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A Study of some Pre-Cambrian Schists from Yankee Jim Canyon, Park County, Montana

Charles K. Presley

A STUDY OF SOME PRE-CAMBRIAN SCHISTS FROM YANKEE JIM CANYON, PARK COUNTY, MONTANA

By
Charles K. Presley

A Thesis
Submitted to the Department of Geology
in partial fulfillment of the
Requirements for the degree of
Bachelor of Science in Geological Engineering

MONTANA SCHOOL OF MINES
BUTTE, MONTANA
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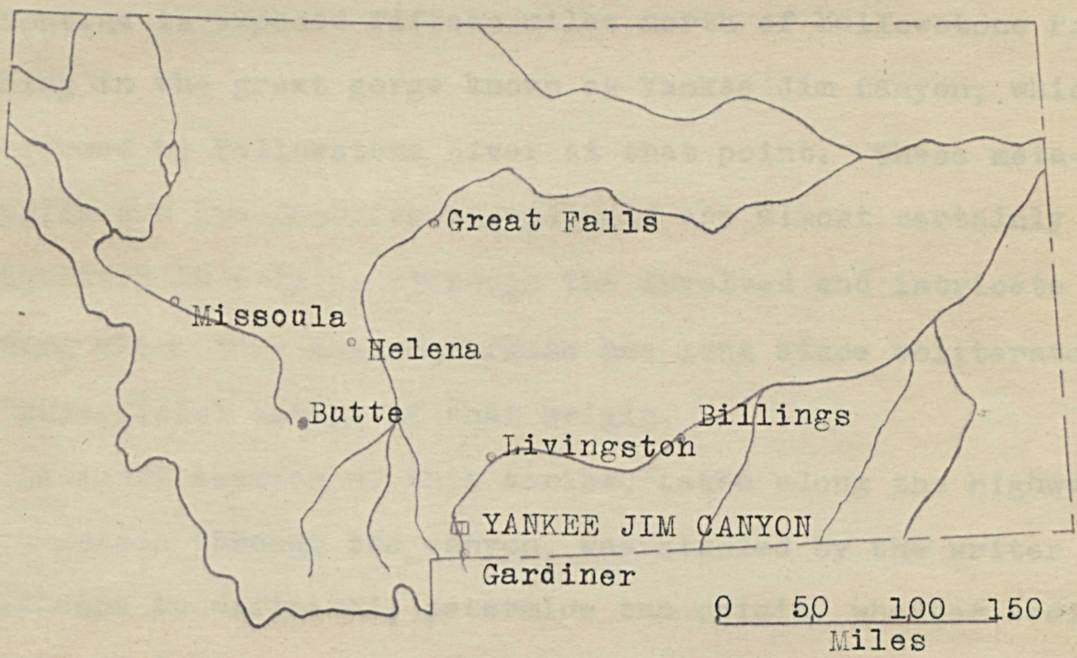
Plate 1



Index Map of Montana, Showing Location of Yankee Jim Canyon

A STUDY OF SOME PRE-CAMBRIAN SCHISTS FROM YANKEE JIM CANYON, PARK COUNTY, MONTANA.

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INTRODUCTION

One of the most highly deformed metamorphic rock series in Montana is exposed fifteen miles north of Yellowstone Park, Wyoming in the great gorge known as Yankee Jim Canyon, which was formed by Yellowstone River at that point. These metamorphics are Pre-Cambrian in age, and are almost certainly sedimentary in origin, although the involved and intricate folding which they have undergone has long since obliterated any superficial traces of that origin.

A small section of this series, taken along the highway which passes through the canyon, was studied by the writer in an attempt to definitely determine the origin, whether sedimentary or igneous, and to determine the constituent minerals of the various layers. The rocks have been so intensely folded and faulted as to almost preclude the determination of the regional structure. Lava flows cover much of the country around this exposure, and four miles south is an exposure of the Pre-Cambrian basement granite of the region, which abruptly terminates the schists and gneisses, although they reappear near Jardine, Montana. The subject of this report, however, is primarily a study of the specimens taken along Yankee Jim Canyon.

