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Mayflower, Renova Basin, and South Boulder Creek Areas

Howard Nickelson

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GEOLOGY REPORT

for

GEOLOGY 63

MAYFLOWER, RENOVA BONE BASIN, AND SOUTH BOULDER CREEK AREAS

SEPTEMBER 1947

PARTY
Robert L. Pott
Frank Reynolds
V. A. Stermitz
Howard Nickelson

BY

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TABLE OF CONTENTS

PLATES AND MAPS

INTRODUCTION

In Montana at the turn of the century a great many men sought the riches buried in the earth's crust. Prospectors fanning out from Butte and other early Montana mining areas located veins at the Mayflower, Renova, and Gold Hill areas. Moneyed men like Clark, one of the Copper Kings, developed the Mayflower Mine and other good prospects, but the prospector continued his search for other veins. Remains of his hard work are scattered over the hillsides in the form of pits, adits, and caved shafts.

Not only is this area interesting as a historical chapter in Montana, but it offers interesting and unique problems for the geologist. These interesting features consist of a complete geological section, thrust faults, other types of faults, folding, effects of erosion, and economic possibilities. Since this region is an ideal spot for the study of geology, Dr. Perry selected it for study by the Senior Geologist and Mining Engineering students of the Montana School of Mines.

The purpose of this report is to fulfill one of the requirements in the curricula of Mining and Geologic Engineering at the Montana School of Mines. It also serves to acquaint students with the methods of mapping and interpreting field structures in order that a better correlation may be drawn between theory and practice.

The field work which is the basis for this report began September 2, 1947, and continued for two weeks. About 27 students made the trip along with Dr. E. S. Perry, Head, Geology

Department, M. S. M., Mr. Alvin Hanson, and Dr. George Kiersch, professors of Geology, M. S. M., and Mr. Uuno Sahinen, who helped us at the Renova Bone Basin area. The group was broken down into parties consisting of six crews of four men and one crew of three men. Two crews under one instructor mapped the same area, but all the crews tied in with one another so a complete map of the area was made possible.

The mapping was done by telescopic alidade, plane table, stadia rod, Brunton compass, and pacing. Several crews used open sight alidade, plane table and calibrated automobile speedometer for surveying roads and accessible areas with an automobile. Whenever possible section corner tie-ins were made for the purpose of checking on the section grid. The mapping scale used on all maps made was one inch equal to 1000 feet.

The writer wishes to thank Dr. Perry, Dr. Kiersch, and Mr. Hanson for their help in instructing us on mapping procedure and their willing interpretations of our many problems.

Geography

Location and Accessibility

The areas we visited and mapped are located a few miles south and east of Whitehall, Madison County, in southwestern Montana. The town of Whitehall is readily accessible; Highway No. 10 passes through it and it boasts two railroads. I will list the areas we visited and describe the conditions of the roads to each.

The Mayflower Area is about 10 miles south and east of Whitehall. A good graveled road goes to the mine. From the

