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# Geology and groundwater resources Stockett-Smith River area Montana

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# GEOLOGY AND GROUNDWATER RESOURCES
# STOCKETT-SMITH RIVER AREA, MONTANA

by


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ABSTRACT

The Stockett-Smith River area, located immediately south of Great Falls, Montana, includes 300 square miles of moderately dissected plains along the northwest front of the Little Belt Mountains. The Missouri River, Smith River and Sand Coulee Creek are the principal streams in the area.

The exposed stratigraphic section is about 1500 feet thick and contains units of Middle and Late Mississippian, Middle and Late Jurassic, and Early Cretaceous age. The lowest outcropping unit, the Middle Mississippian Mission Canyon Formation, is a cyclic alternation of limestone and dolomite. Stromatolitic algae present in the upper part of the Mission Canyon represent initial restriction of the marine environment, culminating with deposition of an overlying anhydrite bed which is now marked by a solution breccia zone. The Mission Canyon is unconformably overlain by clastics of the upper Mississippian Big Snowy Group, which is restricted to the southern part of the area by pre-Middle Jurassic erosion. The Kibbey Formation, basal unit of the Big Snowy, is probably in part a Terra Rosa soil, reworked during the transgression of the seas that deposited the overlying Otter Formation.

Two separate lines of evidence suggest that Early Pennsylvanian sediments were deposited across the area. Post-Early Pennsylvanian and pre-Middle Jurassic doming in the area may represent an early South Arch. After a long hiatus representing Pennsylvanian, Permian, Triassic and Early Jurassic time, Middle Jurassic seas covered the area and deposited the Ellis Group, which consists of the Sawtooth, Rierdon and Swift Formations. Oolitic limestone of the Sawtooth is present only in

the southern part of the area, unconformably overlies the Big Snowy, and is unconformably overlain by Swift sandstone. The Rierdon Formation is absent from the area, and north of the Little Belt Mountain front, the Swift directly overlies the Mission Canyon.

Marine sedimentation ceased with the deposition of the conformably overlying Upper Jurassic Morrison Formation. Continental shale and coal of the Morrison are overlain in slight unconformity by predominently red clastics of the Lower Cretaceous Kootenai Formation. The basal conglomeratic sandstone of the Kootenai probably represents a drastic change toward a drier climate. The Kootenai is conformably overlain by near-shore marine sandstones of the Flood Member of the Blackleaf Formation.

A second deformation, probably Late Eocene in age, involved all the rocks in the project area and created Pilgeram dome and the present South arch. A large normal fault at the southern border of the map area and normal faults at the crest of Pilgeram dome are probably related to the Eocene deformation.

Unconsolidated Tertiary and Quaternary deposits include Missouri River terrace gravel, glacial outwash, laminated silts from glacial Lake Great Falls, landslide deposits, and recent alluvium. Conclusive new evidence is presented to show that Sand Coulee Creek is a preglacial channel of the Missouri River.

The groundwater in the area is generally of good quality. Well and spring water is largely derived from the upper part of the Mission Canyon Formation, lower Kootenai sandstones, and the Flood Member of the Blackleaf Formation. A number of wells obtain water from Smith River alluvium and recent and preglacial alluvium of the Missouri River. A few wells and springs produce water from the Swift Formation. In spite of a multiplicity of potential sources, water is locally difficult to obtain. The groundwater section of this thesis treats these problems in terms of recharge areas, drawdown, and stratigraphic and structural control of water occurrence, and concludes with suggestions to water-well drillers.

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## PURPOSE AND SCOPE

This investigation, sponsored by the Montana Bureau of Mines and Geology, was conducted to evaluate the potential sources of groundwater in a 300 square mile area south of Great Falls, Montana. Preparation of a geologic map and interpretation of the geologic history of the area are both ends in themselves and necessary parts of the groundwater study. With emphasis on interrelationships between available water and areal geology, this report provides information concerning the source, quantity, quality, and utilization of well and spring water. Each near-surface stratigraphic unit is considered as a potential source of groundwater.

Data were obtained by measuring water wells and springs, talking with residents of the area, examining well-driller's reports, measuring and describing stratigraphic sections, and geologic mapping. The geologic map (Plate 1) is scaled at one inch to the mile and shows water well and spring locations.

## LOCATION AND ACCESSIBILITY

The 300 square mile map area is located immediately south of Great Falls, in Cascade County, Montana (Figure 1). The entire map area is within the Great Falls two degree topographic quadrangle. Eighty percent of the map area is within the Stockett and Gore Hill fifteen minute quadrangles, hence only the southernmost sixty square miles are not covered by topographic maps with a scale as large as one inch to the mile.

