to the southern part of the area and here appears to be rather thin, between 50 and 100 feet thick, although an accurate measurement of thickness could not be made. Hanson (1952, p. 28), has measured a Cambrian section on Camp Creek to the southeast of this area and has determined the Wolsey to be 217 feet thick. The Wolsey has been liberally intruded by sills.

Unmetamorphosed Wolsey is generally composed of a series of micaceous, thinly-laminated, gray and purplish-gray argillites with an upper unit of brownish-gray dolomite (Hanson, 1952, p. 28). In this area, however, these lithologies are changed by contact baking and the Wolsey is converted to the metamorphic rock types described below.

The dominant lithology is a massive, black, "spotted" hornfels. The rock, in thin section, is very fine-grained except for the porphyroblasts, which are cordierite. The rock has a very fine quartz and plagioclase matrix, and often has a pitted appearance on weathered surface, making it easily mistaken for an igneous rock.

In many places, rocks with the above mineralogy and general appearance have a dominant foliation, probably the remains of bedding planes.

The brownish-gray dolomite member of the Wolsey was not visible in the mapped area. It is possible that part of the area mapped as Meagher is this unit and that metamorphism has altered the carbonate so that it closely

resembles the Meagher carbonates. In this study, the Wolsey unit has been restricted to the black massive hornfels lithology, helping to account for the apparent thinness of Wolsey.

Meagher Formation - The Meagher limestone is also exposed in the southern part of the area; in the southeast in normal contact with the other Cambrian rocks, and in the southwest where it is in fault contact with Belt rocks. The Meagher is liberally intruded by basic igneous bodies which swell its thickness markedly. In the map area it approaches a thickness of 350 feet.

The type Meagher is a series of massive, resistant dolomites, dolomitic limestones and black-and-gold metttled limestones. But, under the influence of contact metamorphism, these characteristic features have been largely obliterated. The Meagher formation in such a metamorphosed state is not resistant to erosion and, although outcrops are frequent, no ridges or hogbacks are present. The lithology, after metamorphism, is fairly uniform, being a white-to-gray, coarse, crumbly marble. The major mineral is calcite, although some dolomite remains. Locally, near igneous contacts, a skarn mineralogy is found in which garnet, epidote, and idocrase are dominant. Calcite particles litter slopes where the Meagher outcrop is especially crumbly. There are many areas where the Meagher is not so coarse, and is merely a drab gray, finely-crystalline marble. Bedding is commonly obliterated in local areas.

The metamorphic characteristics of the Meagher formation are very similar to those of other carbonates in the geologic column, such as the Pilgrim, Madison and Jefferson formations. Only stratigraphic sequence enables distinction.

Park Formation - The Park crops out in the southern part of the area and at one place just north of Moose Creek, where it is relatively thin, somewhat less than 100 feet.

Hanson (1952, p. 28) describes the Park in the Camp Creek section as a series of tan and gray shales interbedded with gray limestones. The shales of the Park are finely micaceous whereas the Wolsey argillites are coarsely micaceous. This property aids in differentiation of the two formations.

As mentioned previously, the metamorphosed Park closely resembles the metamorphosed Wolsey formation. In many places, the two formations cannot be distinguished except by their respective stratigraphic positions. The Park has been changed to a series of hornfels and siliceous argillites, similar to those which characterize metamorphosed Wolsey lithology. Perhaps a dense, black foliated quartzose argillite is the most common rock, although the spotted hornfels containing cordierite porphyroblasts is common. The Park also closely resembles some of the basic igneous rocks in the area, and in many specimens the petrographic microscope must be used for positive identification. The criteria for mapping the Park unit in this area has been based on the hornfels-argillite lithology. Carbonates, which, after metamorphism, are not distinguishable from carbonates in the Meagher and Pilgrim formations, have not been included in the Park map unit. Thus the thickness estimated for the Park may not be accurate.

Pilgrim Formation - The Pilgrim is present exclusively in the eastern part of the area, predominantly north of Moose Creek. The formation is extensively intruded by basic sills, and its thickness is thereby increased from an estimated norm of about 200 feet (Hanson, 1952, p. 28) to approximately 450 feet.

Characteristically, the Pilgrim is a massive dolomitic limestone and displays a pink and gray to black and gold mottling. However, as

in Meagher lithology, these features have been obliterated here. The Pilgrim is not resistant and is frequently covered by grassy slopes. Bedding is destroyed in most places and the rock is here, like the Meagher, a crumbly white marble. It is perhaps a little whiter in color than the Meagher, but this is not a distinctive difference. Skarn minerals such as idocrase, garnet, epidote and wollastonite are present near igneous contacts; and, also distinctive, in some places, is a green, silicified tactite, probably the result of local silica-rich metasomatic solution.

Red Lion Formation - Sahinen (1950, p. 17) describes the Dry Creek formation as part of the stratigraphic section of this area. However Hanson (1952, p. 17) prefers to call this interval the Red Lion formation, showing that previous workers have restricted the term "Dry Creek" to a lower shale member in this sequence.

The Red Lion formation was nowhere exposed in the map area, but is probably present in the eastern part of the area stratigraphically above the Pilgrim. Sahinen (1950, p. 17), describes this interval as:

"... 50 to 100 feet of brown, yellow, red and pink sandy shales and calcareous sandstones - - - reddish and yellowish shaly and calcareous sandstone or sandy limestone - - - muddy - yellow to buff thin-bedded shaly limestone or calcareous shale."

Hanson (1952, p. 28), finds the dominant lithology at Camp Creek to be tan to gray, thin bedded, silty dolomite.

Metamorphism has altered the lithologic characteristics described by Sahinen and Hanson to a series of hornstones and massive siliceous argillites. The dominant lithology is a drab, brown-to-black, massive, hard, very fine-grained hornstone and closely resembles lithology of the Three Forks formation. In this area the Red Lion was mapped purely on the presence of this type float at the proper stratigraphic horizon, as no outcrops were observed.

Ordovician-Silurian

In this and nearby areas, no Ordovician or Silurian sediments are present, either due to erosion or non-deposition.

Devonian

Hanson (1952, p. 28) describes a Maywood interval in the Camp Creek section, which is generally composed of drab dolomites and tan siltstones. The writer did not attempt to map this interval in his area, and it is included in the Red Lion map unit.

Jefferson Formation - The Jefferson formation is poorly exposed in the area, and is commonly mapped without direct evidence that it is present. However, the formation approaches 700 feet (?) in thickness and, although its contacts cannot be precisely located, the Jefferson is mapped as the interval between areas of abundant Red Lion float and the Three Forks formation.

The Jefferson, like all other local sedimentary formations, has been intensely metamorphosed. Before metamorphism the Jefferson was primarily a black massive resistant dolomite with beds of limestone and siltstone (Hanson, 1952, p. 28). Other characteristics include a fetid odor when struck a hammer blow, and a system of calcareous "veinlets", probably organic in nature and resembling stringers of spaghetti.

Metamorphism has greatly altered the Jefferson formation. The fetid odor is gone, and the "spaghetti" is obliterated completely. In some places, the black color is bleached to a gray, resembling the marbles of the Meagher and Pilgrim formations. Bedding is all but obliterated and the rock is loose and crumbly. In many instances, the magnesium in the dolomite has been driven off leaving a pure calcite marble. Conversely, in other parts of

the map area, the rock is a dolomitic marble. The metamorphism of the Jefferson is by no means uniform; the rock changes character radically laterally in the space of several thousand feet.

Metamorphism has converted the rock to a non-resistant type and the Jefferson is therefore mostly covered, and exposed only where drainage has cut through it.

Three Forks Formation - The Three Forks formation is well exposed in the center of a small anticline on the western border of the area. It is also present in the eastern part of the area, but is not exposed and its mapped relations are based, therefore, on float. In the map area, the formation is about 200 feet thick (Sahinen, 1950, p. 18).

Sloss and Moritz (1951, p. 2153) describe the Three Forks as consisting generally of a lower member of gray-green shales and shaly dolomite and limestone, and some minor amounts of evaporite breccia; and an upper member of yellowish sandstone and sandy limestone, termed the Sappington member of the Three Forks formation.

The Three Forks in this area is a series of thin bedded, impure, yellow to brown quartzites and carbonaceous phyllites and hornstone. The quartzites are intensely colored with limonite and are very hard and dense. For the most part, bedding is well preserved and the phyllites are black in color and very fissile. These phyllites closely resemble phosphate rock except that no oolitic structure exists. Where micaceous sheen is lacking these rocks have been classified as slate.

Some tan to brown blocky rocks which might be termed quartzites could be silicified limestone. These rocks show no fissility but relict bedding is preserved.

Whatever fossils originally existed in the Three Forks have

been completely eradicated by metamorphic processes.

Mississippian

Madison Group - The Madison group is one of the thickest rock sequences in the area, approaching 1,300 feet in thickness (Sahinen 1950, p. 18). It crops out with regularity on the north, east and west borders adjacent to the igneous bodies.

This group contains some igneous sills which expand its thickness somewhat abnormally but it does not appear to be as commonly intruded as the Meagher and Pilgrim limestones of Cambrian age.

The Madison group is usually divided into two formations: a lower, thin-bedded, highly fossiliferous impure limestone, called the Lodgepole formation; and an upper massive gray saccharoidal limestone, called the Mission Canyon formation.

Sloss and Moritz (1951, p. 2156) further divide the Lodgepole into a lower member, called the Paine, and an upper Woodhurst member. Subdivision is based on the observation that the Paine is very thin bedded, cherty, fragmented limestone with shaly units and a characteristic striped appearance due to weathering while the Woodhurst is thicker bedded and less shaly.

In this area, however, no differentiation is made because metamorphism has made these rocks more or less uniform in lithology. The Madison is a white to gray crumbly calcite marble. All fossil evidence has been destroyed and bedding generally obliterated. Although the Madison is a ridge former in most Rocky Mountain areas, here it is non-resistant to erosion because of the extensive metamorphism it has undergone.

The Madison closely resembles the Meagher and Pilgrim in every way except that the distinctive and locally developed garnet-epidote-idocrase

contact facies is absent in the Madison. The only thermal alteration evident resulted in extreme iron staining, especially in the northern exposures of this area. This iron stain has made the marble pink-to-red. Sloss and Moritz (1951) also mention red stained solution breccias in the Mission Canyon. After metamorphism, this lithology might produce the redish marble found in this area.

Mississippian-Pennsylvanian

Amsden Formation - The Amsden is nowhere well exposed in the map area, and in places is mapped on the basis of float or by its stratigraphic position. There are places where the Amsden appears to be missing, and this is interpreted as bedding plane faulting (See p. 53). Sahinen (1950, p. 14) states that the thickness of the Amsden is about 200 feet.

Amsden lithology generally consists of a lower unit of red shales and red and purple dolomitic siltstones and an upper series of dolomitic limestones. The contact between the Amsden and Madison is tentatively placed at the point where the upper carbonate unit becomes dominantly sandy (Sloss and Moritz, 1951).

In this area the only definite Amsden lithology observed is a red, hard, siltite. This rock is very fine-grained and is found as scattered float. McMannis (1960, personal communication) reports the presence of abundant idocrase-epidote-garnet skarn lithologies in the carbonate unit of the Amsden. Myers (1952, p. 38) mentions tungsten mineralization in the Amsden carbonates along the contact margins of the Pioneer Range batholith to the west.

Possibly, some of the marbles mapped as Madison are actually the carbonate unit of the Amsden. However, the Amsden carbonates are usually dolomitic, and these are pure, calcite marble. Also, if these red marbles were mapped as Amsden, the Madison section would be unusually thin, while the tentatively mapped Amsden formation would be abnormally thick. This indicates

that the red marbles are truly Madison. Also stratigraphic thicknesses indicate that these red marbles are Madison, and it is believed that the Amsden is merely covered where present.

Pennsylvanian

Quadrant Formation - The Quadrant is one of the most distinctive formations in the area, being one of the most resistant and prominent in outcrop pattern. Mt. Humbug, the highest point in elevation in the area, is underlain by the Quadrant. The formation is approximately 500 feet in thickness (Sahinen 1950, p. 14) and exposures are generally restricted to the northern part of the area.