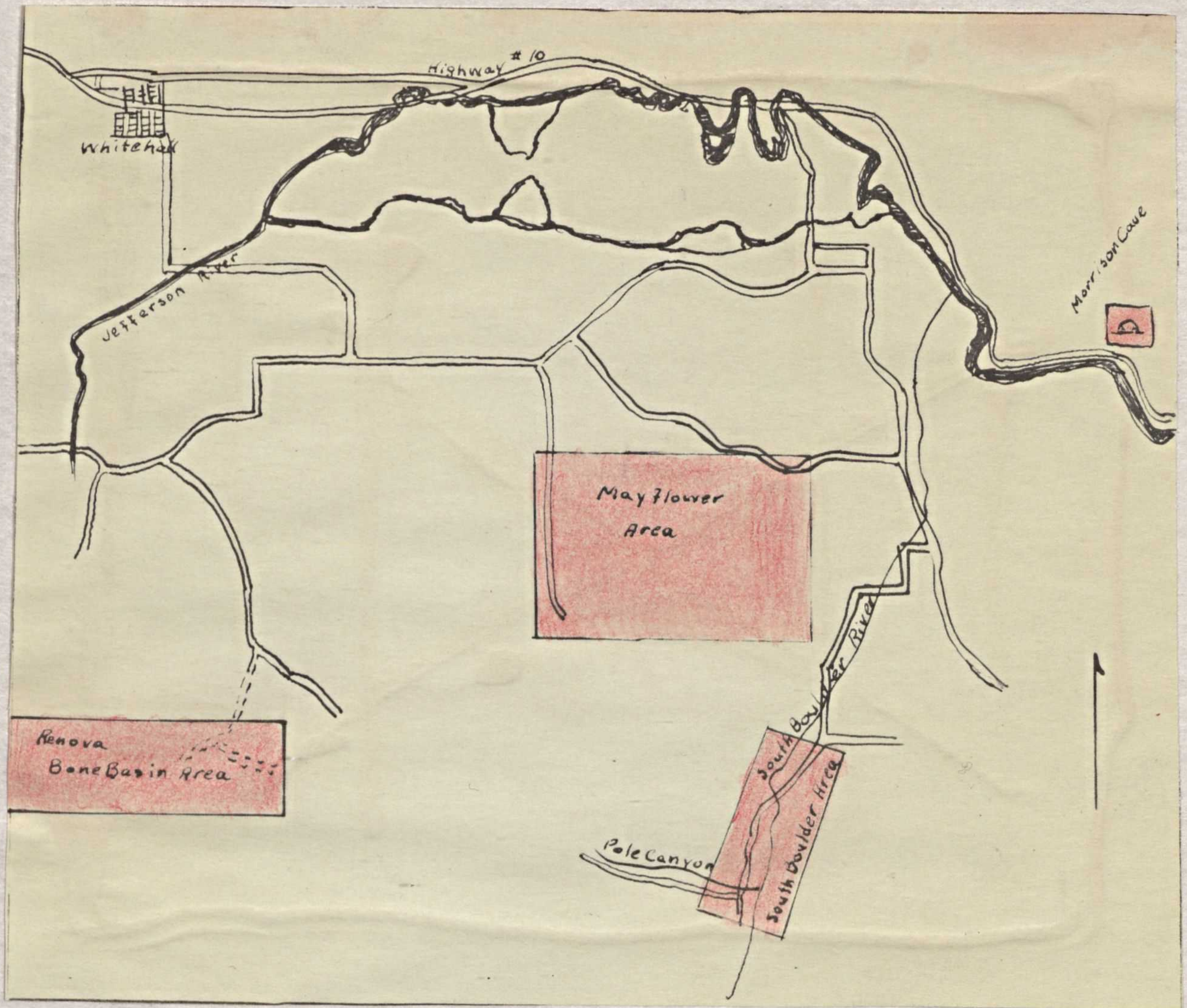

Plate No. 1. Sketch of the roads and general areas mapped by Senior Geologist and Mining Engineers, 1947.

mine eastward only trails exist, but the terrain is not too rough so trucks and jeeps were able to travel over most of the area.

The Renova Bone Basin area is located 10 miles south of Whitehall. The roads to the foothills are good, but the rest of the way they are just passable for a sedan. Jeeps and pick-ups were able to get to the Florence Mine and travel a short distance beyond across the hills.

The South Boulder Canyon dirt road is good but narrow and crooked. This road leads south and west for 18 miles from Whitehall by way of Jefferson Island. It follows up a U-shaped canyon in which we walked over the complete geologic section.

Jefferson Canyon and Morrison Caves may be reached by Highway 10. Jefferson Canyon is 8 to 10 miles east of Whitehall. After continuing on this highway a few miles east of Lahood Park, a good graveled road to the left leads to Morrison Caves.

There are many roads of all kinds and conditions in this region, and almost any area can be reached within a mile by automobile. The better roads are accessible the year around; the poorer ones are not accessible in the winter.

The following sections were mapped by our crew: Mayflower Area - N½ Sec. 32, N½ Sec. 33, SE¼ Sec. 28, Sec. 27 in T.1 N., R.3 W. Renova Bone Basin Area - Sec. 9, Sec. 8 in T.1 S., R.4 W. South Boulder Area - north central part of T.1 S., R.3 W.

Physical Features

The area mapped was in the foothills of the Tobacco Root Range consisting of many intermountain basins and ranges. The

Jefferson River flows through a rich farming valley with hills and mountains on both sides. Many dry creek beds come down off the hills on either side, but the North and South Boulder creeks flow into the Jefferson River east of Whitehall. All the drainage in the area leads to the Jefferson, which flows into the Missouri at Three Forks, Montana. The hills that border high mountain ranges are typical of this part of Montana. In this area we traveled south over rather flat, gently sloping valley floors to the hills that grade into the steep mountains.

In the Mayflower and Bone Basin areas the hills run generally east and west with valleys between the hills. The north sides of the hills are generally dip slope, while the south sides cut across the formations. A few springs are in the area and a small stream cuts across the formations at the Mayflower Mine but it loses itself down on the flat. These east-west valleys or depressions follow the weaker, easily eroded beds that generally strike in the same direction. Bozeman Lake beds form a horseshoe enclosure around the Mayflower and Renova districts.

The Bone Basin area is a basin, as the name suggests, with the top of the hills to the south capped by the hard resistant Cambrian formations. The gullies have eroded down into the softer Belt arkoses. This basin runs about east and west; then an intermittent stream cuts north through the hills toward the Jefferson River.

In the South Boulder region glaciation has carved a U-shaped valley across the strikes of the geologic section, leaving them outcropped along both valley walls.

Climate and Vegetation

The elevation of the area we mapped varies from 5000 to 6000 feet. The climate of the region is semi-arid with a rainfall averaging 10 to 15 inches per year. The summers are warm with cool nights due to the proximity of the mountains; the winters are typical of Montana.