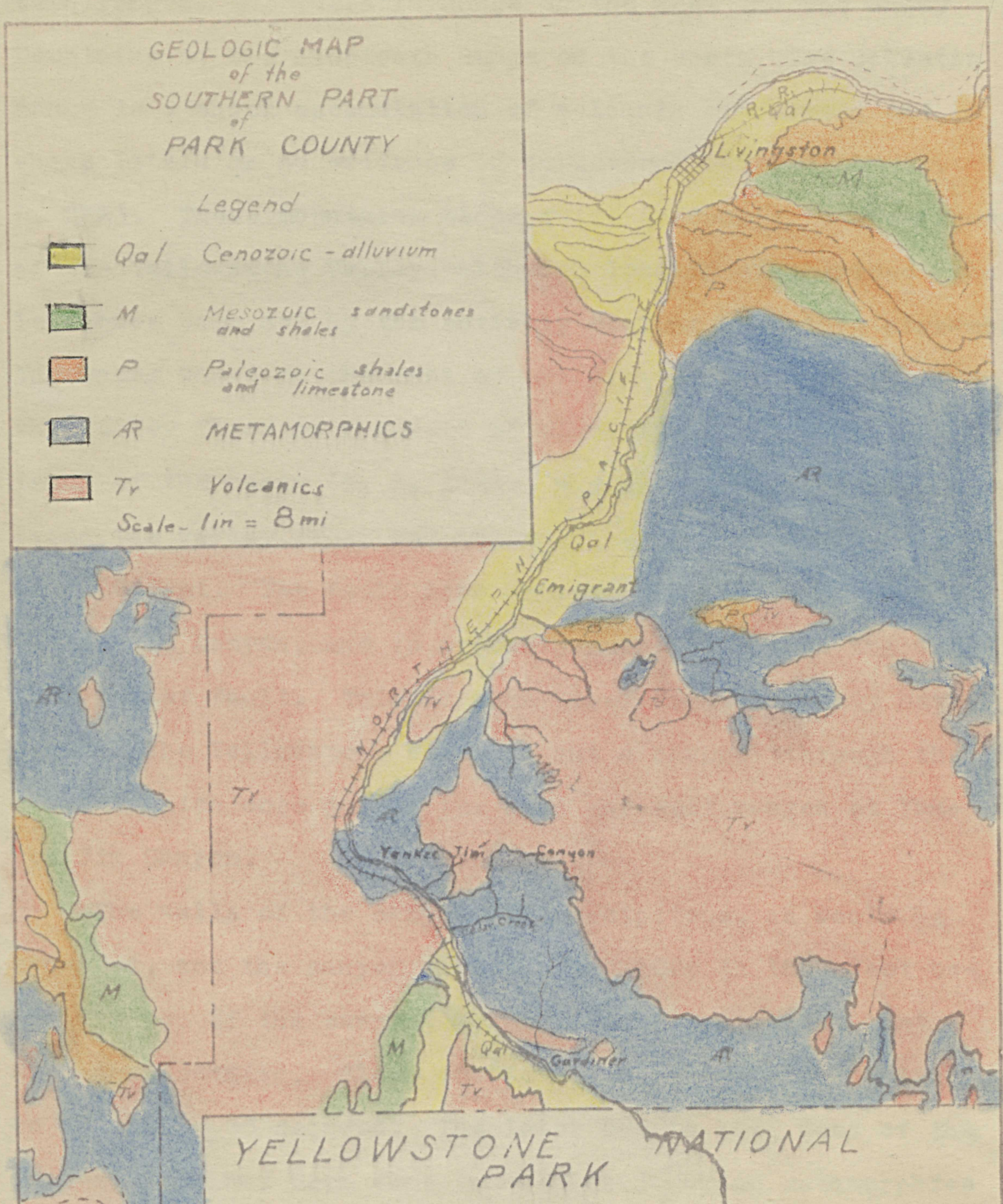
The attitude and character of the various beds which were sample on March 4, 1950 were carefully noted, but the laboratory study of the samples has been the major project since that time. Megoscopic and petrographic examinations have been made, and a heavy mineral determination undertaken. Photomicrographs were taken of interesting and unusual features of the rocks. An index map of Montana showing the general location of the area is shown in Plate 1., and a generalized geological map of the southern part of Park County is shown in Plate 2.

The writer wishes at this point to express his appreciation to Dr. E.S. Perry, Professor of Geology at the Montana School of Mines, for his kind aid in the choice of this problem, and for the subsequent attack on the problem. Thanks are also due Mr. F.S. Robertson, of the Geology Department staff, who gave unstintingly of his time and assistance in the petrographic inspections of the samples.

GEOGRAPHY

<u>Location</u>: Yankee Jim Canyon of Yellowstone River lies in the southern part of Park County, Montana, and fifteen miles northwest of the town of Gardiner, (plates 1 and 2). The Yellowstone River flows out of Yellowstone Park in a northwesterly direction, and at Yankee Jim Canyon makes an abrupt turn to the northeast at nearly ninety degrees and continues on to Livingston. U.S. Highway 89, a macadam road, parallels the river, and it was from the road cuts of this highway in the Yankee Jim Canyon that the thesis samples were obtained. On the west side, the river is paralleled by a branch line of the Northern Pacific Railway, which terminates at Gardiner.

Plate 2


GEOLOGIC MAP
of the
SOUTHERN PART
of
PARK COUNTY
Legend
Qal Cenozoic - alluvium
M Mesozoic sandstones and shales
P Paleozoic shales and limestone
AR METAMORPHICS
Tr Volcanics
Scale - 1 in = 8 mi
Livingston
Emigrant
Yankee Jim Canyon
Gardiner
NORTHERN PACIFIC
YELLOWSTONE NATIONAL PARK

Physical Features of the Region: The Yellowstone River between Gardiner and Livingston is flanked by two mountain ranges, the Gallatin Range on the west and the Snowy Mountains of the Beartooth Range on the east. The Gallatin Range is a thick accumulation of volcanic eruptives, and shows little or no evidence of structural deformation (1, p. 282). These mountains slope quite gradually to the floor of the Yellowstone Valley, although locally steep-sided valleys have been cut by the actively eroding tributary streams. The Snowy Range on the east of the river rises abruptly from the valley floor as a result of block faulting along the front of the range (5, p. 378). Difference in elevation between the valley floor and the crest of the range is as much as 6000 feet. The fault line crosses the northern end of Yankee Jim Canyon, and is probably much later than the Gardiner thrust fault. This or some other fault line may have enabled the Yellowstone River to cut a channel through the rampart which once joined the east and west ranges at Yankee Jim Canyon.