The Quadrant is generally a clean, white to pink, fine-to medium-grained, cross bedded orthoquartzite, commonly speckled with limonite.

After metamorphism, the basic lithology is not drastically altered, the rock being a pure quartzite which is tan to pink in color and very hard. Limonite is disseminated through the rock and the quartz grains are tightly interlocked and fused. In thin section the quartz grains are of varying size, which indicates the recrystallization of a former sandstone. The rock here is very hard and has a closely spaced joint system at varying angles to bedding which obscures the bedding effectively. The rock is very brittle, and the Quadrant outcrop often appears as a giant talus pile or felsenmeer. The Quadrant is similar to the upper unit of the Phosphoria formation from which it cannot be distinguished in hand specimen. Stratigraphic relationships enable accurate differentiation, however.

Permian

Phosphoria Formation - The Phosphoria is distinctive in the area because of its variable lithology and its thickness, which approaches 500

feet (Sahinen 1950, p. 14). The formation is well exposed in the northern and western parts of the area.

The writer has divided the Phosphoria into two units for mapping purposes, which allows more detail to be presented in areas of complex structure. The lower unit consists of interbedded limestones and phosphatic shales, while the upper unit is a massive chert.

Sloss and Moritz (1951, p. 2167) differentiate three members in the Phosphoria: (1) a lower sandstone, limestone and chert; (2) a middle phosphorite and (3) an upper chert. In the map area the two lower units of Sloss and Moritz are represented by the lower unit of the writer; and the upper unit of Sloss and Moritz is correlative to the upper unit of the writer.

The lithology has not been greatly changed by metamorphism. In the lower unit the limestone has been altered to a gray, crumbly, coarsely-crystalline marble. The usual phosphatic shale is changed to phosphatic "hornstone" and is deep black and massive. In places it could be called a hornfels. However, the phosphatic rocks still retain oolitic texture.

The phosphatic hornstone and interbedded marble unit is all that enables differentiation between the Quadrant and the upper quartzite member of the Phosphoria. This upper unit is usually a massive chert. Upon being metamorphosed, however, it has been altered to a finely crystalline pink to tan quartzite. In hand specimen it is similar to the Quadrant, but in thin section this quartzite is equigranular as opposed to a variation of grain size in the Quadrant. This suggests a chert parent rock for the Phosphoria, a sandstone for the Quadrant.

This upper massive quartzite displays jointing exactly like that of the Quadrant and also is very brittle and crops out as talus piles. Bedding is obliterated.

The upper quartzite also pinches and swells abruptly, within short distances, suggesting a period of erosion after its deposition producing an irregular surface, which could account for the thickness changes.

Triassic

Dinwoody Formation - There is an interval of rock approximately 200 to 300 feet thick between the well exposed Phosphoria and Kootenai formations that most likely represents the Dinwoody formation of Triassic age.

Sahinen (1950) believes this interval to be the Dinwoody formation while others believe that these rocks might be a Jurassic sequence.

The writer believes that Sahinen is correct, mainly because the Dinwoody formation is present just to the south of this area in the Big Hole Canyon whereas no Jurassic sediments are represented in this part of Montana. Also, the meta-lithology of this interval could easily represent typical Dinwoody after metamorphism.

Part of the basis for the assumption that these rocks might be Jurassic is based on the fact that the quartzite member of the Phosphoria varies in thickness rather abruptly in some localities.

If one wishes to explain this thickness change of the Phosphoria as an ancient erosion surface, then there must have been a period of erosion between the Phosphoria deposition and the deposition of these Triassic (?) rocks. Cressman (1955, p. 21) mentions the possibility of hiatus between the Dinwoody and Phosphoria, based on abrupt faunal and lithologic changes. However, he further states that the Dinwoody appears to be conformable to the Phosphoria, and, if there is hiatus, it is in the form of a paraconformity rather than disconformity. This apparent thickness change might possibly be a depositional phenomena or might also be the result of structural alteration.

Thus, the assumption that this interval cannot be Dinwoody because the thickness variation in the Phosphoria demands a Triassic hiatus is a poor excuse for awarding these rocks a Jurassic age.

These rocks are best exposed just north of Mt. Humbug and in Tucker Creek Canyon. Other than these areas, mapping of this unit was on the basis of float. This interval varies in thickness between 200 and 300 feet.

Moritz (1951, p. 1786) describes the Dinwoody as an interval of thin, silty, chocolate brown-weathering, gray and light brown to tan limestones, gray siltstones and sandstones, and gray or green to tan shales.

The Dinwoody interval in this area, represents, probably, a metamorphosed limestone unit where the limestones have been greatly silicified so that their meta-equivalents are actually quartzites. There is no real indication of metamorphosed shale.

The rock is, after metamorphism, a yellow to tan, or brown, drab quartzite, which probably represents a silicified limestone. It is very hard and tends to break into rhombohedral blocks. On fresh fracture the rock is blue or dark gray, and consists almost entirely of fine-grained quartz. Bedding planes stand out in the rock, preserved by silicification. Limestone features such as calcite veinlets and vugs are preserved by silicification. Some skarn minerals are preserved and can be recognized with careful observation. These minerals include garnet and epidote.

Cretaceous

Kootenai Formation - Exposures of the Kootenai formation are restricted to the northern part of the area, north of Mt. Humbug and in the vicinity of Tucker Creek. The Kootenai is well exposed in Tucker Creek Canyon. South of Tucker Creek, the Kootenai is mapped by the occurrence of float

as there are no definite exposures. The formation is quite thick, as much as 1,000 feet in this area (Sahinen 1950, p. 14).

In adjacent areas to the east the Kootenai consists of a basal chert and quartzite pebble conglomerate and a thick sequence of variegated shales and siltstones. Some thin beds of freshwater limestone containing gastropods usually occur in the upper part of the formation.

In this area metamorphism has greatly altered this basic lithology. The basal chert and quartzite pebble conglomerate is still recognizable. It is entirely silicified, but the pebbles stand out markedly, as white to tan or some other light color against a dark blue or black matrix. This spotted pattern is very distinctive. The rock is entirely composed of quartz and the pebbles are very finely crystalline quartzite. They were probably originally quartzite pebbles; metamorphism has not altered them greatly. These pebbles are up to 2 inches in diameter.

The thick sequence of variegated shales and siltstones is thoroughly altered to a series of argillites, hornfels, and massive quartzites. This sequence possesses a strong joint pattern that obliterates bedding and allows the outcrop to be reduced to talus rather easily. The rocks are drab in appearance, commonly tan to brown on weathered surface and a dark green or gray to black on fresh fracture. The mineral content in almost all cases is characterized by a high percent of quartz with some magnetite, and is extremely fine-grained. Only the microscope can distinguish a grain pattern.

Some specimens in this sequence contain biotite, plagioclase and magnetite along with quartz. Sahinen (1950) mentions sillimanite in the hornstones, but this mineral was not observed in thin sections prepared by the writer.

The limestone beds, like all carbonate sequences in this area, have been altered to a coarse, crumbly marble. There are two such marble beds in the area, each about 10 feet thick. The marble is pure calcite and is generally white in color. Bedding is still visible, but all evidence of the characteristic fresh water gastropods is obliterated. The upper boundary of the Kootenai is tentatively selected at the top of the highest marble unit.

Colorado Group - Sahinen (1950) does not include Colorado sediments in his discussion of the stratigraphy of the area. However, a sequence of sediments occurs above the second marble unit of the Kootenai which is too extensive to be included in the latter formation. The writer feels certain that these sediments represent part of the Colorado group or equivalent sediments as nowhere is there much sediment assignable to Kootenai above the limestone members. These sediments are truncated to the north by the Boulder batholith, thus it is probable that the whole Colorado group is not represented. The thickness of sediments representing the Colorado in this area cannot be accurately determined because of the truncation by the batholith and structural complications within the sediments. However, an approximate thickness of Colorado sediment in this area is 1200 feet.

The Colorado group, like the Kootenai, consists mainly of a thick sequence of shales, siltstones, and sandstones. After metamorphism, the result is a lithology which is identical to the series of Kootenai meta-shales and siltstones. The rock is predominantly quartzite and hornstone with a drab brown color on weathered surface and a dark green or black on fresh fracture. No minerals other than an extremely fine-grained quartz is visible in hand specimen. Biotite, magnetite and plagioclase are also visible in thin section, but in minor quantities.

The Colorado commonly crops out in the extreme northwest part of the area where it is bounded by Tertiary sediments to the west and the Boulder batholith to the north. It can only be separated from the Kootenai if the Kootenai marbles are visible as a boundary.

Tertiary

"Basin" Deposits - On the western border of the area, the structurally deformed and metamorphosed Paleozoic and Mesozoic rocks are covered by a series of consolidated clays, gravels, sandstones and conglomerates. This series of sediments is described as follows by Richards and Pardee (1925, p. 14-15) (from Sahinen 1950, p. 23):

"About three miles north of Divide, east of the Oregon Short Line Railroad, thick beds of buff clay with interbedded thin layers of gravel or conglomerate are exposed that aggregate 200 feet in thickness. The beds strike N. 15 W. and dip 12 NE. In the same neighborhood along a ridge extending eastward are several exposures of the gravel beds, which owing to their comparative hardness, project somewhat above the adjoining clay beds. These gravel layers are from 3 to 6 feet thick and consist of subangular cobbles and pebbles in an abundant matrix of sand and clay. In places they contain boulders as large as 3 feet in diameter.

"An apparent thickness of at least 500 feet of Tertiary beds is indicated by these exposures. However the beds may be repeated by faults that are concealed by the superficial cover."

These sediments most certainly originated from the east. Distinctive Belt argillites, incorporated in these sediments, are only present to the east (see figure 6). Other lithologies match exposures to the east such as the abundance of granitic sand most probably derived from the Moose Creek stock and the Boulder batholith. In places the basin deposits are calcareous where the older carbonate units in the section have served as important source materials.

These sediments display, for the most part, very distinctive

thin bedding. Close examination demonstrates cross bedding, and this cross bedding indicates currents flowing generally from east to west. Distinctive imbrication also points to an east to west current and an eastern source for the sediments. The sediments display sharp differentiation between fine and coarse sediments, which might be channels or could represent seasonal change floods which increased the capacity of the depositing streams. The cobbles are subangular which indicates that they have not been carried far by streams.

These sediments have been termed "lake beds" by Sahinen (1950) and others, but, it seems fairly definite that much of the sediment is stream deposited. Thus the term "basin deposit" seems more applicable.

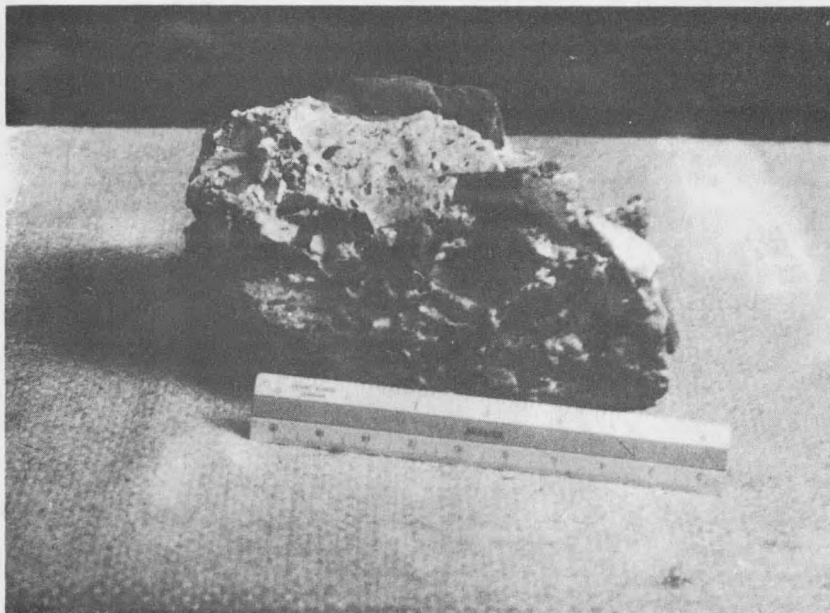


Fig. 6. - Conglomerate from the tertiary basin deposits on the west side of the area. Pebbles in this specimen are mostly Belt argillites, which are only exposed to the east and thus indicate an eastern source of these sediments. Matrix is predominantly igneous material.