The Jefferson Valley south and west of Whitehall has excellent farms and cattle ranches. The south sides of the hills are quite barren with only juniper trees, sage brush, and some types of hardy bunch grass upon them. The north sides of the hills are grass and brush covered and have fir and pine trees growing higher up in the mountainous area. In general no trouble was encountered with thick timber and brush in our mapped areas.

The hills are pretty well inhabited by rattlesnakes. We were given warning to watch where we stepped because snakes are rather dangerous this time of year.

GEOLOGIC COLUMN OF SO. BOULDER CR., MONTANA SECTION

M.S.M. Geological Survey — Scale: 1"= 600' — September 1947

ERA	PER	FORMATION	SYMBOL	THICKNESS	LITHOLOGY
MESOZOIC	U. CRETACEOUS	LIVINGSTON	Klv	3000ft.	Four general divisions of agglomerates and lavas--- andesitic in character grading through basalt and latite.
		COLORADO	Kc	260ft.	Greasy green shale with sandstone base.
	L. CRET.	KOOTENAI	Kk	800ft.	Formation rests on basal sandstone of white quartz and black chert. Next is predominantly red shale and gastropod limestone.
	JURASS.	MORRISON	Jm	190ft.	Basal sandstone through variagated shales.
		ELLIS	Je	170ft.	Shale, sandstone and limestone. Star crinoids.
PALEOZOIC	PERMIAN	PHOSPHORIA	Pp	110ft.	Ss and Sh. Oolitic material bleaches to gray.
	PENN.	QUADRANT	Pq	240ft.	Peach-colored vitreous cliff and ridge-former.
	MISSISSIPPIAN	AMSDEN	Pa	230ft.	Shales, sandstones and limestones. Rests on base of red shale which is indicative.
		MADISON: MISSION CANYON	Mmc	1440ft.	White massive crystalline limestone. Index fossil is horn coral; also find crinoids in this mountain-making bed.
		MADISON: LODGE-POLE	Mlp	840ft.	Dense, fine-grained black limestone. Shaly partings between beds. Cliff-forming.
	DEVONIAN	THREE FORKS	Dtf	360ft.	Gray-greenish sandy and limey beds containing innumerable brachiopods. Forms depressions and valleys.
		JEFFERSON	Dj	1100ft.	Lower portion has gray, muddy appearance. Upper is black sugary dolomite emitting fetid odor from clean exposures. Forms ridges.
	CAMBRIAN	DRY CREEK	Єd	100ft.	Red-brown shale to beige sandstone. Valleys.
		PILGRAM	Єp	310ft.	Lower division is mottled in tones of black and rust; upper in gray and black. Blocky.
		PARK	Єpk	190ft.	Paper-like argillaceous shale, green in color.
		MEAGHER	Єm	350ft.	Black and rust mottle to a hard, fine-grained dolomitic limestone. Contains oolitic bands with trilobites near top of formation.
		WOLSEY	Єw	320ft.	Argillaceous, micaceous shale with characteristic worm-like markings. Brownish-green.
		FLATHEAD	Єf	100ft.	Crossbedded, coarse-grained pink quartzite.
ARCHEO.		PONY	Ar	5000ft.	Schists and gneisses with bands of biotite.

Plate No. 2

STRATIGRAPHY

The rocks in the area will be described as they appear in the South Boulder Section. In this section the whole stratigraphic column of Montana appears in perfect chronological order except for a few formations that were not deposited or had been eroded away before the deposition of the succeeding beds.

An accompanying map clearly shows the exact character and structure of the beds. A geologic column was constructed for the South Boulder Section giving the usual pertinent data in successive order.

ARCHEOZOIC ERA

Pony and Cherry Creek Series

The Archeozoic Age consists of the Pony and Cherry Creek series. These are the oldest exposed rocks in this region. We did not see the Cherry Creek formations in our area, but farther south they are exposed. Part of the Pony formation, consisting of dark hornblende gneisses, was observed underlying the Flathead formation up the South Boulder Creek area.

The Pony series are described by Tansley and Schafer as follows:

"These rocks are light-gray quartz-feldspar gneisses with subordinate hornblende and mica; hornblende gneisses with minor amounts of feldspar and quartz; black amphibolite schists composed almost entirely of hornblende; white quartz feldspar gneiss having the appearance of metamorphosed pegmatite; several narrow bands of dark hornblenic-garnet schist, and a few thin bands of mica schist. The reddish brown, gray and light gray gneisses of granitic composition are the most abundant.

"This gneiss and schist complex is literally criss-crossed by igneous injections of both pre-Cambrian and later age. Rocks which have the appearance of metamorphosed granites associated with pegmatites and quartz veins are numerous. Basic gneisses of medium to coarsely crystalline hornblende appear to have been originally sills and dikes of basalt or amphibolite. Many dark sills and dikes contain small lenses of feldspar oriented parallel to the prevailing schistose and gneissic structure. These are pre-Cambrian intrusives, but unlike the other gneisses and schists of igneous origin, they are probably post-Cherry Creek, since many of them cut both Pony and Cherry Creek Series."