The walls of the canyon are precipitous, as would be expected, and the canyon floor is now 1000 to 1500 feet below the top of the canyon, which indicates at least that much down-cutting. Slope of the walls ranges from vertical to as low as 35 degrees. The lower 500 to 1000 feet of the down-cutting has been done in the Pre-Cambrian metamorphics with which this report is concerned. Above these metamorphics lie unconformable volcanics, most of which probably emanated from volcanoes to the east. The east wall of the

Canyon continues upward to the crest of a large and somewhat isolated mountain mass known locally as Dome or Dailey Mountain. The elevation of this peak is 8600 feet, and it is isolated from the main range of the Snowies by a low pass between Dailey Lake, to the north, and Slip and Slide Creek, to the south. The higher elevations of this mountain are heavily timbered, but on the lower slopes, and on the canyon walls, timber is scattered and small.

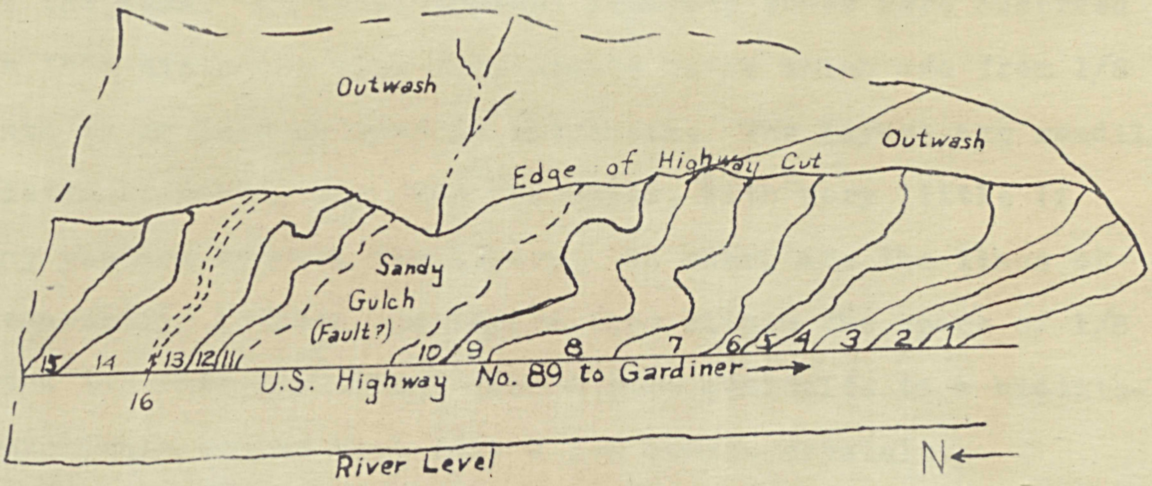
GENERAL GEOLOGY

On the west side of the Yellowstone River the Pre-Cambrian metamorphics are covered a short distance away by unconformable volcanics, mostly a basalt breccia. In many places these volcanics extend almost to the river bank, notably about 1 mile downstream from the canyon. Just north of the Carbella bridge, at the north end of the Canyon, the volcanics extend across the river to the east side and form a low ridge at the north end of what is known as Carbella Flat. Aside from this point, the early basal breccias are generally much higher in elevation on the east side of the river than on the west. Just north of the Canyon, a recent fault scarp cuts across an alluvial fan which spreads out from the base of Dailey Mountain. This scarp supports the theory that the river follows a fault-line through the Canyon, and that the west side of the fault is the downthrown side.

On the east side of the river, the metamorphics are exposed for a much greater distance back from the river than they are on the west, but in the higher elevations they are covered unconformably by the volcanics. A partially eroded volcanic cone lies some seven miles east of the canyon; and near the mouth of Slip and Slide Creek, which is ¼ mile south of the entrance to Yankee Jim Canyon, an occasional granite or grano-diorite outcrop suggest early pre-Cambrian intrusion into the metamorphics at that point. At Cedar Creek, 3 miles south, the volcanics overlie the metamorphics at an elevation of 1300 feet above the valley floor (altimeter reading). Presumably the same difference in elevation exists at Yankee Jim Canyon, although no information was available to verify this.

The metamorphics with which this report is primarily concerned generally strike northeastward parallel to the mountain front and dip to the west at high angles. In the Canyon itself, the metamorphics are highly folded, beds commonly doubling back on themselves within a few feet, so that uniform regional strikes and dips are indeed difficult, if possible, to determine. The particular section of schists from which samples for this study were taken had strikes ranging from N. 45 E. to N. 55° E. within a distance of 250 feet. Dips at the level of the highway ranged from 20 to 30° at the south end to as low as 15° near the center of the section, and on the north end, across what is probably a minor bedding-plane fault, suddenly increased to 35°. However, these figures for dip could well have been altered by many degrees if the dips had been taken a few feet farther up the hill-side, so intense is the folding.

Plate 3



SCALE : 1 inch = 50 feet

Front View Sketch of Thesis Section, Looking E.

FIELD DESCRIPTION OF THESIS SECTION

The section chosen for study is a well-defined band of schistosic material which lies just at the upstream end of Yankee Jim Canyon. It is 240 feet wide, measured along the highway, and about 130 feet wide perpendicular to the dip of the beds. At least sixteen separate zones were observed in this distance, plus many minute bands which are from 1/8 inch to an inch or more in thickness. The layers are readily distinguishable, one from the other, with very little if any grading between the layers. So sharp are the lines of demarcation between the layers that within the space of 1/8 inch the rock may change from a pure quartzite to a biotite-hornblende schist with only a few quartz crystals.