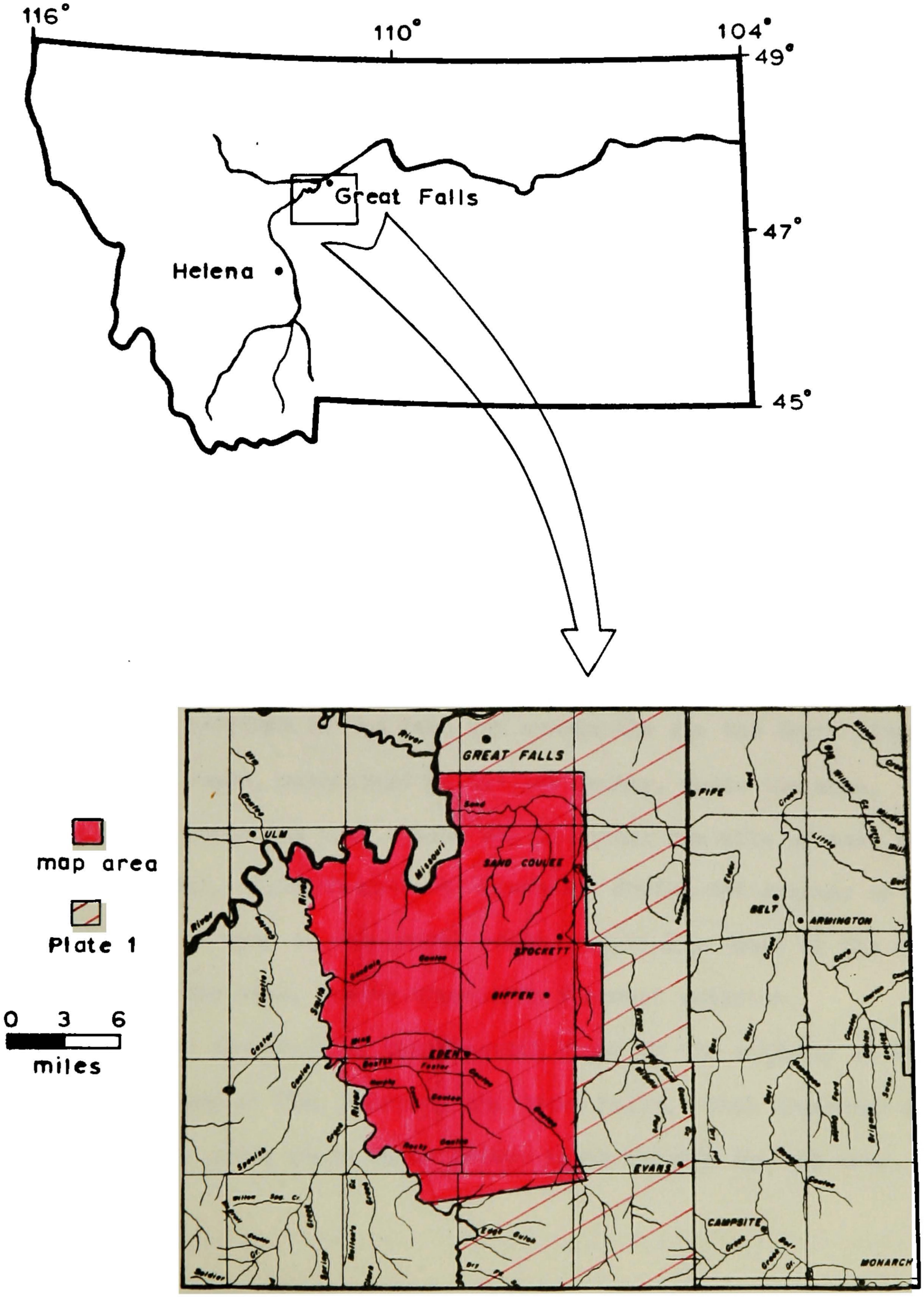


Figure 1. Index map showing the Smith River-Stockett area.
(modified from Buck, 1961).

The limits of the geologic mapping are natural physiographic boundaries. The western and southern boundaries are the Smith River valley and the northern flank of the Little Belt Mountains, respectively. The Missouri River valley and the lower portion of Sand Coulee form the northern boundary of the project area, while upper Ming Coulee and a portion of Sand Coulee delimit the eastern border.

Water well and spring data were collected east and north of the area covered by geologic mapping. For this reason, Plate 1 covers an area larger than that described above.

The area is accessible by a paved county road which extends from Great Falls south to Eden, Montana, and a paved road from U. S. Highway 87 south through Tracy, Centerville, Stockett, and Sand Coulee. The westernmost portions of the area are accessible via the Smith River Road. Many gravel roads, maintained by Cascade County, cross the area. In addition, ranch roads and trails take one to within one mile of most prominent outcrops. Caution must be exercised during wet weather or the spring thaw as many of the gravel roads, especially those in the southern part of the area, become impassable for most vehicles.

The only crossings of the Missouri River in the vicinity of the thesis area are at Ulm, Montana, and Great Falls. Both crossings give access to the paved roads which extend south through the map area.

## PREVIOUS AND RELATED GEOLOGIC WORK

Previous geologic mapping in the project area is limited to the work of Cassius Fisher, who, during the summer of 1906, prepared a reconnaissance geologic map of the Great Falls Coal Field. Fisher's map is scaled at one inch to four miles, encompasses nearly 3000 square miles, and includes much of the study area. The map is available in two U. S. Geol. Survey publications (Fisher 1909-a, 1909-b).