The Cherry Creek series are sedimentary in origin but are highly metamorphosed and intruded by igneous rocks. They probably lie above the Pony Series and consist of marbles, quartzites, etc., that contain mineral deposits of economic value.

PROTEROZOIC ERA

Belt Series

The Belt series are not exposed on the South Boulder section, but a few miles west in the Mayflower region and the Renova region the arkoses are exposed. In the Jefferson Canyon the conglomerates, arkoses, and shales are exposed. Apparently the Belt arkoses are not exposed in the South Boulder region because it was the land mass in which the arkoses and conglomerates were derived.

The Belt formation we mapped in the Mayflower area consists of medium- to coarse-grained arkosic sandstones, whose color was dark green to grey on fresh surfaces and weathered to a dark brown with white spots of feldspar throughout the rock. These were the oldest rocks mapped by our group.

The Belt formation underlying the Flathead formation in the Renova area was finer grained material which consisted of some shales and fine-grained arkosic sandstones that graded into the coarser arkosic sandstone found in the Mayflower area.

In the Jefferson Canyon going west along Highway 10 we traced the Belt formation from a very coarse grey to green conglomerate with boulders as large or larger than a water bucket, grading down to pebbles, many of them quite angular. The conglomerate graded into a coarse arkosic sandstone of the same appearance found in the Mayflower and Renova areas, and this in turn graded into grey to silver grey and red shales. The thickness of the formation is approximately a mile.

The Belt formation in this area was probably derived from the older Pony and Cherry Creek formations that were land masses composed of igneous, metamorphic, and sedimentary rocks in the Ennis area. The formation was laid down in a lense-shaped delta deposit.

PALEOZOIC ERA

Cambrian Period

Flathead Quartzite

Deposited during the middle Cambrian period, the Flathead quartzite is the basal member of the Paleozoic series and consists of fine- to medium-grained quartzite, flesh to light brown in color, which is hard and resistant to weathering in this region. No Lower Cambrian rocks are present in this area. Cross bedding is common with beds six inches to one foot in thickness. The Flathead quartzite is often confused with Quadrant quartzite but can be readily distinguished in the field by the sequence of the other beds, and is easily found because it forms ridges and ledges that can be seen for great distances. The 100-foot bed of quartzite has coarser grained material at the base and lies unconformably with the older beds.

Wolsey Shale

Directly overlying the Flathead quartzite is 320 feet of Wolsey shale, which usually occurs in a depression or gully next to the Flathead. At the base is a sandy bed that grades into a green argillaceous, micaceous shale. The upper portion has limy beds present and erodes easily so good specimens are hard to find. When they are found, numerous worm tracks are present that look like tree twigs. Grass and brush are usually present on this bed. Small green flakes of shale may be found in gopher and mole mounds. Wolsey shale favors ore deposition, as some of the richest gold at the Mayflower was found in this bed, and the Florence mine is also located in it. The name Wolsey was derived from a creek.

Meagher Limestone

Directly above the Wolsey Shale lies the Meagher limestone, about 350 feet thick. This bed of hard, dolomitic limestone contains from five to fifteen percent magnesium. Because of the mottled dark grey and buff color the limestone was given the name of "Montana black and gold marble" and was quarried for a time by some Vermont people. Mottling is prevalent throughout most of the bed. The upper ten or twenty feet carry trilobites, due to shallow water conditions at the time of deposition. The top also contains bands of edgewise conglomerate. The bed usually occurs as cliffs, ledges, or ridges, due to its resistance to weathering. The formation was named after a governor of Montana and Meagher County.

Park Shale

The Park shale, about 190 feet thick, lies on the top of the Meagher limestone. It is a great deal like the Wolsey shale and may be confused with it except for the limestone, shale, and limestone sequence. The Park is a green, fissile, argillaceous and micaceous shale that lies in gullies or depressions or may be covered and protected by the blocky talus of the Pilgrim dolomite.

Pilgrim Dolomite

The Pilgrim dolomite is about 310 feet thick. At the base lies 30 feet of dolomite that resembles the Meagher limestone because it has the same black and gold mottlings. The upper portion is a two-toned grey and is sometimes called the zebra limestone. The talus is composed of large blocks that break off the hard resistant beds. This formation forms cliffs and ridges and is therefore conspicuous in the field.

Dry Creek Shale and Sandstone

The Dry Creek shale and sandstone is the last formation in the Cambrian series in this area, and lies upon the Pilgrim dolomite. It varies in composition from a sandstone to a sandy shale and in some places a shale, weathers down easily, and is recognized by its reddish brown, sandy chips in the rubble. It varies in thickness from 30 to 100 feet. Outcrops are usually uncommon, with the formation occurring instead as terraces.