Color differences are fully as noticeable as is the banding, although most of the rocks are essentially whites, grays, browns, and blacks, with a few yellowish layers interspersed. On old surfaces the weathering of the iron-rich minerals has produced some iron oxide, which stains the surfaces yellow or red. Lichens are also common on the older surfaces, and lend a red color to some rocks. Where the highway cut has exposed the new rock surfaces, however, the colors are rather sombre.

Probably the most distinctive feature of this section is the banding of the rocks. From the layers of 10 to 15 feet in thickness, down to the tiny bands 1/8 inch or so thick, all the bands exhibit a general over-all parallelism, which is unaffected by any folding, no matter how tortuous. This striking parallelism is not confined to this section, but is characteristic of these metamorphics in the entire region. Evidently the original, or source, beds were very uniform in thickness. Some of the bands are pure biotite, which may be intensely distorted within the layer and yet preserve the layered effect. Quartzite seams, a small fraction of an inch wide and separated by an inch or two of mafic material, may be traced for many yards, and they maintain their relative positions almost exactly. All bands observed were parallel to the bedding planes.

The rocks break most easily, of course, along the planes of banding. Across the banding, however, the metamorphism has been so complete that fracture is often through, rather than around, separate mineral grains. The rocks are extremely tough and hard, and do not crumble or disintegrate on weathering. So dense and fine-grained are they that frost action and exfoliation do not play an important part in their breakup, as they do in the granites around Butte. Surfaces of rocks broken by the highway cut, built in 1928, are often mistaken for fresh breaks. The strike and dip of the beds have been given elsewhere in this paper (p. 6), but it should be noted that the strike agrees fairly well with the general strike of the metamorphics farther north in the Yellowstone Valley. According to Horberg (1, p. 282), the Pre-Cambrian rocks in this region strike parallel to the mountain front, which would make their strike about N. 40 to 50°E. However, the Yellowstone River changes direction abruptly at the Canyon, from N. 55°W. to about N. 35°E., so that the strata which strike parallel to the river and the mountains farther north, will have an attitude perpendicular to the course of the river in the canyon.

This section of metamorphics, with its interbedded yellow-to-white and brown-to-black bands, resembles nothing so much as the description coined by Dr. Perry. "It looks like the pattern formed by a small child dragging a rake on a newly-laid concrete sidewalk." The deforming stresses must have been great, and the rocks must have been deeply buried, to result in such intense folding and flowing of the now adamantine-like metamorphics.

LABORATORY DESCRIPTION OF ROCK SAMPLES

On Plate 3 is shown a sketch of the section of the Canyon at the point where the theses samples were obtained. This sketch gives the attitude of the beds, and also shows the points where samples were taken. Sixteen samples were taken at 15-foot intervals, and every attempt was made to have the samples as representative as possible. That is, if a band was more than 15 feet wide, the sample was taken from the next band, even if it meant an interval of 18 feet of more between samples. One of the samples was later discarded, as it proved to be a sandy agglomerate stained with iron that was impossible to study in thin section. It seems likely that this unit, about 6 feet wide, represents a fault plane; and that the sandy residue is the leached fault breccia. The "fault line", if such it is, is now a gully, and outwash from the higher ridges precluded the possibility of getting fresh samples.

Only ten thin sections were made of the samples. Those samples were chosen which would give the most representative cross-section of the locality, and in cases where the rocks were very similar in hand sample, only one thin section was made. Nine of these thin sections were made by the Myers' Thin Section Laboratory, and one was made by the writer.

For ease in correlating the megascopic and microscopic descriptions of the rocks, the two descriptions are placed together. However, to avoid confusion, the thin sections have been given a letter as well as a number. That is, a thin section made from sample 2 would be designated 2-A. In one instance two thin sections were made from one sample (9) which showed some unusual characteristics. The descriptions follow.

1. This sample is dark gray with a few yellowish bands through the rock. Foliation is visible, although not marked. The structure, in fact, is almost gneissic. Large quartz crystals interrupt the smooth flow of the tiny bands, giving the appearance of water running around rocks in a stream. Minerals recognizable megascopically are quartz and biotite (predominately), a few flakes of muscovite, some clean striated plagioclase, and some yellowish weathered plagioclase. The color is imparted by the predominance of biotite, and by the presence of some smoky quartz.

1-A: Identifiable minerals in thin section are quartz, biotite, oligoclase feldspar, clinozoisite, cummingtonite, and a zebra-like intergrowth of (a) nephelite and feldspar, or (b) an intergrowth of quartz and feldspar. Some zircon grains are found in the biotite, with the customary pleochroic halos surrounding them. A few minute grains of magnetite and some apatite grains are the only other accessory minerals observed.

An unusual feature of this thin section is the way in which the dark minerals are strung out in tortuous layers, and the way in which these layers "flow around" quartz grains in the same manner described in the hand samples. Another feature of interest, and one seen in almost all the thin sections, is the extreme "corrosion", or irregularity, of the grains. All grains except the accessory minerals are deeply embayed and show very little, if any, of the original crystal outlines. Typically, the plagioclase grains preserve more of their original structure than do most of the other minerals.