Sahinen (1950, p. 23) uses information gathered by Douglass on similar beds in nearby localities to date these sediments as Oligocene and Miocene. Structural relations of these beds are more thoroughly described in the structure section of this paper. Richards and Pardee (1925, p. 14) suggest a possible thickness of 500 feet for these sediments.

Quaternary - Talus and alluvium cover much of the area. In most instances Quaternary alluvium was not mapped if the writer was relatively sure of the bedrock geology below.

Alluvium or gravel is dominant in the west where it generally covers the previously described Tertiary sediments in a terrace system. The alluvium may be derived from the igneous and metamorphic rocks to the east, just as the Tertiary rocks were; and also, partly from the Tertiary sediments themselves, as the lithologies incorporated in the alluvium are very similar to those in the Tertiary sediments, including the distinctive Belt argillite, which is only present to the east.

All major streams in the area have a platform of Quaternary alluvium, but only on Moose Creek, where it is fairly significant, was it mapped. Burton Park, in the northeastern part of the area, also is underlain by Quaternary alluvium, but it was not mapped as the writer is certain that the underlying bedrock is igneous. The topography of this area is generally flat in contrast to the steep ridged topography of other areas underlain by igneous rocks. This is probably because Burton Park represents an old drainage system which has generally smoothed the sharp topography.

IGNEOUS ROCKS

Introduction

The area is dominated by a series of igneous intrusions which have invaded the previously described stratigraphic section. The southern tip of the Boulder batholith occupies the northern part of the map area, and the central part of the area was intruded by a small igneous stock, called the Moose Creek stock by the writer. Numerous basic sills and irregular basic bodies have intruded into the meta-sediments. Some aplite bodies and acidic joint fillings also occur.

Samples of many of these igneous rocks were taken and thin sections prepared and observed through the petrographic microscope. Comparative mineralogy and texture was studied to determine the relationships of these igneous bodies to one another in lithology, mode of origin and emplacement, and age.

The Boulder batholith and adjacent Moose Creek stock were not subdivided by the writer; they are merely mapped as one unit and compared and contrasted to one another. The batholith and stock have several possible relations; but the most probable is that the stock is merely an apophysis of the batholith and does not differ markedly in mineralogy or lithology.

The basic sills are tentatively dated as Late Cretaceous because they intrude Colorado sediments; and as pre-stock and batholith because they are truncated by the stock and batholith. This truncation can be observed on the east side of the Moose Creek stock where the stock abuts against several basic sills and in the southeast part of the area where the stock truncates one sill and cross-cuts another (see fig. 7). In the northwest part of the area, Boulder batholith quartz monzonite can be seen cross-

cutting another basic sill (see fig. 8).

Several samples from sills and other basic bodies intruding sediments of different ages were taken and studied to determine if the sills are of the same general lithology and mineralogy and thus possibly intruded simultaneously; or if they differ lithologically and mineralogically and might represent several phases of intrusion. The lithology and mineralogy was found to be very similar from basic sill to basic sill, thus the hypothesis of simultaneous or near simultaneous injection is a strong possibility. Metamorphic effects on the basic sill rocks, which have altered their mineralogy, also indicate that these basic bodies are pre-stock and batholith, as these igneous bodies are responsible, for the most part, for the metamorphism of the sills and the sediments.

Aplites and vein fillings are described briefly and are believed to be a late differentiate of the magma. Inclusions in the stock and batholith are also studied as possible hints as to mode of origin of the stock and batholith. The writer's ideas as to emplacement will be discussed in the structural sections of this paper.

Location of samples is shown by a number on the geologic map (in pocket).

Petrology

Basic "Sill" Rocks

No. 182 - Sample of a basic sill in the Cambrian Meagher marble, from the southeast corner of the area, about one mile south of Moose Creek.

Megascopeic Description: The rock is a basalt porphyry with aphanitic ground mass and is pitted on weathered surface.

Microscopic Description: The rock is a finely crystalline

gabbro or coarsely crystalline basalt in composition and might best be termed a diabase. It is a porphyry containing plagioclase phenocrysts and the groundmass is equigranular. There is intergranular texture between augite and plagioclase, which is An_{65} in composition.

The rock is altered with some of the plagioclase replaced by sericite and the mafic minerals replaced by chlorite and iddingsite. The feldspar is cloudy. The alteration in this specimen, as well as in all the other basic "sill" specimens, is interpreted as the result of contact metamorphic effects produced by later intrusion of the stock and batholith.

Reaction rims between the mafics are an outstanding feature, with augite replacing hornblende and hornblende replacing biotite. These reaction rims are contrary to the usual igneous crystallization. This is interpreted as an indication of reheating by the intrusive bodies.

Mineral Content: In this thin section, and in all following ones, an attempt is made to count alteration minerals as part of the percentage of the minerals that they are replacing. In this slide, mineral percentages were estimated.

	Plagioclase (An_{65}) (sericite)-----	60-65%
Chlorite	(Augite)	
	(Biotite)-----	35-40%
	(Hornblende)	
	Magnetite -----	1-2%
	Iddingsite -----	trace
	Rutile -----	trace

No. 201 - Basic sill in the Cambrian Meagher limestone in the southeast corner of the area, about one-half mile south of Moose Creek.

Megascopic Description: The rock is thoroughly altered and is crumbly in hand specimen. It is very dark in appearance and medium crystalline, and no minerals can be definitely identified.

PLATE II

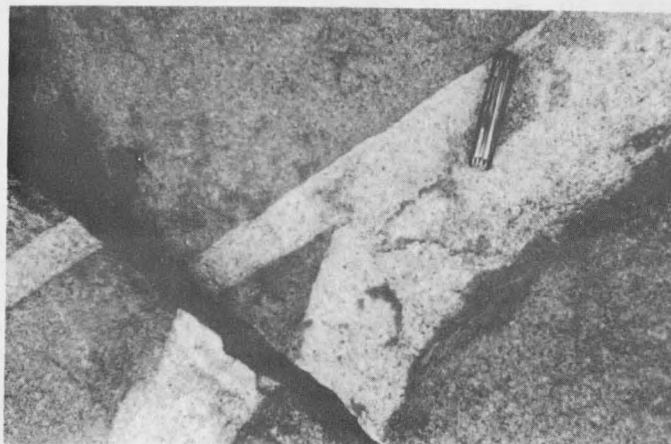


Fig. 7. - Cross-cutting of a basic sill (dark) by a granitic vein of stock material located in the southwest part of the area, intruded into the Meagher (?) formation.



Fig. 8. - Cross-cutting of a basic sill (dark) by a quartz monzonite dike of Boulder batholith material. Located just to the southeast of the "central lobe" of the Boulder batholith, intruded into the Kootenai formation.

Microscopic Description: The rock is a diabase and is altered both by weathering and contact metamorphism. The rock is relatively coarse in comparison with other sill rocks. It would be classified as fine-to medium-crystalline.

The plagioclase shows both Carlsbad and albite twins and has gradational zoning. Approximate plagioclase composition is An_{65} based on extremes of An_{75} and An_{55} . Basal twinned augite replaces hornblende in a reaction rim relationship.

The plagioclase is sericitized and the mafic minerals are altered to chlorite. Stilpnomelane is also present.

Mineral Content: Mineral percentages in this specimen are estimated:

	Plagioclase (An_{65}) (sericite)	-----	45-50%
Chlorite	(Augite	}-----	45-55%
	(Hornblende		
	(Biotite (stilpnomelane)		
	Magnetite	-----	less than 1%

No. 286. - Basic sill in the Cambrian Pilgrim limestone in the east part of the area, about two hundred yards north of Moose Creek.

Megascopic Description: The rock is porphyritic with plagioclase phenocrysts in an aphanitic groundmass. Biotite is the only other mineral visible. The weathered surface is pitted.

Microscopic Description: The rock is a diabase and is finely crystalline and has intergranular texture between plagioclase and augite. Augite replaces hornblende and biotite in a reaction rim relationship. The plagioclase is An_{70} in composition.

The rock is altered showing an abundance of chlorite replacing the mafic minerals. However, plagioclase is not heavily sericitized.

Stilpnomelane is also present.

Mineral Content: Mineral percentages in this specimen were estimated:

	Plagioclase (An ₇₀) -----	65%
	(Augite -----	3-5%
Chlorite	(Hornblende -----	5-7%
	(Biotite (stilpnomelane)-----	25%
	Magnetite -----	1%

No. 291.- Basic sill intruding Cambrian Pilgrim formation on the eastern border of the area, about one-half mile north of Moose Creek.

Megascopic Description: The rock is fine-grained with some biotite and amphibole visible, along with plagioclase. The weathered surface is pitted, which seems to be characteristic of most of the sill rocks.

Microscopic Description: The rock is an altered diabase with the plagioclase sericitized and the mafics chloritized. Stilpnomelane is also present. The rock is finely crystalline and is relatively equigranular.

The plagioclase shows gradational zoning and is cloudy. It has an average composition of An₆₅ which is approximate due to zoning. This composition is an average of the extremes of An₅₅ and An₇₅. Intergranular texture between augite and plagioclase was observed.

Mineral Content - Mineral percentage in this specimen was estimated:

	Plagioclase (An ₆₅) -----	50-60%
	Quartz -----	2%
	Magnetite -----	less than 1%
Chlorite	(Hornblende -----	10%
	(Augite -----	15%
	(Biotite (stilpnomelane) -----	15%

No. 293. - Basic sill in the Cambrian Red Lion formation from the eastern part of the area, about one-half mile north of Moose Creek.

Megascopic Description: The rock is porphyritic with an aphanitic matrix and the phenocrysts are plagioclase. No other minerals are identifiable.

Microscopic Description: The rock is an "amphibole rich" basalt porphyry as there is a greater percentage of amphibole than pyroxene. It is finely crystalline and equigranular and is altered, with plagioclase almost obliterated by sericite and the mafics converted, for the most part, to chlorite and magnetite. The mafic minerals show reaction rims and augite forms intergranular texture with plagioclase.

Mineral Content: Mineral percentages in this specimen were estimated:

	Plagioclase (An ₇₀)	-----	65%
	(Biotite)		
Chlorite	(Hornblende)	-----	30-30%
	(Augite)		
	Magnetite	-----	1-2%

No. 343 - Rock is from an irregular basic intrusive in the Madison limestone in the eastern part of the map area, about one-fourth mile south of the southern border of the Boulder batholith.

Megascopic Description: The rock is very dark, aphanitic, and is not porphyritic. Tentatively an amphibole and plagioclase can be identified while other minerals are microscopic.

Microscopic Description: The rock is diabasic texturally, and is rich in augite and plagioclase. It is very finely crystalline and equigranular. The rock is altered, the mafics replaced by chlorite and iddingsite and the plagioclase sericitized.

Mineral Content: Mineral percentage was estimated:

	Plagioclase (An ₆₅) -----	55-60%
	(Biotite -----	5-10%
Chlorite	(Hornblende -----	10%
	(Augite -----	25-30%
	Magnetite -----	3-5%
	Iddingsite -----	trace

No. 635 - Irregular basic intrusive in the Cretaceous Kootenai formation in the northern part of the area, about 100 yards north of Tucker Creek.

Megascopic Description: The rock is dark and aphanitic and some plagioclase is visible, but other minerals are not identifiable.

Microscopic Description: Based on the large percent of augite and plagioclase, the rock is a basalt. It has some phenocrysts of plagioclase and augite and a finely crystalline groundmass. This specimen is not heavily altered as there is little chlorite present and the plagioclase is not sericitized. Some iddingsite was seen. Reaction rims are present with augite replacing hornblende, and there is intergranular texture involving augite and plagioclase. The plagioclase displays Carlsbad and albite twinning and shows gradational zoning. The average composition of the plagioclase, based on extremes of An₅₅ and An₈₀ is An₇₀.

Mineral Content: A 1500 point count was made to accurately determine mineral percentages.