East of the Mayflower Mine this bed occurs as a hard quartzite about 30 feet thick that juts from the ground for a distance of three-quarters of a mile around the side of the hill. In the South Boulder area the beds in this formation are well exposed.

Devonian Period

Jefferson Limestone

The Jefferson limestone is the basal member of the Devonian, so somewhere between the top of the Dry Creek and the base of the Jefferson is a time lapse of approximately thirty million years. This part of the story (the Ordovician and Silurian periods) is missing in this section either through non-deposition or erosion.

The Jefferson, total thickness of which is about 1100 feet, consists of two members--the lower member a massive, muddy grey dolomitic limestone about 300 feet thick and the upper member a black crystalline dolomite that has a fetid odor when freshly broken. In some local areas drussy quartz geodes are found. Due to its resistant beds and great thickness, the Jefferson forms conspicuous ridges in this area.

Three Forks Shale

Lying on the top of the Jefferson limestone is the Three Forks shale, which consists of about 360 feet of grey green shale. Included within the shale beds are sandy beds one inch or so in thickness; thin beds of limestone are also present. This formation is usually found in depressions, valleys, and creeks, due to its soft, easily weathered nature. Outcrops are uncommon.

Mississippian Period

Lodge Pole Limestone

The Lodge Pole limestone is the basal member of the Mississippian. At the base is a thin bed of sandstone that grades into a limy shale and rests on the Three Forks formation. On the top of this thin bed lies 840 feet of quite pure Lodge Pole limestone, which is blue-grey in color and looks very much like basalt. Many fossils are present which help to distinguish it readily--namely, Bryozoans, Crinoids, Brachiopods, and Corals.

Mission Canyon

A stratigraphic break between the Mission Canyon and the Lodge Pole is very difficult to determine. A change in rock character is not present, but by detailed study of the fossil content the change can be determined. We were shown this break in our trip over the section in the South Boulder area. It lies in a small valley and is marked on the map of that section.

The Lodge Pole limestone is very pure white, crystalline, massive limestone 1440 feet thick in this area. Horn corals, crinoids and other fossils are well preserved in this formation and can be found in abundance. The upper portion of the formation contains chert in the form of nodules which helps to locate this portion of the Mission Canyon.

The Lodge Pole and Mission Canyon formations are referred to as the Madison Group, due to the difficulty in determining the break between the two members, and this is a logical and well-used way of naming this great bed of mountain building limestone.

Amsden Formation

The Amsden Formation consists of two distinct beds in two periods--the lower portion, 10 to 20 feet of red shale and sandstones in the Mississippian period, and the upper 200 feet, slabby beds of limestone in the Pennsylvanian period. The upper section contains some hard beds about 10 to 15 feet thick that resist weathering and stand out as minor ledges, but in general the whole bed occupies depressions and is usually covered with grass and brush.

The geological societies of America have accepted the lower red beds as Mississippian and the top limestone beds as Pennsylvanian as established by stratigraphers. In the field the red beds are sometimes difficult to find, but close examination of gopher and mole holes and the pinkish tint to the soil will give the clue to the top of the Madison Group.

Quadrant Quartzite

The Quadrant quartzite is the last formation in the Pennsylvanian period. It is composed of a hard vitreous quartzite, white, pink, to yellow in color, which is almost impossible to distinguish from the Flathead quartzite in the hand specimen. The bed is 240 feet thick and forms outstanding ridges in the area it occupies. In the north east and east central part of the state it is a sandstone, called the Tensleep, in which are located several important producing oil fields.

Permian Period

Phosphoria Formation

The Phosphoria formation is the only formation in this area in the Permian period. It is about 110 feet thick in the location studied, but in western Montana it increases to about 600 feet. At the base is a band of black to dark brown chert that is easily recognized by the chert fragments in the rubble. Above this bed is a bed of black or brown fissile oil shale, known as Kerogen shale, which will yield 10 to 15 gallons of oil by destructive distillation. Above these oil shales lies a band of oolitic phosphate rock that bleaches white when exposed to the weather; these fragments help to identify the formation in the field. The oolitic phosphate-bearing bed is only a foot or so thick in this area and of no commercial importance, but at Garrison, Divide, and several other localities the phosphate bed is economically important. The upper portion of the formation is composed of beds of dark-colored shales and sandy shales. The formation occupies rather flat areas but it is easily recognized by the black chert pebbles and white oolitic phosphate fragments.

MESOZOIC ERA

Jurassic Period

Ellis Formation

The Ellis formation consists of 170 feet of interbedded limestones and shales. At the base of the formation there is six to eight inches of yellow chert that lies on an unconformity. The limestones have a dark grey sandy appearance, and on a weathered surface the index fossils of star crinoids and Pelecypod shells may be found. The Triassic sediments are missing in this area.

Morrison Formation

At the base of the Morrison formation, which is usually located in depressions, is a rusty looking sandstone that grades into a variegated shale to make up the 190 feet of the formation. The shales vary in color through yellows, reds, browns, greens and greys. The Morrison was deposited as a land formation and is noted for its dinosaur bones and land animal fossils.