The plagioclase is often distorted, so that the twinning shows as wavy lines. The more eroded grains usually show the most distortion. Most of the quartz crystals have been distorted, and have the sweeping or wavy extinction so characteristic of strained quartz. A few crystals even show strain lamellae (pl. 4, A & B). There are a great many very small mosaic-like quartz crystals which in some thin sections form bands, and in others surround the larger quartz grains. In general, the large grains show strain effects and the tiny ones do not. This is probably a mechanical effect and not due to an age difference.

The cummingtonite is a fibrous, somewhat radiating, aggregate of crystals (pl. 4, C & D). It is colorless, nonpleochroic, and in some sections does not form fibrous clusters, but instead is in prismatic diamond-shaped crystals, which show a preferred orientation.

2. Sample number 2 would probably be called a granodiorite if seen in hand sample alone, and unrelated to the rest of the metamorphics. It is light grey, fine grained, and composed mostly of quartz and plagioclase, but it is given a speckled effect from small bits of biotite. Seen at a certain angle, the biotite seems to have a faintly striated appearance, but it is not as pronounced as the schleiren in many granites. Along one edge of the sample is a layer of highly crumpled and folded biotite which is sharply delineated from the rest of the rock. From the polished appearance of the biotite surface, in spite of the crumpling of the individual grains, one would surmise movement along the planes of foliation with the biotite acting as an incompetent bed.

2-A This is a relatively simple thin section, containing only quartz, biotite, oligoclase feldspar and sericite. The same "eroded grains appearance" is manifested in this sample. Parallel arrangement of the grains is not noticeable.

3. This sample is very similar from a superficial examination to sample one, both in color and appearance. However, it exhibits more foliation. The micas show a definite banding, with the same "stream a round rocks" effect seen faintly in sample 1. It is dark gray with quartz bands almost white, and some very yellowish plagioclase and yellow quartz occur near one edge. Predominant constituent minerals are quartz and biotite nearly equal in amount, together with much yellowish or transparent plagioclase. Some muscovite or more probably, chlorite, is present in small flakes and also a few grains of garnet. No thin section was made from this sample.

4. This rock is an extremely hard dense fine-grained dark-gray rock, with a band of almost white quartzite and feldspar along one edge. Several small bands (1 to 3 mm. wide) extend across the sample in almost parallel lines. Garnets are plentiful, scattered throughout the dark portions of the rock, but with none in the white quartzitic layers. The rock contains mostly quartz with an abundance of fine-grained biotite, plus some clear crystalline needle-like alteration mineral which is probably cummingtonite. Some plagioclase is also present, but it is small in amount.

4-A The petrographic examination of this thin section verifies the composition of the rock as determined from the megascopic examination. Quartz is the predominant mineral, with strain lamellae present in some of the grains. Some sericite intrudes the few orthoclase grains present. Biotite and almandite garnet is common. A length-slow fibrous aggregate in quartz, relief higher than quartz, with moderate to low birefringence, parallel extinction, and biaxially (?) positive, was identified as cummingtonite. A few grains of oligoclase are scattered through the sample, zircon and magnetite are the accessory minerals.

5. This is a dark (practically black) sample, very dense, and composed almost entirely of hornblende. Numerous small 1/8 inch ± pink garnets are scattered throughout the rock. An interstitial mineral, clear in color, and resembling gypsum in hardness and appearance, makes up about 20% of the rock. This mineral was found to be cummingtonite on thin section study. Some very small grains of quartz are also to be seen, but the total quartz is less than 5 percent. A band of big garnets (2 to 5 mm.) lay between this layer of the section and an adjacent layer of light-colored quartzite and feldspar.

5-A The thin section shows a hornblende-quartz-biotite schist, with hornblende predominating. Some oligoclase is present. The hornblende has many magnetite inclusions. Grain boundaries are fairly well defined in this sample. Accessory minerals are zircon and magnetite.

6. This sample is a grayish white, with some weathered plagioclase and some iron stains lending a faint yellow tinge to certain parts of the rock. Occasional laminations caused by flakes of biotite parallel to the foliation, cut across the rock. It is composed predominantly of feldspar, some of which is transparent and some of which is yellowish-white. Quartz is abundant and is in small grains. Grain size does not exceed 2 mm. for either the feldspar or quartz. A green mineral, apparently a blocky form of chlorite which breaks into tiny green flakes, forms two or three localized blebs in the rock. The biotite is the only other mineral identifiable in hand sample. There is no corresponding thin section for this sample.

7. This is a vari-colored specimen, which ranges from almost pure white in the quartz-feldspar bands, to a reddish yellow in the feldspar and biotite layers, and to black in the biotite seams. Garnets are large and numerous, and are scattered throughout the sample. Grain size is larger than in most of the other specimens, with some feldspar grains 5 mm. or more across. The plagioclase, which is the dominant mineral in the rock is mostly transparent, but on weathered surfaces it has the typically yellowish appearance. Constituent minerals are plagioclase, quartz, biotite, garnet, and what appears to be a pyroxene. The rock is but faintly striated, except for the pure biotite layers, which

form regular bands. No thin section was prepared from this rock.