Due to many revisions, corrections, and subdivisions of the stratigraphic nomenclature, Fisher's excellent geologic map has diminished in utility. Because of the vast area covered in a relatively short time, it is understandable that many details were omitted and that minor errors occur on the map of the Great Falls Coal Field.

Alden (1932) and Calhoun (1906) discussed the physiography and glacial geology of the area. Buck (1961) discussed the current sources of irrigation water and potential irrigation projects for Cascade County. Surface water and its utilization were his primary concerns and he gave scant attention to underground water.

Pulju (1964) mapped the Black Butte area immediately south of the project area. Fox (1966) studied the hydrogeology of the Cascade-Ulm area, Cascade County, Montana. His area joins mine along the Smith River and provided a valuable point for departure along the western border. Harris (1966) studied the Cretaceous-Jurassic boundary in the Great Falls - Lewistown Coal Field, and we spent a number of mutually profitable field days in the map area.

## PRESENT STUDY

Geologic mapping and the gathering of groundwater data required about eighty days during the summer of 1965. In addition, four weekends in October and November of 1965 and ten days in May of 1966 were spent finishing and field checking the geologic map. Because of limited coverage by large scale topographic maps, all geologic mapping was done on aerial photographs. The data were then transferred by vertical sketchmaster to a base map modified from the Cascade County Highway Map and scaled one inch to the mile.

To facilitate coordination of aerial photographs and the terrain, and to locate geologic contacts more accurately, a mirror stereoscope was used in the field. The geologic map was compiled from traverses by automobile and on foot, with the latter predominating in the more inaccessible and structurally complex southern portion of the area. Stratigraphic sections were measured using a Jacob's staff and were painted at five foot intervals. Data concerning the source, permanence, quantity, quality, and utilization of well and spring water were obtained by measurement, examination of well-drillers' reports, and interviews with property owners.

## ACKNOWLEDGEMENTS

I gratefully acknowledge the inspiration, advice, and assistance given me by many people during this study. Financial assistance for the summer field work was provided by the Montana Bureau of Mines and Geology. Dr. Sidney L. Groff, Head, Groundwater and Fuels Branch of the Montana

Bureau of Mines and Geology, conceived and supervised the study and gave helpful assistance in the field.

Assistance in the field, personal guidance, and supervision of the preparation of this thesis by Dr. Arnold J. Silverman of the Department of Geology, University of Montana, Missoula, is greatly appreciated. Dr. Donald Winston of the Department of Geology and Dr. Richard Konizeski of the Forestry School, University of Montana, gave valuable criticisms of the manuscript. William Harris and Dr. James Peterson of the Department of Geology were helpful in the field and engaged the author in many valuable discussions based on their own research.

Dr. Dwight V. Ager, Department of Geology, Imperial College of Science and Technology, London, took the time and effort to examine and describe an undescribed Jurassic brachiopod from the Swift Formation.

Deep gratitude is extended to my wife, Cheryl, without whose devotion, help, and understanding, this thesis would not have been completed.

# PHYSICAL GEOGRAPHY

## CLIMATE

As the thesis area is situated well east of the Continental Divide, its climate has many midcontinental characteristics and may be classed as that of the semiarid high plains. Relative humidity and annual precipitation are commonly low and are accompanied by large daily and seasonal temperature variations.

In Great Falls, the average annual temperature is 45.1 degrees Fahrenheit. The average daily temperature in January is 29° F. and the minimum January average is 7° F. In July, the average maximum daily temperature is 82° F. and the minimum average is 46° F.

Dightman (1960) lists the following average freezing dates for a thirty year period, 1921-1950, at the Great Falls Airport:

| | |
|---|---|
| Mean date last freezing frost in the spring. | May 14 |
| Mean date first freeze in fall. | Sept. 26 |
| Mean days between frosts. | 135 |

Because of differences in elevation between portions of the map area and the Great Falls Airport, the dates require revision of several days with a gradual but marked decrease in the frost free period at higher elevations near the Little Belt Mountains.

The moderate relief of the project area and a sheltering effect by the surrounding highlands cause striking differences in precipitation over the area. Twenty-five year precipitation records at the Great Falls

Airport indicate an average yearly precipitation of 14 inches. Buck (1961) states that some of the favorably situated mountains immediately south of the project area receive as much as forty inches annual precipitation. Most of the precipitation falls as rain during the spring and early summer. Winter snowfall and local summer convection thunderstorms provide the bulk of the remaining moisture.

## VEGETATION

Ninety percent of the map area is semiarid high plains and the majority of the native vegetation is that which can survive the rugged winters and arid summers with hot, gusty winds. Native grasses, thistles, and prickly pear cactus predominate with variety added by an occasional wind-gnarled pine that is able to procure water from a shallow aquifer. Rushes, lush grasses, cottonwoods, and willows may be found along streams or near springs. Dense stands of conifers are restricted to northfacing slopes in canyon walls and to two exposures of Madison carbonates that crop out along the northern flank of the Little Belt Mountains.