Cretaceous Period

Kootenai Formation

The basal member of the Kootenai is a sandstone about 75 feet thick composed of medium-grained sand of white quartz and black grains of chert--thus its name "the salt and pepper sandstone". This bed of sandstone is the best oil producer in

Montana. Above it lie beds of brilliant red shales which in turn are overlain by fresh water limestone beds which abound with gastropod fossils. Interbedded between the limestone beds are soft shales. A small seam of coal is present in this area but is of no economic importance.

Colorado Formation

The Colorado formation is about 60 feet thick in the South Boulder area while in other parts of the state it is over 2000 feet thick. The base consists of a dirty dark-colored sandstone that grades into a black greasy shale. The greater part of this formation has been eroded away and then covered with the Livingston Volcanics.

Livingston Volcanics

The Livingston formation consists of 2000 to 5000 feet of volcanic material which lies almost parallel with the older beds and occurred before the mountain building period. These volcanic materials were ejected during the upper Cretaceous time and early part of the Laramide Orogeny. They lie upon a disconformity. The formation consists of a series of agglomerates and andesite and basalt lava flows in the lower section; the upper section consists chiefly of andesite and some basalt lava flows. The basalts are very vesicular with the resulting formation of muralitic cavities containing calcite and zeolites. The andesites are porphyritic and make up the greater part of the agglomerate. The white phenocrysts of feldspars give these andesites a speckled appearance for which they have been nicknamed "oatmeal rock".

CENOZOIC ERA

Tertiary Period

Bozeman Formation

In the valleys up to the edge of the foothills lie the Bozeman lake beds, a formation quite common in the valleys of this part of Montana. They consist of loosely consolidated chalky-colored lake deposited material, sandy with some clays intermixed. These deposits make excellent farming lands, and the important farms around Whitehall and the Gallatin Valley are located in them. Some evidence of Pleistocene glaciation remains in the South Boulder region.

GEOLOGICAL HISTORY OF THE AREA

During Pre-Cambrian time the Pony series of gneisses and schists had the Cherry Creek series of sedimentary rocks laid upon them, probably in the same manner as the Cambrian and later rocks were deposited, i.e., by the submergence and emergence of the land masses. These old formations went through a period of crustal movements, igneous intrusions, and metamorphic conditions before the Cambrian seas invaded this area. With later orogeny and igneous activity these rocks are now highly folded and intruded by igneous bodies, making them complex and of economic importance. During and after this period of uplift and mountain building a period of erosion took place during the time of the Belt. The sea was to the west, as shown by the thick sediments of the Belt series in the Deerlodge National Forest area. The Whitehall area was the shore line, which accounts for the thick beds of arkoses and conglomerates we found with our mapping and examination of these Pre-Cambrian sediments. The mountains must have been steep and high to account for the tremendous thickness and character of this formation. The Belt formation indicates deltaic or huge alluvial fan conditions deriving their material from the steep land masses which lie to the east.

During the early Cambrian, the area we mapped was still land, but seas were gradually working their way toward it from the south and from the north in the great Cordilleran syncline. By the middle Cambrian the sea was in this area. We have the evidence of this left in the form of the Flathead quartzite, which was laid down on a level land mass. As the sea became deeper, the Wolsey shale and then the Meagher limestones were deposited. Animal life was present during the time of deposition of the Wolsey and the Meagher. Worms in the Wolsey and trilobites in the Meagher are common. During the late Meagher, a slight uplift must have taken place to deposit the Park shale. Again the sea became clear, and the Pilgrim limestones and dolomites were deposited. The Dry Creek shale marks the beginning of another great uplift of the land masses which took place during Ordovician and Silurian time. In Boulder Creek and most of Montana no Ordovician or Silurian is present. Therefore no sediments were laid down, or if any were deposited they were eroded away.

This period must have been extremely quiet because in the Devonian the seas again invaded the land and deposited the Jefferson limestone upon and parallel to the Dry Creek formation. All during the early and middle Devonian period a sea that favored limestone deposition was present, leaving about 1100 feet of limestones. During the late Devonian period emergence again took place, causing the deposition of 360 feet of Three Forks shale. This ends the Devonian period.

During the Mississippian Period the land submerged and great beds of limestone were laid down. Animal life was abundant during this period. In all, more than 2000 feet of Madison limestone leaves its record in this area. At the end of the Mississippian period, uplift again took place, leaving a red shale resting upon the Madison limestone.

The early Pennsylvanian period was a period of limestone deposition, which accounts for the remaining Amsden limestones.

During the middle and end of the Pennsylvanian period uplift took place; the resulting deposit was a great bed of sands which later formed the 240-foot bed of Quadrant quartzite.

Beginning the Permian period a very peculiar condition existed in which were deposited the cherts, Kerogen shales, phosphate beds and shales of the Phosphoria formation. The area we mapped must have been close to the eastern edge of this peculiar depositional condition, because the Phosphoria formation west of this area is thicker and the phosphate beds are of economic importance. The Phosphoria formation is the last formation in the Paleozoic Era.