8. Sample 8 could be confused with a pegmatitic granodiorite very easily. It is light gray, except for large blebs of an almost black pyroxene and some dark-green chlorite (?) agglomerations. Grain size is large for this section (3 to 5 mm.), and no banding or layering of the minerals can be observed. No preferred orientation of any grains is observable. The plagioclase content is very high (60 to 70%), and small interstitial quartz grains are numerous. The greenish-black pyroxene, plus some blebs of biotite, makes up the rest of the rock.

8-A A quartz-biotite schist, this thin section also contains a great deal of oligoclase. The biotite is partially altered to chlorite and penninite. Sericite is scattered along small fractures. Some diopside is present as eroded grains. Zircon and magnetite are accessorites.

9. This sample is very similar in color and composition to number 8, but the grain size is much smaller. Few grains are more than 1 mm. in diameter. The faintly gneissic appearance of the rock is due to a vague banding of the minute biotite flakes which abound throughout the sample. As in sample 8, the major constituent is plagioclase, but the quartz content is

higher, and the pyroxene inclusions not so numerous. Biotite is plentiful, but in very tiny flakes.

9-A Two thin sections were made from sample 9. The first contains much quartz and oligoclase. Biotite is abundant and occurs finely shredded and laminated. The orientation of the biotite shreds indicates a shearing action along the bands of biotite. The oligoclase shows no preferred orientation, which likewise is true of all the samples, but it is commonly distorted. Cummingtonite is included in many quartz grains, both as fibrous aggregates and as diamond-shaped crystals. Some sericite is observable. Apatite and magnetite are the accessory minerals.

9-B The quartz in this second thin section shows definite evidence of having been fractured after crystallization. As shown in Plate 5, tension fractures extend across the quartz grain boundaries without changes. Oligoclase is the predominant mineral in the section. Other minerals are hornblende, biotite, sericite, cummingtonite; the accessory minerals are magnetite and zircon. Mineral grains, especially the iron-rich minerals, show much corrosion at the grain edges.

10. An extremely dense, fine-grained rock, this sample is reddish to black on all but sawed surfaces, where it is nearly black. The biotite is very fine grained, and exhibits the same tendency to "flow around" the

quartz crystals that was noted before. A few phenocrysts of plagioclase and quartz are noticeable, but the ground mass is aphanitic. Constituent minerals are quartz, plagioclase, biotite, and what appears to be hornblende. Foliation is observable, but fracture is often across the bands, rather than along them.

10-A This sample is not complex, except that it exhibits the typical irregular grain outlines. Constituent minerals are quartz, oligoclase, sercite, biotite, and the accessory mineral zircon.

11. This sample has a very sharp line of demarcation between a pure quartzite band about 2 cm. wide, and a band of shredded biotite which contains some quartz crystals, and a few plagioclase crystals. These are the only minerals evident in hand sample. The quartzite layer is brownish-yellow in color, and the biotite band is a dark gray. The quartz crystals are larger than those in most of the samples (2 to 4 mm.), but the line of demarcation between the two bands of the sample is as sharp as though it was drawn by a knife.

Between sample 11 and sample 12 was a 40-ft., sand-filled gully, which may or may not be an eroded fault line. Samples taken from a partically cemented layer were yellowish and sandy and looked very much like a leached fault-breccia, although the grain size was uniformly small. The samples crumbled badly and no thin section of them could be made.

12. About in the middle of this specimen is a somewhat indefinite boundary line between a yellowish quartz and plagioclase band, and a very dark rusty-colored fine-grained biotite schist. The light portion is almost pegmatitic in texture, with some grains 5 to 7 mm. in diameter. There are also several inclusions of biotite and a greenish pyroxene in this section. The dark layer has a much finer texture. It has quite a few plagioclase phenocrysts and some small quartz crystals in it. The biotite is very finely shredded. Some pyroxene in fine grains is present. The line between the two bands is well garnetized with garnets up to 2 mm. in diameter.

13. Except for one band of quartz and plagioclase across the center of the rock, this sample could easily be called a granodiorite. It is a medium-grained grayish rock, with the quartz and plagioclase band showing a yellowish-white color. The sample is liberally flecked with biotite, and contains several larger aglomerations of a greenish pyroxene. Some localized garnet may be seen. Foliation is not discernible except for the one band of pure quartz-plagioclase.

14. This sample, rusty yellow and somewhat stratified, contains numerous small garnets, some of which are

rounded. It contains minute layers of quartzite interspersed with bands of what looks like pure rust. The rock shows evidence of having been subjected to leaching. Quartz and garnet are the only recognizable minerals.

14-A Unique among the sections studied, this sample contains but two minerals, quartz and almandite garnet. The two minerals are in definite, tightly-folded bands, with little mixing between the layers. Both are fractured into very small grains and show the result of shearing.

15. This final sample is black on fresh surfaces, rusty colored on older ones. At first glance the black mineral seems to be hornblende, but the lack of hornblende cleavage leads to the conclusion that it is an elongate pyroxene, probably hypersthene, although it may be anthophyllite. Quite a bit of interstitial quartz may be seen plus a few crystals of plagioclase. There is no preferred orientation of the elongate pyroxene. Some few tiny garnets are localized here and there.

15-A This corresponding section in hand sample looks very much like a pure hornblende. However, in thin section only a few tiny grains of hornblende are to be seen. The bulk of the rock is an elongate pyroxene identified as diopside. There is no preferred orientation to the crystals. Augite is abundant, as is also another pyroxene with a very low 2V, high relief, and high pleochroism. This mineral is almost certainly diopside. Some quartz is present interstitially, and there are a few fractured garnets.