	(Augite -----	49%
Chlorite	(Hornblende -----	8%
	(Biotite -----	2%
	Plagioclase (An ₇₀)-----	36%
	Magnetite -----	5%
	Sphene -----	trace
	Iddingsite -----	trace
Total - - - - -		100%

No. 673 - Contact between the Moose Creek stock and a basic sill

in the southwestern part of the area. The basic sill is in the Cambrian Meagher (?) marble.

Megascopeic Description of Basic Rock: The contact between the acidic stock and the dike rock is very sharp. Megascopeically there is no alteration. The sill is finely crystalline but equigranular and holocrystalline; and biotite, amphibole and plagioclase are visible.

Microscopic Description: The mafic sill has been altered considerably with mafic minerals converting to chlorite and magnetite and plagioclase to sericite. There is a chill border on the "granite". The sill grades from finely crystalline in the center to very finely crystalline near the contact.

Mineral Content: The mineral count is not dependable since alteration is so advanced. Contact metamorphism is most probably responsible for this extreme alteration.

	Calcic Plagioclase (very sericitized) ----	65%
	(Biotite	
Chlorite (	Hornblende -----	30%
	(Augite	
	Magnetite -----	5%

No. 685 - Basic sill in the Cretaceous Colorado formation in the northern part of the area, just to the southeast of the "central lobe" of the Boulder batholith on the map.

Megascopeic Description: The rock is dark and aphanitic with all minerals being microscopic.

Microscopic Description: The rock is a "diabase" porphyry with easily visible laths of plagioclase in an almost cryptocrystalline groundmass. There are also large grains of augite present. The plagioclase shows gradational zoning and Carlsbad twins, and is partially sericitized.

An average composition for the plagioclase, based on extremes of An_{60} and An_{80} , is An_{70} . The mafic minerals are chloritized and twinned augite replaces hornblende in reaction rims. Stilpnomelane is also present.

Mineral Content: Mineral percentage is estimated:

	Plagioclase (An_{70}) (sericite)	-----	35%
Chlorite	(Hornblende)	)	
	(Augite)	)	-----
	(Biotite (stilpnomelane))	)	60%
	(Magnetite)	)	
	Sphene	)	-----
			5%

Summary of Basic Sills

Petrography shows that sills generally are of the same mineral composition, although samples are random and not more than one was taken from any particular body. It is possible that mineralogy might vary more than is shown. However, this apparent similar mineralogy from sill to sill suggests a common source and time of emplacement for all the basic igneous bodies. Had there been different source in time, the mineralogy would probably vary from sill to sill. Also, the rocks are generally altered showing the effects of baking or contact metamorphism. This indicates intrusion of the basic sills to be pre-batholith and stock in age as the latter apparently are responsible for the metamorphic alteration. Truncation and cross-cutting by these massive acidic intrusives also shows that sill intrusion is pre-batholith and stock (see p.28).

In general, rocks are diabasic. The plagioclase shows gradational zoning in some specimens and not in others; and is cloudy in some specimens, and not in others. It is probable that the basic bodies have a common origin and all are probably of the same age, or nearly the same age, of intrusion.

Average mineralogy of the basic rocks is:

Chlorite	Plagioclase (An ₆₀₋₇₀) (sericite) -----	50%
	(Augite -----	25-40%
	(Hornblende -----	10%
	(Biotite (stilpnomelane) -----	5-10%
	Magnetite -----	trace
	Idingsite -----	trace.

Moose Creek Stock

No. 135 - Sample from an isolated igneous body in the southeastern corner of the area, intruded into the Belt.

Megascopic Description: The rock is generally gray in color and is medium-grained, phaneritic, equigranular and holocrystalline. The rock displays an abundance of quartz and biotite. Both plagioclase and orthoclase are present under the hand lens although it is difficult to determine their relative percentages megascopically.

Microscopic Description: The rock is a quartz monzonite. Plagioclase is sericitized slightly and many crystals show gradational zoning. An average plagioclase composition is An₄₀, based on extremes of An₃₀ to An₅₀. The amphibole is hornblende and there is a trace of augite with hornblende replacing the augite in reaction rims. There is a greater percentage of plagioclase than orthoclase.

Mineral Content: Mineral percentage was estimated:

Quartz -----	5 - 10%
Plagioclase (An ₄₀) -----	35%
Orthoclase -----	23 - 30%
Hornblende -----	10 - 15%
Augite -----	trace
Biotite -----	15 - 20%
Magnetite -----	1%

No. 383 - Sample from the northwest corner of the Moose Creek stock, just to the northwest of the large Madison roof pendant.

Megascopic Description: This rock is generally very light

in appearance and appears to be very acidic and phaneritic, equigranular and holocrystalline. Biotite is the major dark mineral although some amphibole can be seen. There is an abundance of quartz. The feldspars cannot be differentiated in hand specimen.

Microscopic Description: Though megascopically it looks like true granite, the rock is a quartz monzonite and is very coarsely crystalline, equigranular and holocrystalline. There is some hornblende in the rock and the potassic feldspar is microcline.

Mineral Content: A 1500 point count was made for accurate percentage determination:

Quartz -----	22%
Plagioclase (An ₄₀)-----	32%
Microcline -----	23%
Perthite -----	9%
Biotite -----	9%
Hornblende -----	3%
Magnetite -----	2%
Total - - - - -	100%

No. 671 - Sample from the southeast corner of the stock, adjacent to a much intruded outcrop of Cambrian Meagher (?) marble.

Megascopic Description: The rock is very white and is fine- to medium-crystalline. Abundant quartz, and some biotite are visible. The feldspars cannot be differentiated.

Microscopic Description: The rock is a fine-grained granite as it is very rich in quartz and potassium feldspar and is lacking in mafics. It is finely crystalline and is equigranular and holocrystalline. Most of the feldspar is microcline.

Mineral Content: Mineral percentage is estimated:

Quartz -----	65-75%
Microcline -----	25-35%
Biotite (chloritized)-----	2%

Magnetite ----- trace
 Plagioclase (An₁₀) ----- 3%

The rock is extremely acidic and is not a representation of the true stock rock. It is more likely a late differentiate; perhaps the southwest corner of the stock is more acidic than the main body and could represent late differentiation.

No. 673 - Sample of a stock-like rock and a basic sill in contact in the southwest part of the stock. The sill is in the Cambrian Meagher (?) marble whereas the stock-like rock is separated from the main mass of the stock.

Megascopic Description: The "granite" section of this rock is very light in appearance and is fine-to medium-crystalline. It is phaneritic, equigranular and holocrystalline. Quartz is a major mineral and the feldspars are also abundant, but there are few mafics.

Microscopic Description: Quartz and orthoclase make up almost the entire rock. It is equigranular, holocrystalline and medium crystalline. It might be termed an alaskite.

Mineral Content: The mineral percentage is estimated:

Quartz ----- 55%
 Orthoclase ----- 40%
 Hornblende ----- 1%
 Magnetite ----- trace
 Biotite ----- 4%

The rock is not representative of the major mass of stock but it is on the edge and may be a late differentiate. It is similar to No. 671 and strengthens the possibility that the southwest part of the stock is a late differentiate.

Stock Inclusions

No. 16 - "Xenolith" found in the east-central portion of the

stock, about one-half mile north of Moose Creek and one-half mile west of the eastern border of the stock.

Megascopic Description: The rock generally is dark in appearance and is finely crystalline. Its edge in contact with the stock is altered. Biotite, quartz and plagioclase are abundant.

Microscopic Description: After staining, it was found that orthoclase is not abundant. Plagioclase of composition An_{40} is the dominant feldspar. There is a very high percentage of magnetite and the rock is quartz diorite in composition although it is peculiar in its mineralogy. It has probably been carried from depth and, in transport, plagioclase has been altered and made more sodic. It is generally true that the magma will alter xenolith minerals towards its own composition. Perhaps quartz has also been added. The rock might have originally been more basic, perhaps a piece of one of the basic intrusives.

Mineral Content: Mineral percentage is estimated:

Quartz -----	15%
Orthoclase -----	5-10%
Plagioclase (An_{40}) -----	25-30%
Hornblende -----	10%
Biotite -----	30%
Magnetite -----	10%

No. 120 - Sample of "joint filling" from southeastern border of the stock.

Megascopic Description: The rock has the appearance of an aplite in composition, being very fine-grained, light in color, and rich in quartz. Few mafics were seen. The contact between the stock and the fracture is very sharp.

Microscopic Description: The rock is granitic in composition, being rich in microcline and quartz. The edge of the intrusion is chilled,

and the rock as a whole is very fine grained.

Mineral Content: A 1500 point count was made for accurate estimation of mineral percentage:

Quartz -----	29%
Microcline -----	64%
Plagioclase (An ₅)-----	3%
Biotite -----	2%
Perthite -----	1%
Magnetite -----	1%
Total - - - - -	100%

This rock is probably a late differentiate, perhaps controlled by the jointing.

No. 407 - Inclusion from the northwestern border of the stock.

Megascopic Description: The rock is dark, fine-to medium-crystalline, and equigranular. Quartz and biotite and what is assumed to be plagioclase are in evidence. There are "pods" of quartz in the rock which may be the result of reaction of the "acidic" stock with the xenolith.

Microscopic Description: The mineralogy indicates that there has been reaction between the stock and the xenolith. The xenolith is rich in plagioclase and biotite with minor amounts of quartz. Quartz may be the result of stock influence as the other mineralogy indicates a fairly basic rock. There may have been reaction in which orthoclase of the stock reacted with augite in the "basic" inclusion to produce biotite and quartz (Ramberg, 1952, p. 152). Also, the plagioclase of the xenolith might have originally been about An₇₀ in composition and reaction with plagioclase of the stock has altered it to its present An₅₀. This reaction is probably very similar to the reaction in specimen 16.

Mineral Content: A 1500 point count was made for accurate estimation of mineral percentage:

Quartz -----	7%
Plagioclase (An ₅₀) -----	67%
Biotite -----	18%
Hornblende -----	4%
Magnetite -----	4%
Sphene -----	trace
Total - - - - -	100%

The rock now is a quartz diorite but might have originally been a more basic rock; possibly one of the previously described sill rocks.

Summary of Moose Creek Stock

The average composition of the main body of the stock is quartz monzonitic with:

Quartz -----	20%
Orthoclase or microcline -----	25-30%
Plagioclase (An ₄₅₋₅₅) -----	30-35%
Biotite -----	15%
Hornblende -----	5-10%
Magnetite -----	1%

However, evidence is strong for differentiation. Slides 671 and 673 are very acidic granite and probably represent a late differentiation, perhaps most common in the southwest part of the stock. This late differentiation might also be responsible for the "joint fillings" (No. 120) which are also very acidic. The writer, however, did not attempt to map this differentiation. The average composition of these acidic rocks is:

Quartz -----	35%
Orthoclase or microcline -----	60%
Plagioclase (An ₅) -----	2%
Mafics (biotite) -----	2%
Magnetite -----	1%
Total - - - - -	100%

The inclusions (xenoliths, numbers 16 and 407) are most likely altered basic igneous rocks which have been brought up from depth during injection of the stock and have been altered.

The quartz in these inclusions may be the result of reaction with

the stock magma as mentioned in discussion of slide 407. This reaction of orthoclase with augite can produce quartz and biotite (Ramberg, 1952, p. 152). Lack of amphibole and pyroxene is also probably the result of this reaction. Plagioclase has probably been saturated with sodium, perhaps altering its An ratio from An₇₀ to about An₄₀. The approximate composition of the inclusions is:

Plagioclase (An ₄₀)	-----	60%
Quartz	-----	20%
Biotite	-----	15%
Hornblende	-----	5%.

Boulder Batholith

No. 488 - Sample of batholith rock from the northeast part of the area.

Megascopeic Description: In hand specimen the rock is relatively dark, is phaneritic, of medium grain size, and is equigranular. Quartz, biotite, and plagioclase are all readily visible under the hand lens.

Microscopic Description: The rock is quite rich in plagioclase of approximately An₅₀ in composition which shows Carlsbad twinning and gradational zoning. The biotite, hornblende, and small percent of augite shows a reaction rim relationship. Augite is being replaced by hornblende and hornblende by biotite.