As is common in semiarid and arid regions, torrential runoff from summer cloudbursts is more of a problem for soil conservationists during a year that is dryer than average. Low availability of shallow soil moisture is reflected in a paucity of the protective grass cover on the uplands. Thus, most of the heavy rain from convection thunderstorms is quickly lost as runoff. In August of 1965, the author noted a flash flood in a small, usually dry gully. The flood was the result of one inch of rain that fell in one hour. Cobbles as large as ten inches in diameter were moved downstream.

## DRAINAGE

The major streams of the area are the Missouri River and two of its tributaries, Sand Coulee Creek and the Smith River. The area's drainage is predominantly to the northeast, with the Missouri River flowing eastward, and its tributaries flowing northward. Small tributaries of the above streams impart a dendritic drainage pattern to the area (Figure 1).

### Missouri River

The Missouri River is the largest stream in the region. That portion of it which borders the map area is nearly in equilibrium with a temporary base level formed by the Great Falls of the Missouri near Great Falls, Montana. Hence, the river has an exceptionally low gradient and a meandering course along the northwestern border of the map area.

A water stage recorder, located on the Missouri River six miles east of Ulm, Montana (nine miles downstream from the junction of the Smith River) has records from August 1957 to October 1959. According to Buck (1961), the drainage area at the station is 20,941 square miles and the maximum and minimum discharges were 19,000 cubic feet per second (cfs) on June 19, 1959 and 1,900 cfs on September 5, 1959.

The Smith River and Sand Coulee Creek are the only permanent streams that join the Missouri River from within the map area.

## Smith River

The Smith River flows northward along the western border of the map area and joins the Missouri River approximately 1.5 miles downstream from Ulm, Montana. A wire-weight gauge at Truly, Montana, six miles upstream from the mouth of the Smith River, records runoff from 2006 square miles of the Smith River Basin. The maximum and minimum discharges recorded were 8,800 cfs (June 24, 1907) and 0.2 cfs (September 10, 1931). Buck noted that diversions for irrigation of 24,700 upstream acres were responsible for the low minimum discharge.

Semipermanent tributaries of the Smith River, that dry up only during an extreme drought, are Goodwin Coulee, Ming Coulee, Boston Coulee, Murphy Coulee and Rocky Coulee. All flow in a westerly direction and are fed throughout most years by springs in their canyon walls or the walls of small box canyons that join them.

## Sand Coulee Creek

Sand Coulee Creek flows generally northward, except for its lower seven miles where it flows due west along a preglacial channel of the Missouri River (Refer to discussion of Quaternary geologic history). Sand Coulee Creek heads in the Little Belt Mountains, but receives a major portion of its water from Number Five Coulee which rises in the east-central portion of the map area.

Number Five Coulee receives red acidic water, high in sulphur and iron, from abandoned coal mines along its course. This water flows from the bottom of the basal Kootenai sandstone, which has been exposed by coal mining operations west of Stockett, Montana. The water obtains its color and high content of dissolved solids as it moves through gob and coal left in the mines. As a result, Sand Coulee Creek runs red from the junction of Number Five Coulee to its mouth on the Missouri River south of the city of Great Falls.

## TOPOGRAPHY

Gently sloping, moderately dissected plains dominate the area. These upland areas are stripped surfaces developed on resistant Cretaceous sandstones. The Smith River, a portion of Sand Coulee Creek, and smaller streams such as Ming Coulee Creek, Number Five Coulee Creek, Cottonwood Creek, and Goodwin Coulee Creek have cut narrow, steepsided canyons into this gently undulating upland surface.

Although these canyons have over 400 feet of local relief, and are in most places less than 100 yards wide, alluvial deposits have produced rather flat bottoms. The Missouri River and lower Sand Coulee Creek have broad, flat-bottomed valleys that average one half mile in width and are locally more than one mile wide.

The large prominent bench capped by Flood sandstone in the northwestern portion of the area is considered a remnant of Alden Bench Number Two (Alden, 1932; Lyons, 1944). Lower, less obvious benches occur at various elevations in the outcrop areas of the Kootenai Formation. Rather than attribute these features to stages of epeirogenic uplift, I prefer to consider them as stripped surfaces developed on a number of semicontinuous Kootenai sandstone units that were exposed as the Flood sandstones and the upper Kootenai shale were removed.

Two major structures form conspicuous topographic features at the southern end of the map area. A structural dome in T. 17 N., R. 4 E. has produced two large bald knobs which are capped by quaquaversally dipping Kootenai sandstone (Figure 2). Normal faulting and decreased resistance to erosion at the crest have made the center of the dome a topographic low, the head of Boston Coulee. The northern flank of the Little Belt Mountains is marked by a sharp-crested linear ridge that can be followed along the entire southern portion of the map area. This ridge is the topographic expression of the upthrown side of a large scale normal fault named the Smarker fault by Pulju (1964).

In general, the map area is moderately dissected. Average local relief along the smaller streams is approximately 400 feet and the total relief of the area is approximately 1900 feet. The highest point is more than 5200 feet at the top of the westernmost bald mountain mentioned above, and the lowest elevation is 3310 feet where the Missouri River leaves the map area. Most of the project area lies between 3310 and 4000 feet above sea level.