During the early Triassic period of the Mesozoic Era, the seas moved westward into Idaho, leaving land in this area. In some places in Montana erosion cut down into the Madison limestone leaving a Karst topography. Erosion does not seem to have removed a great deal in this area. No Triassic beds are present here.

Beginning in the middle of the Jurassic period, a sea from the north spread over most of Montana leaving sandstones, shales and limestones as the Ellis formation. During the late Jurassic the sea retreated and the great land deposits of sandstone conglomerates and shales of many colors which make up the Morrison formation were left as evidence. The Morrison formation is famous for its fossils of dinosaur bones, land animals and plants. This formation ended the Jurassic period.

In the early Cretaceous period the seas to the north and the south were spreading toward this area. By the end of the early Cretaceous they were connected and the basal Kootenai salt and pepper sandstone was deposited. Shales were later laid down and the sea began to retreat to the south, leaving many fresh water lakes in which were deposited limestones with many fresh water fossils--gastropods, snails, etc. Shales and coal beds were also deposited in the swampy conditions during this time of retreating sea.

These great thicknesses of sedimentary beds caused unrest in the deeper portions of the earth; the result was many volcanoes and lava ejections, making the great deposits of andesites, basalts and agglomerates of the Livingston formation. These lava beds were laid down on the flat but eroded Kootenai beds. This was the beginning of the Laramide Orogeny. During the later part of the lava flows folding, igneous intrusions, and faulting, which accompanies mountain building, were making the Rocky Mountains. The Mayflower fault and other great thrust faults occurred during this time. A great period of erosion followed this period of mountain building, then renewed upthrusting to leave the mountains as we see them today. Glaciation carved the mountains down, and when the glaciers melted lakes were formed in the mountainous area, leaving rich alluvial farm lands in the valleys. The Bozeman lake beds are examples. The present time is a period of quiescence and erosion.

GEOLOGICAL EXPLANATION OF THE AREAS

Mayflower Area

Faults

The first day Dr. Perry took us to the Mayflower Mine and started the crews mapping from the mine eastward. We noticed the lavas of the Livingston formation next to the Cambrian formations, which suggested a huge fault.

As we mapped, we could follow the fault for a mile or so in a north-east direction without much difficulty, but in the NE$\frac{1}{4}$ of Sec. 33 we lost the indications of the main fault but found three other faults all lying parallel to the Mayflower fault. In SW$\frac{1}{4}$ of Sec. 27 the three faults intersect a north-south fault and continue in that direction as far as we mapped, as shown on the Mayflower map.

In the Renova Bone Basin area the Mayflower fault was again found striking in a north-east south-west direction.

The Mayflower fault is a high angle thrust fault that dips approximately 70° to the northwest. It must have served as a channel way for the mineralizing solutions that made the ore deposits at the Mayflower Mine.

Minor Faults

Quite a number of minor faults occur normal to the Mayflower fault as seen on the map of the area.

A few hundred feet west of the Mayflower Mine a small fault, probably of a hinge type and probably due to the drag of the Mayflower fault, causes the Cambrian bed to dip in the opposite direction of the adjacent Cambrian beds.

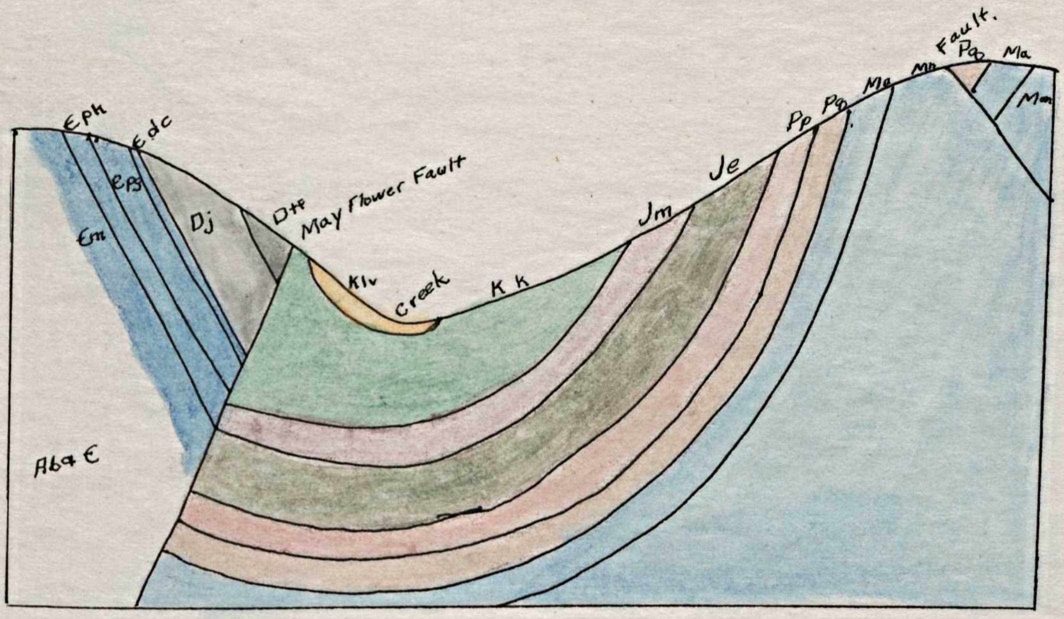

Plate No. 3. Cross sectional diagram of Mayflower Area as marked AB on the Mayflower Area Geologic Map.