OBSERVATIONS AND GENERAL CONCLUSIONS

From the mineral composition and mineral associations in this section, and from the intense fracturing and folding everywhere evidenced, one major conclusion and two minor conclusions may be reached.

First, the metamorphics are certainly of sedimentary origin. Second, they have been highly metamorphosed and have undergone at least some hydrothermal alteration. Lastly, they have been subjected to folding and/or faulting after the original recrystallization, and this last movement occurred probably at too shallow a depth for re-recrystallization. The age of these rocks is also almost certainly Pre-Cambrian.

Reasons for the belief that the rocks are of a sedimentary origin are many. Accessory minerals commonly exhibit a good bit of rounding, although this effect is often lost through the later fracturing. The sharp banding effect would indicate the layering of sedimentary deposition. Probably the most important evidence of an alteration of sedimentary rocks is the juxtaposition in the bands of mafic and utra-mafic minerals with highly felsic minerals. These relationships are so rare in igneous bodies as to make them noteworthy under any circumstances. The presence of an oligocene in contiguity with diopside and hypersthene is not very feasible for an igneous rock. However, it is entirely plausible that such an association could occur from the metamorphism of a silica-rich, iron-magnesium-calcium carbonate layer of sedimentary origin.

The quartzite bands with minor bands of biotite (a very common feature) could very easily be the end product of the metamorphism of a fairly pure sandstone with admixed layers of shale. The granodiorite-appearing bands, and some of the biotite quartzite schist layers, may be the result of the metamorphism of an arkose, a belief held by the writer.

The regional metamorphism undergone by this suite of rocks would not reasonably alter too much the constituent minerals of a magma, but would have a vast effect on a sedimentary series.

For these reasons, and investigations of similar sections by other writers bear this out, it is believed that this entire section of metamorphics is of sedimentary origin. According to Harker (3, p. 212-252), regional metamorphism will form all the minerals found in this section provided the proper constituents are available in the original rock. The aforementioned sandstones, arkoses, shales and carbonates have all the essential materials, even those necessary to the formation of an "almendine garnet zone" described by Harker (3, p. 218-224).

The assumption of at least some hydrothermal alteration is a more difficult premise to defend. The presence of radiating fibrous cummingtonite is a strong argument for hydrothermal activity, since some of the cummingtonite is in the original prismatic crystals. Also it shows a tendency to alter into hornblende at the ends of the aggregates, which according to Seager (2, p. 26) is a hydrothermal reaction. Another argument for hydrothermal alteration is the intense corrosion and pitting exhibited by almost all the grains. Most of the original grain boundaries are gone, and the embayments and niches in the grains do not resemble the tension fracturing so evident in some of the thin sections. More likely these pits are the result of solution and redeposition by hydrothermal solutions.

Much easier to demonstrate is the hypothesis that the rocks were subjected to post-metamorphic movement. The minute grains of quartz and mica in some specimens, and the intense fracturing and flowing of the garnets in others, indicates tensional or shearing fracture. This idea was discussed fully under the description of the thin sections. However, it should be reiterated that some fractures go directly across grain boundaries without discernible swerving.

The age of these metamorphics has been set as Pre-Cambrian by such men as Seager, Horberg, and Iddings and Weed (4). This age is determined by the extent of the metamorphism and by a tentative correlation with the Cherry Creek series elsewhere in Montana.

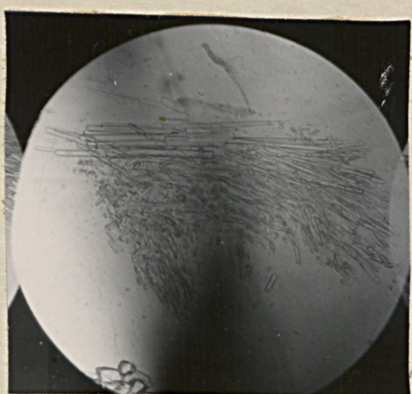
This section of metamorphics does not differ markedly from the metamorphics described by Dr. Seager in his work on the Jardine Mining District (2). The major differences seem to be the larger proportion of quartzites in this section, and the presence of a almandine garnet layer between other layers, which are apparently missing in the Jardine district. They are an interesting series and one of great age. The economic possibilities are nil in this small section, but in other areas, as at Jardine, igneous intrusions have formed valuable deposits. A small ilmenite deposit in a pegmatite dike in these same schists was discovered by the author on Cedar Creek, 4 miles southward, Otherwise no mineralization was discovered.

Plate 4.

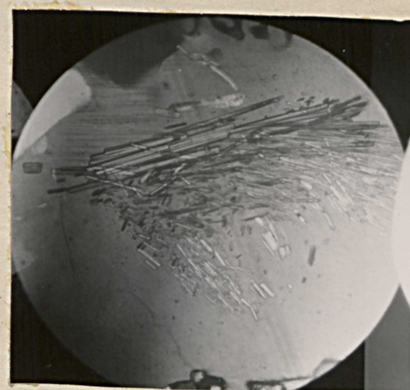
A.

B.

Quartz crystals, showing strain lamellae and sweeping extinction. Crossed nicols. X70.