## LAND UTILIZATION

Since cessation of commercial coal mining in the 1940's, the land is used exclusively for agriculture. Wheat, which is strip-farmed to conserve soil moisture, is grown on the benches in the area. The stream bottoms support up to three excellent cuttings of alfalfa a year. Barley and oats are minor crops. Cattle and sheep grazing utilize all untillable land.

Scenic bluffs overlooking the Missouri River near the mouth of Sand Coulee are being promoted as sites for housing developments. This activity will accelerate with the growth of the city of Great Falls and will require moderate amounts of groundwater for domestic use.

## IRRIGATION

Water is diverted from streams to small ditches that irrigate alfalfa along the flood plains of streams. Within the project area, Buck (1961) lists 345 irrigated acres along the Smith River and indicates that about 500 acres on the south side of the Missouri are irrigated. In addition, I have seen numerous small irrigation projects in the bottoms of most of the smaller streams in the project area.

Figure 2. View looking south from Eden Highway to Pilgeram dome in middle distance. Ming Coulee visible east of the dome. Topography in the foreground is representative of benches in the area.

# STRATIGRAPHY

## INTRODUCTION

Sandstone, mudstone, siltstone, and shale of Early and Middle Cretaceous age crop-out over most of the area (Plate 1). The youngest rocks in the area, marine sandstones and dark gray marine shales of the Flood Member of the Blackleaf Formation, support a vast, irregularly dissected bench in the northwest portion of the map area. Other uplands are capped by outcrops of the continental Kootenai Formation.

Older units of Jurassic and Mississippian age appear where they have been exposed by stream dissection or localized uplift. Outcrops of the Jurassic Sawtooth, Swift, and Morrison Formations are common in the valley walls of well developed drainages. Cyclic, thin-bedded, clastic limestones and fine grained dolomites of the Mississippian Madison Group are exposed in small outcrops associated with structural domes and along the northern front of the Little Belt Mountains.

Two separate episodes of pre-Upper Jurassic erosion have left the Madison carbonates overlain by units of the Upper Mississippian Big Snowy Group in the south and by units of the Middle and Upper Jurassic Ellis Group in the north. Thus, north from the Little Belt Mountains, the Madison is overlain by progressively younger units.

The Kibbey, lowest formation of the Big Snowy Group, is predominantly red silty mudstone with local minor gypsum lenses and unconformably overlies the Madison Group in the southern part of the area. It is conformably overlain by marine green shales and thin limestones of the Otter Formation.

The Kibbey and Otter Formations are present only in the extreme southern part of the area. Due to pre-Middle Jurassic erosion, their combined thickness decreases from more than 400 feet at the Little Belt Mountain front to zero one mile north. Younger formations in the Big Snowy Group are absent in the area.

The marine Jurassic Ellis Group everywhere overlies rocks of Mississippian age. The Sawtooth Formation, basal unit of the Ellis, is predominantly sandy, oolitic limestone. Widespread erosion, that occurred prior to the deposition of the Swift Formation, controls the thickness of the Sawtooth and has removed the Rierdon, middle formation of the Ellis, from the thesis area. Hence, where present, the Sawtooth is unconformably overlain by glauconitic, calcareous sandstone of the upper Ellis Swift Formation.

The contact between the Swift and continental shale and coal of the Upper Jurassic Morrison Formation is sharp and conformable. With only a minor break in deposition, terrestrial sedimentation continued through the deposition of red siltstones, sandstones, and shales of the Lower Cretaceous Kootenai Formation. The validity of placing the Jurassic-Cretaceous boundary at the Morrison-Kootenai contact is still in question. No unconformity is postulated at the contact of the Kootenai and the overlying Flood Member of the marine Blackleaf Formation.

Unconsolidated deposits include Missouri River terrace gravels, glacial outwash, laminated silts from Glacial Lake Great Falls, landslide deposits, and recent alluvium.

The most complete and pertinent data regarding the pre-Mississippian rocks present in the subsurface are presented in Maughan (1961). Table 1 lists his subsurface section as described from a deep well in Sec. 12, T. 20 N., R. 1 E., near the northwest corner of the project area.

Table 1

Subsurface stratigraphic section (modified from Maughan, 1961).

| | | | | | |
|---|---|---|---|---|---|
| Mississippian | | Madison | Mission Canyon limestone | | 637 |
| Mississippian | | Madison | Lodgepole limestone | Woodhurst limestone Member | 363 |
| | | | | Paine shale Member | 22 |
| | | | ----- Unconformity ----- | | |
| Cambrian-Devonian | Upper Devonian | | Three Forks shale | | 33 |
| | | | Potlatch anhydrite | Upper anhydrite Member | 150 |
| | | | | Middle dolomitic Member | 58 |
| | | | | Lower anhydrite Member | 419 |
| | | | Jefferson limestone | | 190 |
| | | | Maywood Formation | | 103 |
| | | | ----- Unconformity ----- | | |
| | | | Red Lion Formation* | | 60 |

* In the Little Belt Mountains, the uppermost Cambrian unit is the Meagher Limestone. It is probable that the Red Lion of Maughan, 1961, is actually the Meagher. The Meagher is underlain in descending order by the Woolsey Formation, Flathead Formation, and metasediments of the Belt Supergroup. Exact thicknesses of these units are not known.