Mineral Content: A 1500 point count was made to accurately determine mineral percentage:

Quartz	-----	7%
Orthoclase	-----	19%
Plagioclase (An ₅₅)	-----	55%
Biotite	-----	9%
Hornblende	-----	3%
Augite	-----	5%
Magnetite	-----	2%
Total	-----	100%

The rock is a "basic" quartz monzonite although there is not enough quartz to have to restrict it to quartz monzonite. It can be termed a monzonite. It is slightly more basic than the typical stock quartz monzonite.

No. 502 - Boulder batholith rock from the northwest part of the area - southern tip of the Boulder batholith. The sample was collected about a mile from the batholith-country rock contact.

Megascopic Description: The rock is relatively dark, phaneritic, medium-grained, and equigranular. Quartz, feldspar, biotite and amphibole are all visible in the hand specimen.

Microscopic Description: The potassium feldspar-plagioclase ratio is almost equal and the rock is a quartz monzonite as there is an abundance of quartz.

Mineral Content: Mineral percentage is estimated:

Quartz -----	15%
Orthoclase -----	25%
Plagioclase (An ₅₀)-----	25-30%
Hornblende -----	15-20%
Biotite -----	10-15%
Magnetite -----	1%

No. 504 - Boulder batholith sample from the northeast part of the area. This sample, like 502, is also from well within the batholith.

Megascopic Description: The rock is almost identical to number 502 in appearance. It is dark and medium-grained, phaneritic, and equigranular. Quartz, feldspars, amphibole and biotite are all visible megascopically.

Microscopic Description: Reaction rims are present with biotite replacing hornblende, which is replacing augite. The plagioclase displays Carlsbad twins and gradational zoning and is about An₄₅ in compo-

sition.

Mineral Content: A 1500 point count was made to accurately determine mineral percentage:

Quartz -----	13%
Orthoclase -----	16%
Plagioclase (An ₄₅)-----	46%
Biotite -----	9%
Hornblende -----	6%
Augite -----	6%
Magnetite -----	4%
Total - - - - -	100%

The rock is a "basic" quartz monzonite. Actually, it might be termed granodiorite as the plagioclase-orthoclase ratio is 3/1.

No. 677 - Boulder batholith sample from the northwest part of the map area; in the western "lobe" of the batholith. The sample is close to the Tertiary sediment-Boulder batholith contact.

Megascopic Description: The rock is dark, phaneritic, medium-grained, equigranular and holocrystalline. There is a large percent of amphibole in this specimen. Plagioclase and quartz are also visible.

Microscopic Description: There is a trace of pyroxene, but most of it is replaced by hornblende. Plagioclase occurs in abundance and is Carlsbad and albite twinned. It also shows gradational zoning and is about of An₄₅ composition.

Mineral Content: A 1500 point count was made to accurately determine mineral percentage:

Quartz -----	13%
Plagioclase (An ₄₅)-----	41%
Orthoclase -----	18%
Hornblende -----	12%
Biotite -----	11%
Magnetite -----	3%
Pyroxene (augite)-----	2%
Total - - - - -	100%

The rock is a "basic" quartz monzonite or granodiorite.

No. 676 - Joint filling found in the Boulder batholith in the northwest part of the area, separated slightly from the main body.

Megascopic Description: The rock shows a "graphic granite" texture and is very light in color and fine grained. There are a few mafics present but the rock is almost entirely quartz and orthoclase.

Microscopic Description: It has definite intergrowth of orthoclase and quartz. Orthoclase is strained slightly and, as the stage is rotated, all of the orthoclase is extinct at once indicating it to be one large crystal with quartz stringers. The quartz shows extreme strain shadows.

Mineral Content: Mineral percentage is estimated:

Quartz -----	40%
Orthoclase -----	59%
Biotite -----	less than 1%
Pyrite -----	less than 1%

This rock is a graphic granite and is probably a late differentiate, perhaps closely related to the granitic joint fillings (number 120) in the stock.

Summary of Boulder Batholith

The Boulder batholith is fairly uniform in composition. It is a "basic" quartz monzonite or, based on its plagioclase-orthoclase ratio, close to granodiorite.

An average mineral assemblage is:

Quartz -----	15%
Orthoclase -----	18%
Plagioclase (An ₄₅) -----	40%
Biotite -----	10-15%
Hornblende -----	10%
Augite -----	2-5%
Magnetite -----	1%

The "joint filling" (number 676) is probably a late differentiate and not closely related to the batholith. It may represent a later acidic period which has also produced the very granitic joint fillings in the stock.

Conclusions

It is shown that the basic rocks are pre-stock and pre-batholith in age. The stock and batholith differ in some respects: the texture of the stock is generally coarser than that of the batholith and the stock is also lighter in color. However, mineralogically, the stock and batholith both appear to be quartz monzonite in composition, although the batholith is a bit more basic quartz monzonite. However, it is believed that they are closely related in time of intrusion and are probably merely one body with overlying metasediments burying the contact. Evidence is not strong enough to assume that the stock is a later differentiate.

The stock has some rocks which appear to be closer to granite in composition and may represent a later acid phase of intrusion. The joint fillings and aplites definitely represent a late acid differentiate.

The inclusions in the stock might represent a more basic igneous rock carried upward with the intrusives and reacted upon to form the present rock. Their actual origin can only be speculated upon.

STRUCTURE

Structure in the area is inherently complex, and the structural picture is further clouded by poor exposures, necessitating the use of question marks for inferred structural interpretation on the map.

The area was deformed during "Laramide" time, and perhaps at other intervals during geologic time. Following Laramide deformation, igneous intrusion and metamorphism has further complicated the deformation. There is

PLATE III

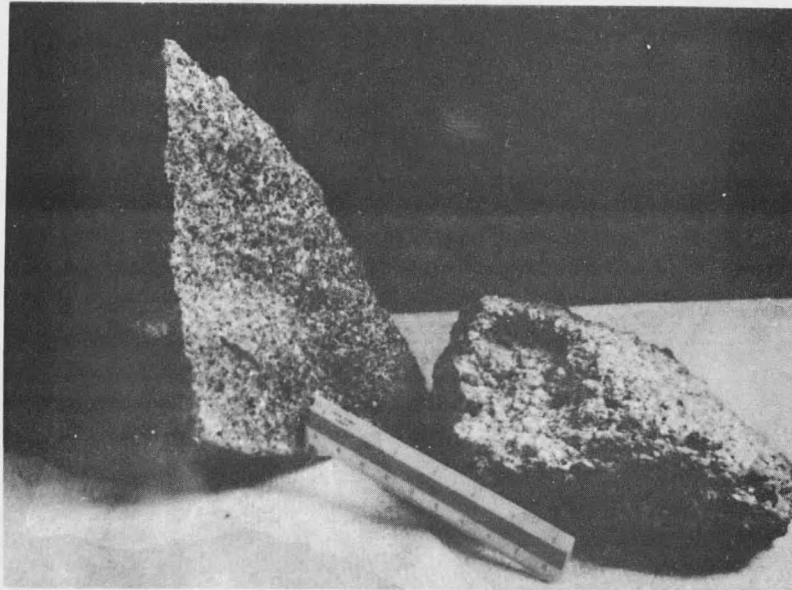


Fig. 9. - Photo illustrating color and texture differences between quartz monzonites of the Boulder batholith (left) and stock (right). The stock is more coarsely crystalline and is lighter in color than the batholith.

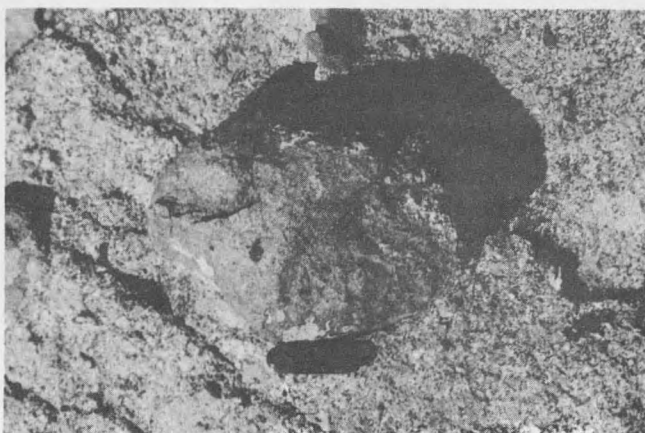


Fig. 10. - Inclusion in the Boulder batholith. The inclusion is generally darker and more finely crystalline than the rock of the batholith and differs in its more basic composition (see petrology).

also evidence of latter structural activity in that the Tertiary basin deposits to the west are deformed.

Fold System

Regional dip in the area is generally 30 to 40 degrees to the north. McMannis (1960, personal communication) believes that this regional dip might be the result, in part, of uplift along a major east-west trending fault to the south of the map area. Sahinen (1939) has mapped this phenomena as an unconformity between Belt sediments and Precambrian metamorphics, but McMannis feels certain that the true relation is a fault. This regional uplift might then have been further accentuated by similar faults to the north of this area which have since been obliterated by the Boulder batholith. Northward regional dip could also originate as phenomena along the southern flank of a large east-west trending syncline with its north flank assimilated by intrusion of the Boulder batholith. However, the idea of regional uplift along fault planes has more direct evidence in its support than does a regional syncline.

The northward regional dip is complicated by several tight north-northwest trending folds which deform the meta-sediments around the edges of the igneous intrusions. These north plunging folds, which are best developed to the east and southeast of the Moose Creek stock, are further complicated by extensive small scale faulting. In the northern part of the area, in the vicinity of Tucker Creek there is only one major fold, a large anticline involving all the meta-sediments in this part of the map area. This anticline is nearly asymmetrical and its west flank is very steep and slightly overturned.

On the west side of the Moose Creek stock one obvious anticline and some less conspicuous folds comprise the major Laramide structure.

McMannis (1960, personal communication) confirms the presence of several north-northwest trending folds to the south of the map area. He further states that these folds are more gentle than the tighter folds found in the writer's area. It appears likely, then, that forceful injection of the igneous rocks accentuated preexisting folds. The area north of the Moose Creek stock is extensively faulted and this faulting is probably related to intrusive forces (see fault system). If this is a correct assumption, then the tightening of preexisting folds may also be attributed to forceful injection. There is no direct proof of this idea, but field relations indicate that it is a strong possibility.

The folds in the eastern and southeastern parts of the area involve Precambrian to Devonian rocks as well as basic igneous sills. These folds are roughly symmetrical and dip approximately 40 degrees on both limbs. The relationships date the sills, probably, as pre-folding. The sills are assumed to be of post-Colorado age in that they intrude these Cretaceous sediments. Thus, the period of folding is, at least, of post-Colorado age.

To the west of the Moose Creek stock is a small, steep-limbed, slightly asymmetrical anticline which does not trend parallel to the other folds in the area, but swings more to the northeast. Its trend may be the result of faulting or of extreme distortion due to igneous injection.

Fault System

Structure of the area is complicated by much small-scale faulting which is especially common to the north of Moose Creek stock. There is no clear-cut pattern to these faults as they are generally at random directions throughout the area. Most of these faults appear to be normal, although some are probably reverse. Poor exposures prevent accurate observation of fault planes.

Many faults have minor displacements and, in some instances, minor faults were mapped from air photos without direct field evidence. In few instances is a fault plane observable in the field, thus most of the mapped faults are dashed indicating that they are hidden and often their mapped extent is questionable. Also, since their angles of dip are unknown, they are tentatively constructed as vertical faults on the cross sections.

The random orientation of the fault system indicates to the writer that, for the most part, these faults may be the result, or partially the result of, effects resulting from the injection of the igneous bodies.

The hypothesis has been previously forwarded that the forceful injection of the igneous stock and batholith probably accentuated pre-existing folds by exerting strong lateral force. In conjunction with this lateral force, the overlying block of sediments could have been subjected to shearing or tensional forces producing the present fault pattern. Whether the faulting was contemporaneous with, or followed intrusion remains conjectural. If the faulting had occurred during injection, there should be igneous material along some of the fault planes. However, this phenomena was not found in the area.