A series of echelon faults occurs along the Cambrian strata. The same general type of faults occurs in the Renova Bone Basin area when the hard resistant beds bend or try to fold, and break instead.

Several other normal faults occur, as shown on the map of the area.

Folding

On the north side of the Mayflower fault the Paleozoic beds dip from 65° to about 50° to the south-east and toward the Mayflower fault. On the south side of the fault the beds dip north-west and toward the Mayflower fault. These Paleozoic and Mesozoic formations form the limb of a syncline that has been cut by the Mayflower high angle thrust fault. As seen on the map, these formations swing sharply to the north in Section 27, and the resulting syncline plunges to the southwest.

The cross section across the line AB should help make the above explanation clearer.

General Explanation

The outcrops on almost all the beds were fairly easily determined except as marked by dotted lines between the formations. These areas were pretty well covered with over burden and no sharp line could be drawn.

The Mayflower ore deposits are located in the Wolsey shale and Meagher limestone.

East of the Mayflower Mine where the Meagher limestone comes in contact with the Mayflower fault it is in contact with the Dry Creek formation. Apparently a fault traverses along the strike of these beds and eliminates the Park shale and Pilgrim limestone. It is not marked on the map in this manner.

Renova Bone Basin Area

Faults

Three major systems of faults occur in this area.

The Mayflower fault continues from the Mayflower Mine, and in Section 10 we find Livingston against the Belt formations, as we found in the Mayflower Mine area. The fault continues up through the Belt into the Cambrian formations and apparently at this area the displacement greatly diminishes.

A big fault in South ½ of Section 10 brings the Cambrian formation to the surface against upper Paleozoic and Mesozoic formations.

A system of echelon faults occurs in the Cambrian and Belt sediments, possibly due to the hard beds breaking instead of bending when this area was folded or possibly related to the forces that formed the Mayflower fault.

Folds

The Cambrian beds bend in Sections 9, 8, and 5. The beds do not show any folds but have been faulted in this shape.

The Livingston formation in this area lies upon an angular unconformity formed by the beds of the syncline mentioned in the Mayflower area.

General Explanation

In section 10 the Livingston formation extends south along the fault to the Quadrant formation.

In Sections 8 and 5 the Meagher formation covers the west side of the steep hill as dip slope down to the flat land adjacent to the Jefferson River.

Florence Mine

On arriving at the Florence Mine I met Mr. Mike Dulula, a neighbor of mine from near Livingston, who was operating the mine. He had driven a 40°, 120-foot winze into the Wolsey shale at a point 100 feet east of the old workings and then leveled off and turned to the west toward the vein. He was having trouble drilling by hand because he had driven the winze at a steeper angle than the dip of the Wolsey shale and had cut into the hard Flathead quartzite. I figured he had about 30 to 50 feet to crosscut before he intersected the vein below the old workings. He claimed manganese, lead and silver were in the vein, which is questionable. The upper workings showed black manganese.

South Boulder Creek Area

The complete geologic section was plotted on a print issued to us and is included in this report. All the points were either paced or located by points on the map. Dips were taken at frequent intervals. The reason for plotting the beds on the print was to familiarize us with the same formation we mapped later.

The older beds all dip about 45° and gradually flatten so the Colorado and Livingston dip about 30°.

One small normal bedding fault was encountered, which caused the repetition of the Pilgrim dolomite and the Dry Creek shale.

Cambrian Island

North of the east end of the Mayflower area we spent the morning of the last day in the field mapping a small island of Cambrian formations surrounded by Bozeman lake beds. These formations occur as a small hill and probably represent the limb of a small eroded anticline.

A discussion ensued between our party and our associate party on the point of whether the Meagher limestone continued south to the Lake beds, or whether this region was Park shale and part of the Pilgrim dolomite; we decided on the latter.

A large spring occurs in the Wolsey shale east of the road and suggests a fault may be present. The map of this island is included in the report.

Morrison Cave

One rainy morning when field work was impossible the group visited Morrison Cave. The cave occurs in a large block of Upper Madison (Mission Canyon) formation that has been wedged into the Belt series. The area has been intensely folded and faulted. The cave was caused by fissures due to the faulting, which occurred in Tertiary time. Water charged with calcium carbonate drips from the roof of the cave and creates the beautiful stalagmites and stalactites found within the cave.