Northward truncation of the Kibbey, Otter, and Sawtooth Formations is illustrated by generalized stratigraphic columns from near Stockett, Montana, and two locations along Ming Coulee (Figure 3). The Morrison-Kootenai contact is the datum plane. The Flood Member of the Blackleaf Formation, youngest consolidated unit in the map area, does not crop-out in the area of the stratigraphic columns.

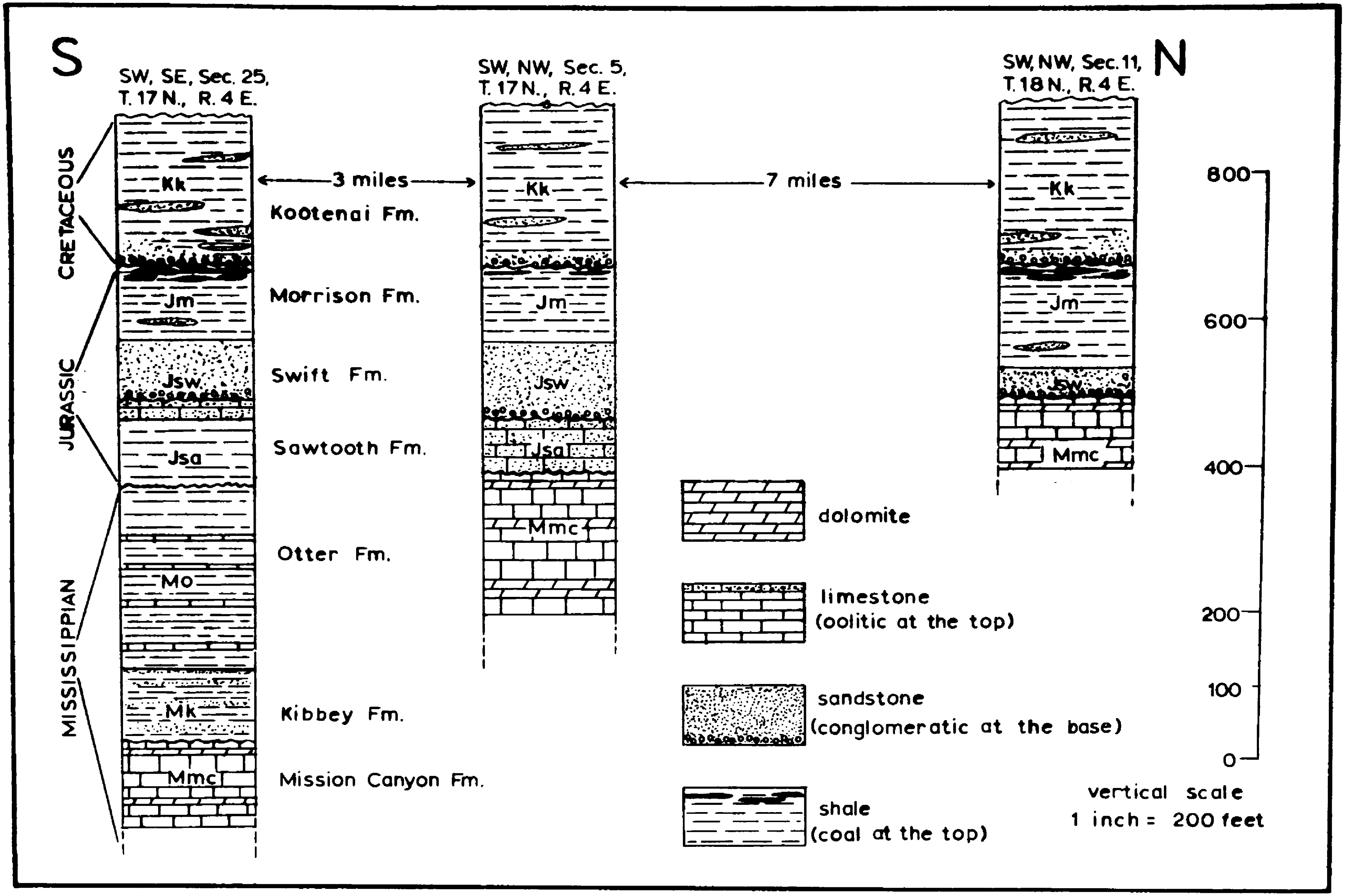


Figure 3. Generalized stratigraphic columns from south to north across the thesis area.