The more acceptable hypothesis is that the faulting occurred during the late phase of injection, perhaps as a result of shear. Then possibly, during cooling and contraction of the igneous bodies, the resulting shear patterns might have been accentuated. However, to definitely support this hypothesis, there should be evidence of offset on the igneous contact along some of these faults. The writer found no such definite offsets.

In almost every case the faults were tentatively extended to contact with the igneous bodies, without direct evidence of these faults being present. Also, in almost every case, the igneous-country rock contact is

covered. This cover might easily obscure the offset in the igneous body, especially if offset is not particularly great. Most of these faults do not appear to have large offset; thus, the possibility of late or post-igneous intrusion faulting is good. The faulting in the northern part of the area is more extensive than in other parts mainly because this block of meta-sediments is bounded on almost all sides by the igneous material and has probably been subjected to greater pressures; probably by squeezing between the stock and batholith. Areas to the west, east and south are not completely surrounded by the igneous rocks, and thus escaped more severe deformation.

Northern Fault System

The "northern fault system" is designated as that area to the north of the Moose Creek stock and to the south of the Boulder batholith. Included in this area are Mt. Humbug and Tucker Creek. Twelve faults are mapped in the "northern" block" and more may exist.

The most westerly fault in this block strikes approximately N 45 E and places the Madison marble against the upper quartzite member of the Phosphoria. This fault parallels the strike of bedding and also is truncated by a lobe of the stock; it then reappears to the east where it strikes more nearly north and continues to conform to the strike of the bedding. This fault is probably a strike fault and there is a strong possibility that it was developed during the initial orogeny which folded the sediments; and then has been further distorted, along with the sediments, during intrusion. The fault's termination against the Moose Creek stock suggests that it is pre-intrusion in development and, unlike most of the other faults, is probably not directly the result of forceful intrusion. Some of the other faults which appear to be truncated by the igneous bodies

may not actually extend to the igneous bodies, the actual relationship being covered (see p. 52).

Just to the east of this bedding plane fault, and tentatively truncating it, is a N 10-15 E trending fault. This fault apparently terminates to the north against a small aplitic body, but its southern termination is unknown and it is tentatively extended to the northern border of the stock. Perhaps the later intrusion of the aplitic body is related to it, although it is possible that it was developed during intrusion of the stock and batholith and that the aplite was later intruded along this weakness plane. This fault generally places the Quadrant and the marble-phosphate member of the Phosphoria on the east against the upper quartzite member of the Phosphoria on the west. The fault appears to have a strike-slip movement, the east block being moved to the north. However, this relationship might be explained by steep, normal movement with the west side down.

The east side of the above fault truncates a N 50 W trending fault. The latter's trace is marked by two springs making it relatively accurate in location. It terminates in its northwest extreme against the previously described northeast trending fault; and in its southeast extreme against the stock. The fault truncates a small fold to the southwest and places the Quadrant against a series of older beds. Normal movement with southwest side up can explain its relationships (see cross-section C-C').

To the northwest and trending in the same N 45 W direction is another small fault which terminates to the northwest against the Boulder batholith and to the southeast against the previously mentioned small aplite

body. This fault offsets Cretaceous and Triassic meta-sediments, generally displacing the section to the northwest on the southwest side of the fault. This relationship could be the result of partial strike slip movement, but can also be accounted for by steeply dipping normal movement, with the southwest side down, when topography and dip of sediments are considered.

In the central part of the "northern block" is a N 60 E-trending fault which approximately follows the north fork of Tucker Creek. This fault terminates on the southwest against the previously described N 45 W-trending fault; and on the northeast, probably, against the Boulder batholith. This fault generally complicates the north-plunging anticline in this area by displacing the southeast segment of the eastern limb to the northeast. This relationship is probably a high angle normal fault with the north side down, rather than strike slip, when topography and dip relationships are considered.

Also, in the central section of the "northern block" a N 80 W-trending fault occurs and terminates to the west against an irregular-shaped basic intrusive and to the east, probably, against the Boulder batholith. This fault further complicates the eastern flank of the fold which occupies the "northern block." Its major effect has been to move the southern side of the fault slightly to the west with respect to the northern side. Displacement is probably not great and the movement on this steeply-dipping fault is south side down.

Branching from the latter fault, and striking N 45 E, is another small fault which terminates against the stock to the southwest. This fault has slightly displaced the northwest side of the fault to the southwest. Displacement is small and the movement is probably a high angle normal fault, with the northwest side down. The fault does seem to broaden the outcrop width of the upper quartzite member of the Phosphoria, which is probably due

to drag phenomena or a lessening of dip (see map).

There are four small faults to the east of this fault in the vicinity of Mt. Humbug. These faults have small displacement and are actually little more than strong fractures. Their extent is not great and their movement is probably dip-slip on a vertical fault plane.

The last fault included in the "northern block" occurs in the north central part of the Moose Creek stock where the Madison is almost surrounded by the intrusive and has been badly distorted. This fault is mapped because of a sudden 90 degree shift in strike of the Madison. This is the only mapped fault in this small area, but there may be others which account for other drastic strike changes in this block of marble. Displacement and relative movement were not determined.

Western Fault System

The "western fault system" lies in that area west of the igneous stock and south of Tucker Creek.

Structural relationships in this part of the area are largely covered by Tertiary basin deposits, but two small exposures display complex structure.

The central part of this "western block" contains a series of folds which are complicated by two (?) hypothetical N 45 E to N 60 E trending faults. These faults were mapped on the basis of structural and stratigraphic relations. They are buried by alluvium.

Both faults essentially eliminate the synclines in this area (see cross section D-D'). Anticlinal folds involving the Madison and Three Forks formations are repeated. Structural relationships indicate that these are probably high angle normal faults, with south side down in both cases,

and have fairly large displacement, although an estimate of displacement is conjectural.

In the extreme southwestern part of the area, there is a small block of Paleozoic limestone. It has been mapped tentatively as Meagher, but could be Pilgrim or Madison. Theodosius (1952) maps it as Madison and also maps some Amsden in this area. The writer did not observe the Amsden, however, and can find no other definite indication that the marble is Madison.

This block of carbonate appears to be in fault contact with the Belt to the south, though covered, and the fault apparently strikes N 65 E. The movement along it is probably normal with the north side down. Estimates of the amount of displacement depend directly upon the identification of the carbonate unit. If it is Meagher, the indicated displacement is not nearly so great as if it is Madison marble. The carbonate block also is severely distorted by multiple intrusion of basic dikes, sills and aplite bodies. These have severely fragmented the marble and produced minor faulting within this unit.

Southeastern Fault System

The southeastern block consists of the area on the eastern and southern sides of the Moose Creek stock, and to the south of Mt. Humbug. This large area is not overly complicated by faulting, and only four minor faults were mapped.

On the eastern side of the stock are two small, generally north-trending faults, which slightly displace part of the Paleozoic section. The fault to the north truncated by the stock eliminates the Three Forks formation for a short distance. The fault located just north of Moose Creek and east of the stock slightly displaces some of the basic sills found in the

Pilgrim. It is probably a high angle normal fault with the west side down and is of unknown extent.

South of Moose Creek are two small faults trending generally north-northwest. The largest of these two, which terminates against a lobe of the stock, displaces the east side to the north. This fault is probably a high angle normal type, and the attitude of the beds and slope of topography in conjunction with nearly vertical movement, give the fault the false appearance of strike-slip movement on the map. The other fault, to the west, is very minor, displacing the Belt-Flathead contact slightly.

Late Cenozoic (?) Faulting

The fact that the Tertiary sediments in the western part of the area dip as much as 15 degrees to the east indicates Late Cenozoic (?) structural deformation. The source of these beds is probably to the east, yet the beds dip toward their source. A feasible explanation for this relation is that there could be a major fault close to the western edge of the stock and trending approximately N-S. A possible fault relation is diagrammed in figure 11.

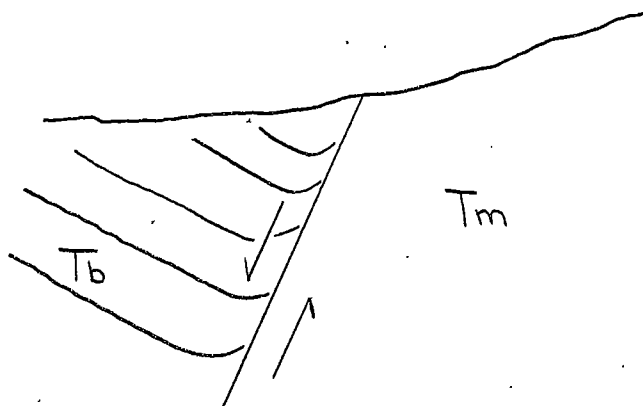


Fig. 11. - Possible fault relation along the west side of the igneous stock and producing the eastward dip of the Tertiary basin deposits.

Downdropping of the Tertiary sediments might explain their eastward dip, although a drag phenomena, such as illustrated in the sketch, was not observed, due to alluvial cover. However, the dip does decrease from west to east which might be an indication of a beginning of drag relationship along the fault trace or, possibly, of deposition during fault movement.

Jointing

Jointing is very common both in the meta-sediments and in igneous rocks.

In the meta-sediments joints are most common in the very brittle quartzites and argillites such as the Quadrant, phosphoria quartzite member, and the Dinwoody. Joint directions are numerous and orientation is random. The jointing usually obscures bedding and is very strong. As many as five directions of jointing are present in some outcrops. There is a possibility that igneous intrusion has been a factor in developing some of this jointing by contact metamorphism, although sedimentary rocks to the south, unmetamorphosed and not in proximity to igneous intrusive, are also strongly jointed.

The Boulder batholith has a joint pattern which has dominant east-west and north-south sets. Dip of jointing varies, but is usually very steep. The dominant joints rarely have more than a five degree variation from true north-south or east-west strike.

The stock, on the other hand, has a more random joint pattern. An overall average in the stock shows a north-south, east-west trend; but several localities can be found where the dominant jointing is at an oblique angle to this trend.

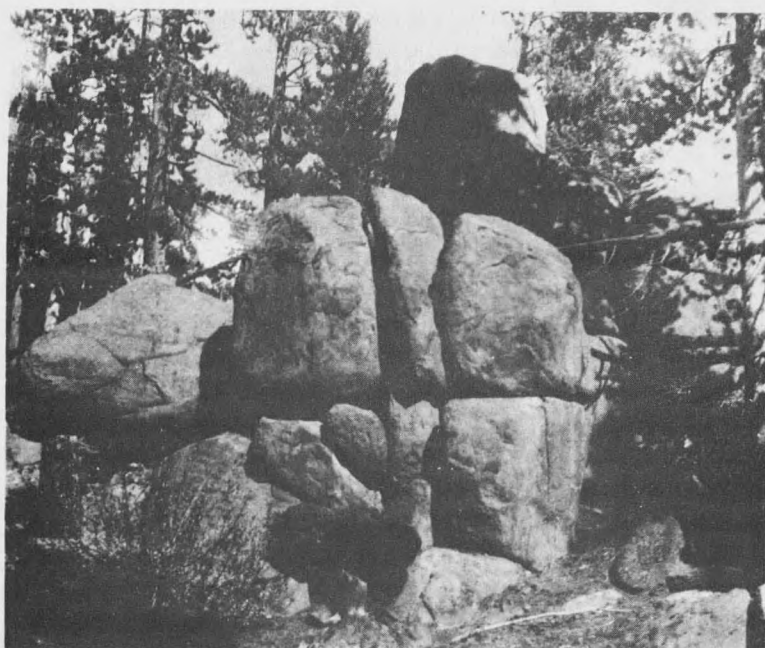


Fig. 12. - Jointing in the Boulder batholith. Joints here are vertical and oriented north-south and east-west. Notice also the presence of horizontal jointing.