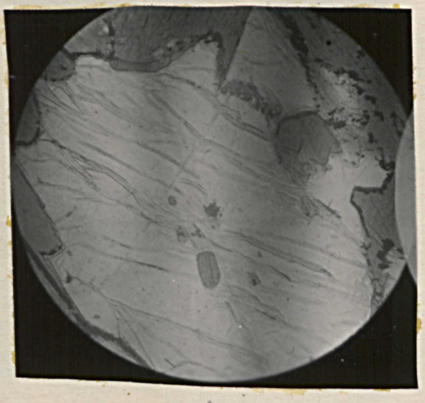
C.



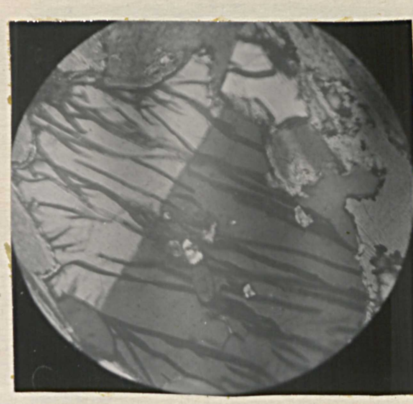
D.

Cummingtonite, showing fibrous structure. C. plane light. D. crossed nicols. X70.

Photomicrographs of Thin-Sections

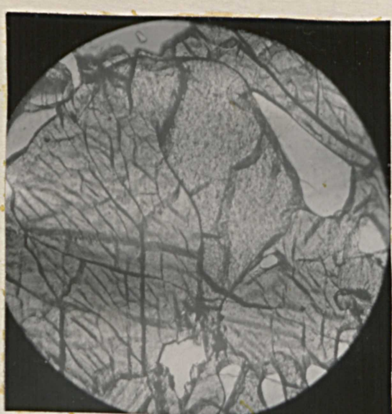


A.

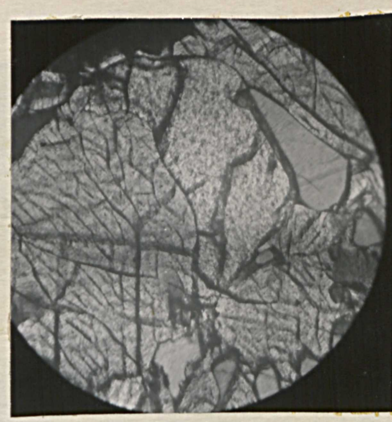


B.

Quartz, showing tension fractures across grain boundaries. A. plane light. B. crossed nicols. X70.



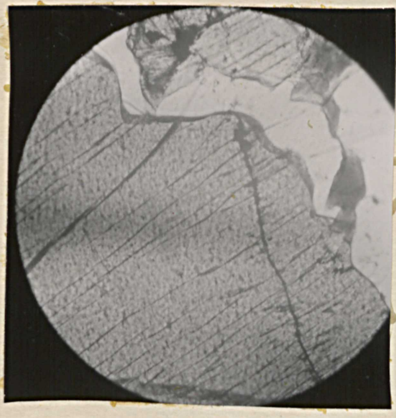
C.



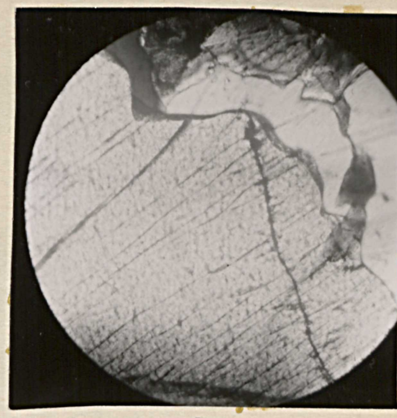
D.

Augite, typical curving fracture, and Diopside, pitted surface. C. plane light. D. crossed nicols. X70.

Photomicrographs of Thin-Sections

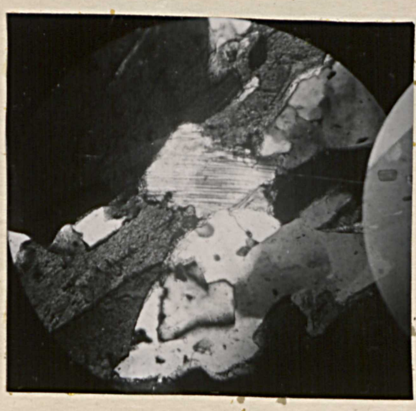


A.

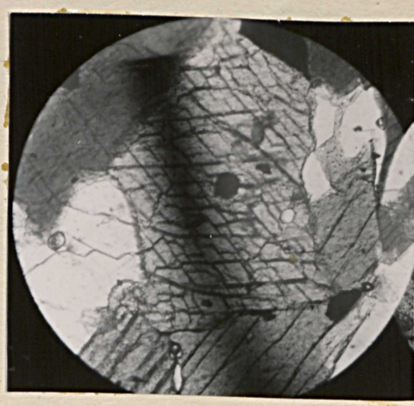


B.

Typical Hypersthene, showing the long, curving cleavage and the high relief. The clear material is quartz. A. plane light. B. crossed nicols. X70.



C.



D.

C. Shows a grain of oligocene with bent and distorted twinning. Crossed nicols. X70.
D. A grain of hornblende, showing typical cleavage and an inclusion of magnetite (black). Light material is quartz. Crossed nicols. X70.

Photomicrographs of Thin-Sections

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