# MISSISSIPPIAN SYSTEM

## Madison Group

Peale (1893) introduced the term Madison as a formational name for Lower Carboniferous limestone in the area of Three Forks, Montana. Weed (1899) applied the name to exposures in the Little Belt Mountains south of Great Falls, Montana, and divided the Madison into lower, middle and upper members: the Paine shale, the Woodhurst limestone, and the Castle limestone. The Madison Formation in the Little Rocky Mountains of northern Montana was elevated to group status by Collier and Cathcart (1922), who divided the unit into the (upper) Mission Canyon and (lower) Lodgepole Formations. Sloss and Hamblin (1942), integrated the Madison nomenclature in southwestern Montana. They retained the group rank of the Madison and adopted Weed's Paine shale and Woodhurst limestone as members of the Lodgepole Formation.

Seager (1942) applied the name Charles to a sequence of carbonates that includes interbedded evaporites and red shale and overlies the Mission Canyon in much of Montana. The high porosity of the Charles influenced Seager to place the unit in the lower part of the Big Snowy Group which overlies the Madison. Perry and Sloss (1943) elevated the status of the Charles to that of basal formation of the Big Snowy Group and designated the California No. 4 Charles well (Sec. 21, T. 15 N., R. 30 E., Petroleum County, Montana) as the type locality of the Charles. Nordquist (1953) redefined the Charles Formation and placed it at the top of the Madison Group. He reasoned that the Charles, being chiefly carbonate, should be placed with carbonates of the Madison Group, rather than clastics of the overlying Big Snowy. It was in this manner that a three-fold nomenclature (Charles-Mission Canyon-Lodgepole) became accepted by most geologists for application to the Madison Group of central and eastern Montana.

Only the upper 300 feet of the Madison Group are exposed in the area of this project. This portion of the Madison contains abundant dolomite and prominent zones of solution brecciation. Although these features have been considered characteristic of the Charles Formation, confusion in the literature and difficulties in correlating lithology over large distances has made exact correlation of the sequence very difficult. A description of Madison rocks found in the thesis area and a review of recent literature concerning the Upper Madison terminology follow. Table 2 presents a historical development of the stratigraphic nomenclature.

MISSION CANYON FORMATION

A maximum of 300 feet of Madison carbonates are exposed within the project area. Stratigraphic sections of the Madison Group measured and painted by the author in Ming Coulee near the southern boundary of the map area, and near Stockett, Montana, are contained in Appendix III (Sections 1 and 2). The rocks are thin to thick bedded recrystallized limestones, dolomitic limestones, limey dolomites, and dolomites. The general sequence is that of a repetitive alternation of thick bedded limestones and thin to medium bedded dolomites that are commonly fractured (Figure 4). Small pods and discontinuous stringers of dark, banded chert are common throughout the section. Two stringers of chert, two inches

Table 2. Historical development of Madison nomenclature in Montana

| Author | Madison units | | Overlying units |
|---|---|---|---|
| Peale 1893 | MADISON FORMATION | | QUADRANT FORMATION |
| Weed 1899 | MADISON FORMATION: Paine Shale Member; Woodhurst Limestone Member | MADISON FORMATION: Castle Limestone Member | QUADRANT FORMATION |
| Collier and Cathcart 1922 | MADISON GROUP: LODGEPOLE FORMATION | MADISON GROUP: MISSION CANYON FORMATION | QUADRANT FORMATION |
| Sloss and Hamblin 1942 | MADISON GROUP: LODGEPOLE FORMATION (Paine Member; Woodhurst Member) | MADISON GROUP: MISSION CANYON FORMATION | BIG SNOWY GROUP (Scott, 1935): Kibbey Formation; Otter Formation; Heath Formation |
| Seager 1942 | MADISON GROUP: LODGEPOLE FORMATION (Paine Member; Woodhurst Member) | MADISON GROUP: MISSION CANYON FORMATION | BIG SNOWY GROUP: Charles Formation; Kibbey Formation; Otter Formation; Heath Formation |
| Nordquist 1953 | MADISON GROUP: LODGEPOLE FORMATION (Paine Member; Woodhurst Member) | MADISON GROUP: MISSION CANYON FORMATION; CHARLES FORMATION | BIG SNOWY GROUP: Kibbey Formation; Otter Formation; Heath Formation |
| Chamberlain 1955 | MADISON GROUP: LODGEPOLE FORMATION (Paine Member; Woodhurst Member) | MADISON GROUP: MISSION CANYON FORMATION; SUN RIVER-CHARLES FORMATION | |
| Mudge, Sando, and Dutro 1962 | MADISON GROUP: ALLAN MOUNTAIN FORMATION (lower member; middle member; upper member) | MADISON GROUP: CASTLE REEF FORMATION (lower member; Sun River Member) | |
| Roberts 1961, 1966 | MADISON GROUP: LODGEPOLE FORMATION (Paine Member; Woodhurst Member) | MADISON GROUP: MISSION CANYON FORMATION (lower member; upper member) | BIG SNOWY GROUP |
| This paper | MADISON GROUP: LODGEPOLE FORMATION (Paine Member; Woodhurst Member) | MADISON GROUP: MISSION CANYON FORMATION | BIG SNOWY GROUP: Kibbey Formation; Otter Formation |

Figure 4. View looking east at western limit of Mission Canyon exposures in Ming Coulee (Sec. 16, T. 17 N., R. 4 E.). Massive white cliffs at base of slope are Mission Canyon carbonates. Swift and Sawtooth Formations overlie the Mission Canyon.

thick, are found at 70 and 75 feet in the Ming Coulee section and remain of constant thickness and at constant spacing for several hundred yards along the outcrop.