Igneous Intrusion

As has been mentioned previously, the writer believes that the major mode of intrusion of the Boulder batholith and stock was forceful injection. The abundant faulting and apparent squeezing of the meta-sediments supports this hypothesis, as has been shown. Stoping is probably very important also, especially in the batholith where the stratigraphic section has been assimilated and its space now is occupied by the batholith. The stock has also assimilated part of the section, notably the Park, Pilgrim, Red Lion, Jefferson and Three Forks formations. However, the stock also seems to have shouldered aside some of the section as it forced its way into the country rock. The Madison and younger rocks seem to "swing" around the stock, especially in the northwest corner. Thus, the stock may be partly con-

cordant in some places.

The stock lies on line with a striking east-west termination of the Boulder batholith as seen on regional maps and this is a possible indication of fault control for these intrusions. Smedes (1960, personal communication) believes in the possibility that the Boulder batholith is fault controlled, and this east-west feature might be supporting evidence for this idea.



Fig. 13. - Jointing in the igneous stock. Joints are oriented at about $N 10^{\circ} W$ and $N 80^{\circ} E$, and are close to vertical.

GEOLOGIC HISTORY

Laramide structural history for this area begins in Cretaceous time. History prior to Cretaceous is dominantly characterized by the deposition of the Precambrian, Paleozoic and Mesozoic sediments with interspersed hiatuses.

Probably the initial important event in the Cretaceous history of this area is the intrusion of the basic igneous sills and other irregular bodies.

These sills intrude the Colorado group, thus they postdate this Cretaceous deposition. In turn the sills are metamorphosed and truncated by the stock and batholith, so they predate this intrusion. They are also deformed as much as the meta-sediments, thus most likely they precede the main deformation of the Laramide orogeny.

Laramide deformation, then, is probably the next major event chronologically after emplacement of the basic igneous rocks. The writer believes that intrusion of the stock and batholith intensified previous folding by applying compression during forceful injection. Also, these igneous bodies truncate the folds and some of the faults in the area. This would tentatively date intrusion as post-deformation.

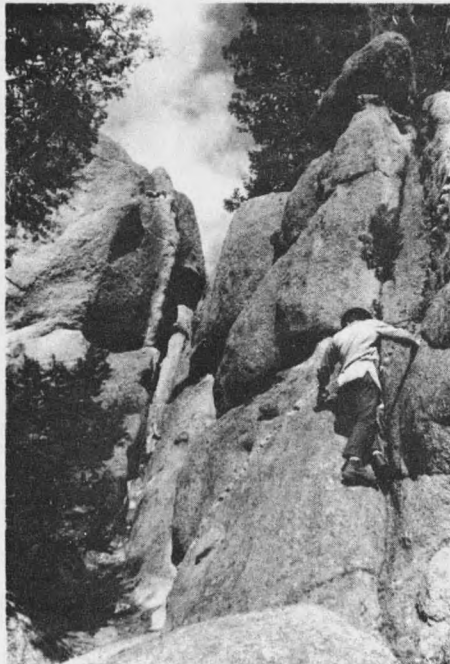


Fig. 14. - Jointing in Boulder batholith.
Note presence of "joint fillings"
which are granitic in composition.

Laramide deformation probably consisted mainly of tilting along the previously postulated major fault to the south which might have produced the regional northward dip of the sediments; and development of the north-north-west trending fold system. Some faulting, notably the strike fault cut by the stock in the "northern fault block", probably also occurred during this formation.

This initial deformation was followed closely by major intrusion of the Moose Creek stock and Boulder batholith. During intrusion, these bodies produced the contact metamorphism which alters all pre-existing rocks in the area. They also were responsible for the extensive faulting around these intrusions, probably by shearing, and probably for the intensification of pre-existing folds.

Late stage acidic differentiation probably accounts for the aplite bodies in the area and the quartz-orthoclase rich "graphic granite" joint fillings.

The above sequence of uplift, deformation and intrusion was probably followed by a period of erosion in which local drainage was to the west, depositing the sediments which comprise the Tertiary basin deposits. Oligocene and Miocene dates on these beds by Douglass (Sahinen, 1950, p. 25) and the preceding data place the orogenic and intrusive interval between Late Cretaceous and Oligocene.

After deposition and consolidation of the Tertiary sediments, further deformation occurred, indicated by the eastward tilt of the Tertiary sediments, probably the result of movement along a normal fault. Nothing more accurate than a post-Miocene - pre-Quaternary date can be placed on this deformation. Even post-Miocene is not certain since deposition of the Tertiary sediments could have gone on simultaneously with movement along this

PLATE IV



Fig. 15 - View looking south across Tucker Creek. Terraces along Tucker Creek are well displayed. The wooded area is underlain by the Moose Creek stock.



Fig. 16. - View looking west from the Tucker Creek canyon. Terrace system is visible. The wooded area here is underlain by meta-sediments. The broad grassy valley is underlain by Tertiary basin deposits.

fault.

Recent history consists primarily of deposition of Quaternary sediments and development of geomorphic features. Geomorphic features include the terraces developed on the Tertiary sediments to the west and along Tucker Creek and other streams. These terraces are underlain by a cover of alluvium which in turn lies on the Tertiary sediments, and are most striking where Tucker Creek leaves its canyon. Here the terrace level is 150-200 feet above the stream. This is the maximum height of any terrace above present streams in the area. This surface is the only major terrace development and it is presently being dissected.

Also prominent in the area are frost features such as felsenmeers, stone stripes and rings. These features are especially common in the vicinity of Mt. Humbug, developed on Quadrant and Phosphoria quartzites, which are so susceptible to frost shattering. Creep and landslide features, probably the result of saturation and gravity movement, are prominent on some bare hills on the flanks of Mt. Humbug, and especially in the large open area south of Mt. Humbug which must be underlain by the Madison and Amsden formations.

The geologic history can be summarized as follows:

- a) Deposition of Precambrian, Paleozoic and Mesozoic sediments.
- b) Basic sill intrusion in Late Cretaceous and Early Tertiary time.
- c) Laramide orogeny, tilting by differential movement along a major fault to the south and developing a north-north-west trending fold system, and causing some faulting in late Cretaceous and early Tertiary time.
- d) Intrusion of the stock and batholith, producing contact metamorphism, intensive faulting, intensification of previous folds in Early Tertiary time.
- e) Intrusion of late differentiate producing aplite bodies and acidic joint fillings in Early Tertiary time.
- f) Erosion and deposition of Tertiary sediments to the west in Oligocene and Miocene time.

- g) Deformation of Tertiary sediments by faulting in Cenozoic (?) time.
- h) Development of present geomorphic features during recent time.

REFERENCES CITED

- Cressman, E. R., 1955, Physical stratigraphy of the Phosphoria formation in part of southwestern Montana; U. S. Geol. Survey, Bull. 1027 A, 31 p.
- Hanson, A. M., 1952, Cambrian stratigraphy in southwest Montana; Mont. Bur. Mines and Geol., Memoir 33, 46 p.
- Moritz, C. A., 1951, Triassic and Jurassic stratigraphy of southwestern Montana, Bull. Amer. Assoc. Petrol. Geol., vol. 35, no. 8, p. 1781-1814.
- Myers, W. B., 1952, Geology and mineral deposits of the northwest quarter Willis quadrangle and adjacent Brown's Lake area, Beaverhead county, Montana; U. S. Geol. Survey Prelim. Report, Open File, 46 p.
- Ramberg, Hans, 1952, The origin of metamorphic and metasomatic rocks; University of Chicago Press, Chicago, 317 p.
- Richards, R. W., and Pardee, J. T., 1925, The Melrose phosphate field; Montana; U. S. Geol. Survey, Bull. 780 A, 32 p.
- Sahinen, U. M., 1939, Geology and ore deposits of the Rochester and adjacent mining districts, Madison county, Montana, Mont. Bur. Mines and Geol., Memoir 19, 53 p.
- , 1950, Geology and ore deposits of the Highland Mountains, southwestern Montana; Mont. Bur. Mines and Geol., Memoir 32, 63 p.
- Sloss, L. L., and Moritz, C. A., 1951, Paleozoic stratigraphy of southwestern Montana, Bull. Amer. Assoc. Petrol. Geol., vol. 35, no 10, p. 2135-2169.
- Theodosius, S. D., 1954, Geologic map of the Melrose area, Beaverhead and Silverbow counties, Montana, PhD thesis, Indiana Univ., unpublished.

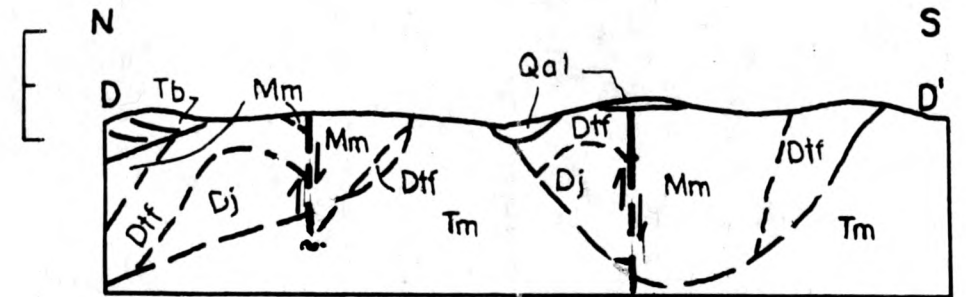
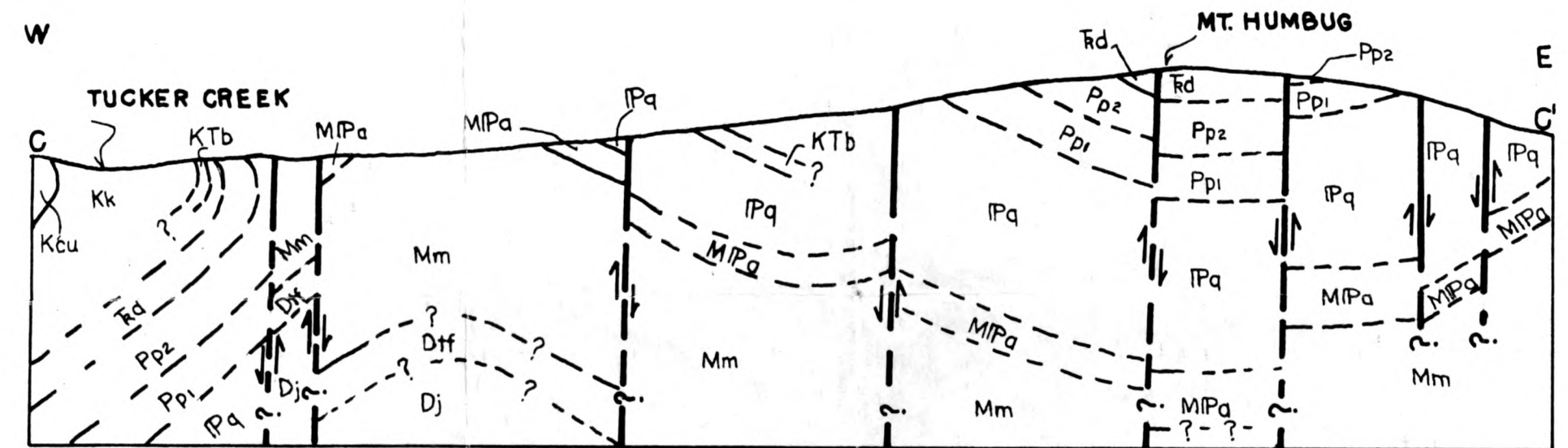
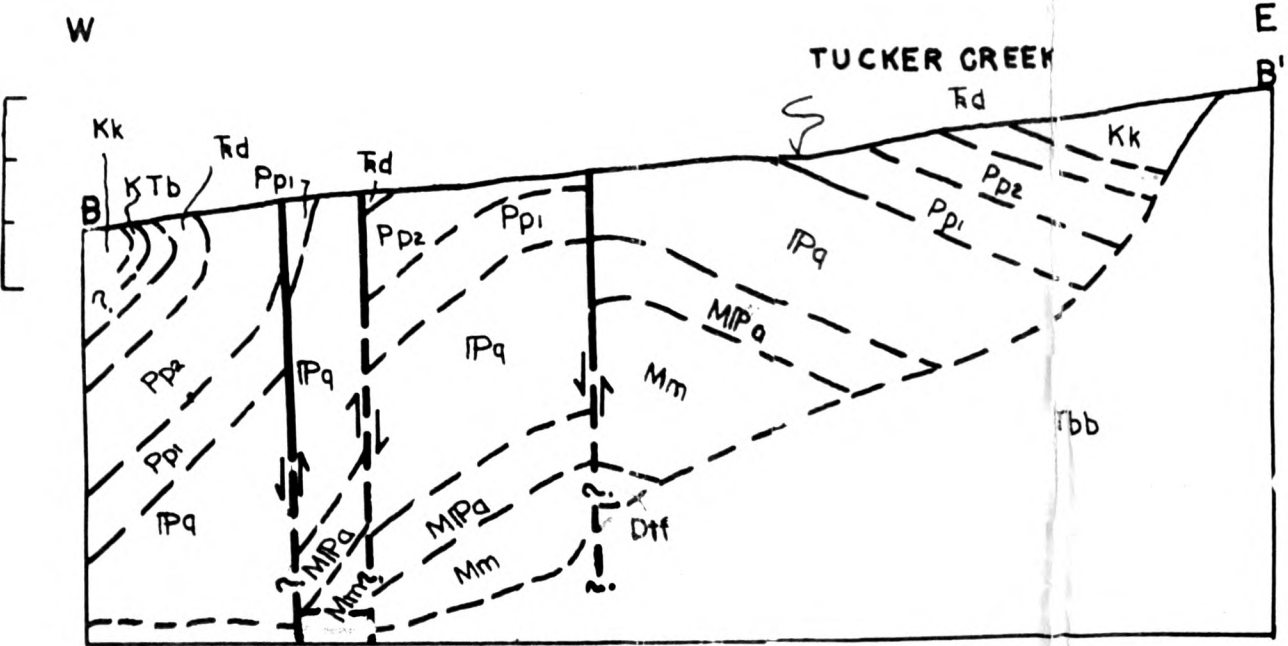
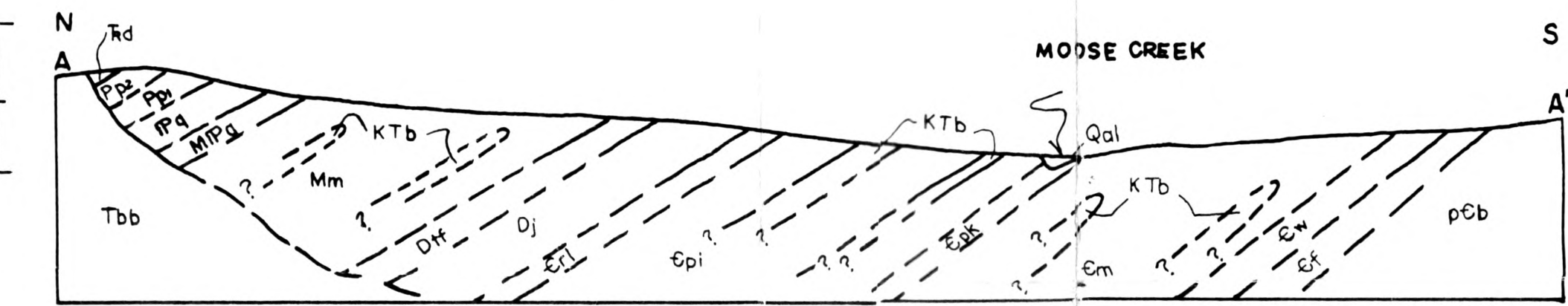
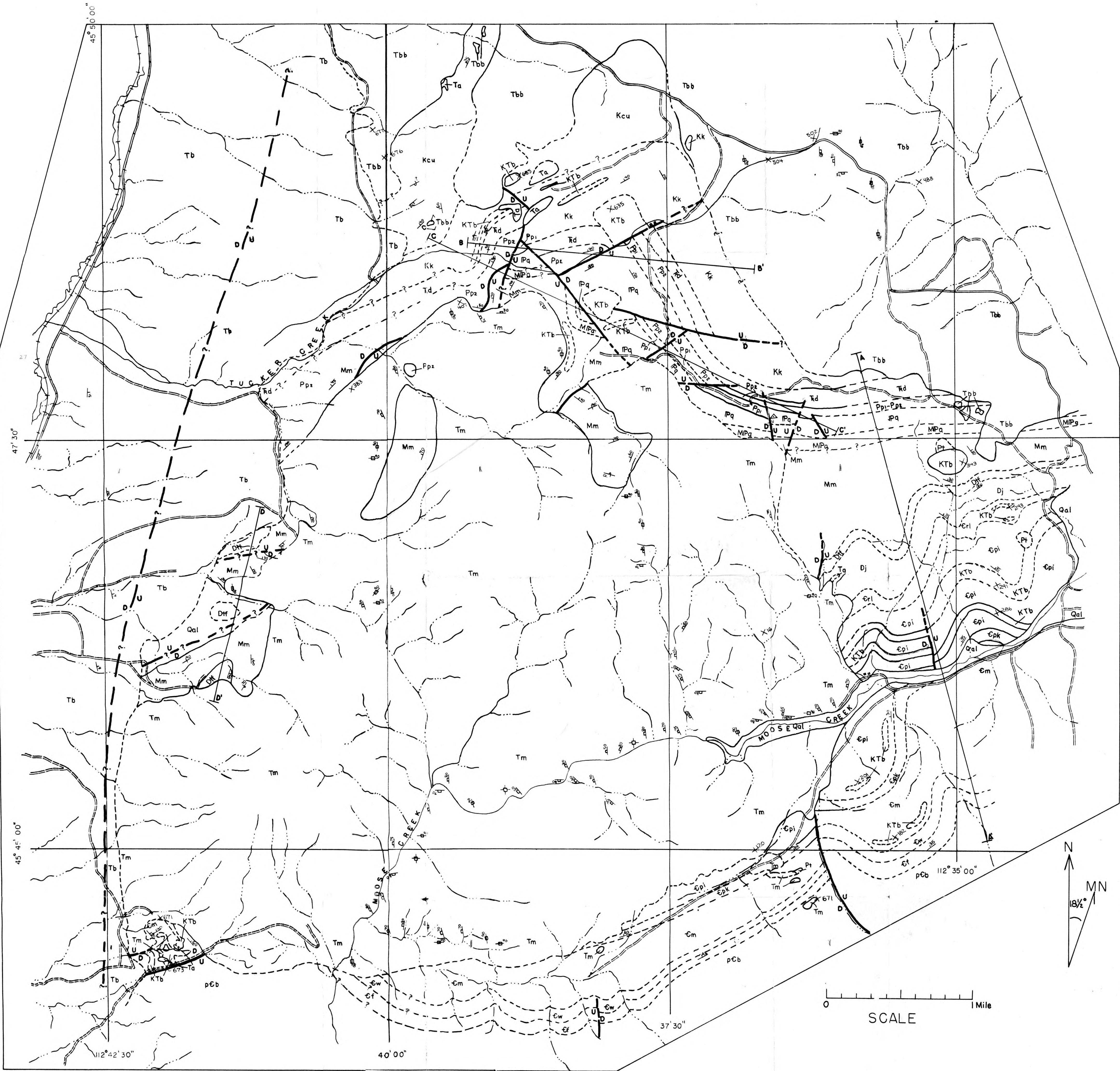
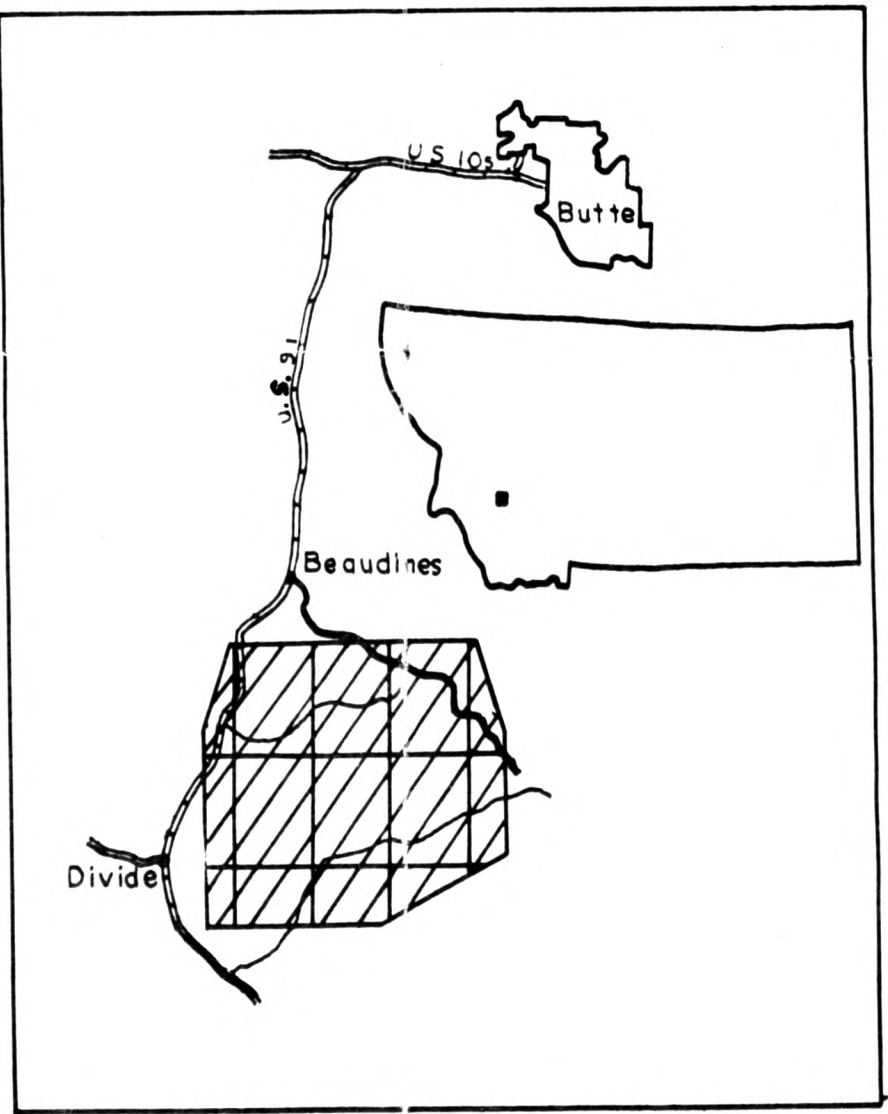
GEOLOGIC MAP AND CROSS SECTIONS OF THE MOOSE CREEK STOCK, HIGHLAND MOUNTAINS, MONTANA

Daniel B. Andretta
November, 1960

EXPLANATION

QUATERNARY	Qal	SURFICIAL DEPOSITS
		alluvium
		terrace and stream deposits
TERTIARY	Tb	SEDIMENTARY-METAMORPHIC ROCKS
		basin deposits
CRETACEOUS	Kcu	Colorado group undivided
	Kk	Kootenai fm.
	Td	Dinwoody fm.
	Pp2	upper quartzite unit
	Pp1	lower phosphate and marble unit
	IPq1	Phosphoria fm.
	MPa	Quadrant fm.
MISSISSIPPIAN	Mm	Amsden fm.
	Mm	Madison group
DEVONIAN	Df	Paleozoic facies in various Paleozoic fms.
	Df	Three Forks fm.
	Dj	Jefferson fm.
	El	Red Lion fm.
	Epi	Elgin fm.
	Ep	Park fm.
	Em	Meagher fm.
	EW	Walsley fm.
	Ef	Flathead fm.
PRE-CAMBRIAN	pCb	Belt series
		IGNEOUS ROCKS
	Ta	aplite bodies
	Tm	quartz monzonite Moose Creek stock
	Tbb	quartz monzonite Boulder batholith
GREY TAC-EOUS	KTb	basic sills and irregular bodies

contact
dashed where approximately located
inferred contact
fault
U-upthrown side
D-downthrown side
dashed where approximately located
dashed with question marks where inferred
strike and dip of beds
strike and dip of overturned beds
strike of vertical beds
strike and dip of joints
strike of vertical joints
horizontal joints
sample location
cross section location
perennial stream
intermittent stream
highway
improved road
unimproved road
railroad
buildings



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