Most of the limestone units examined consist of light gray micrite (microcrystalline calcite), but some have been appreciably recrystallized to sparry calcite. Oolite beds present near the base of the Ming Coulee section are the only units containing allochemical constituents in grain to grain support. Other allochems, such as fossil fragments and fecal pellets, are present in minor amounts throughout the Madison section.

The dolomite is light gray and commonly weathers to faint orange, indicating the presence of appreciable iron in the dolomite structure. Thin sections and staining precedures indicate that a minor portion of the dolomite is iron free. The dolomitic rocks are mostly very fine grained but commonly contain irregular patches of larger recrystallized grains.

Near the top of the Madison in the Ming Coulee section there are 20 feet of thin, platy algal beds with many close-spaced round protuberances along every bedding plane. The irregularities on bedding surfaces in the lower portion of the algal zone are reproduced in detail on bedding planes that lie above. This unusual bedding corresponds to the laterally linked hemispheroidal growth form (LLH) described by Logan, Rezak, and Ginsburg (1964).

A collapse breccia zone lies above the algal buildup and is traceable along strike for more than a mile in Ming Coulee. The breccia zone cannot be explained as a post-Madison karst surface. The following observations support the theory that this breccia zone is due to solution and removal of an evaporite bed of unknown thickness.

1. The solution breccia zone follows the same stratigraphic position along the entire outcrop.
2. Disturbance and brecciation is greatest near the bottom of the breccia zone, where limestone and algal limestone blocks are rotated and broken. Fracturing decreases upward and the overlying limestone is cut by minor fractures which disappear upward.
3. The fractured overlying limestone contains small brachiopods identical to those found lower in the Madison section.

4. A bed of red siltstone that ranges from less than a foot to 20 feet thick occurs at the base of the brecciated interval and is probably insoluable material left after solution of the evaporite.

Paleontologic data are inconclusive regarding the time classification of the Madison units exposed in the thesis area. Sando tentatively identified several corals from the Stockett section as belonging to the genus Vesiculophyllum and stated that the genus has a long range in the Madison Group extending from Zone $C_1$ to Zone D. A well preserved internal mold of a Spiriferoid brachiopod was collected from the Stockett section. It shows in detail the muscle attachment scars on the interior of the pedicle valve (Figure 5). The specimen is definitely of the genus Spirifer and has affinities to Spirifer increbescens.

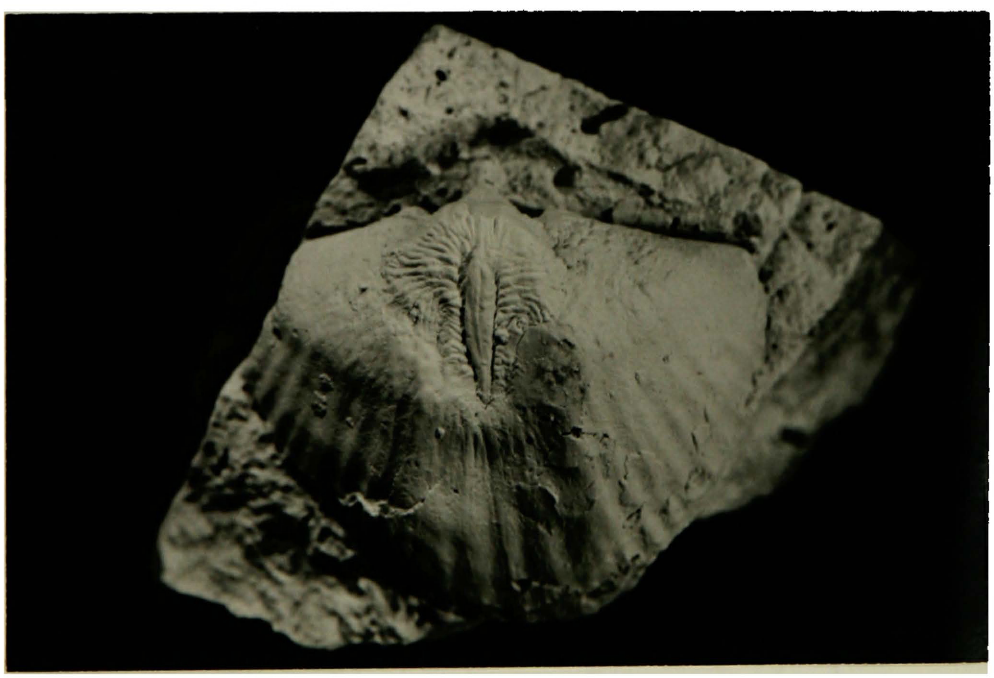

Figure 5. a. Spirifer increbescens, 1.5 X. Internal mold of pedicle valve. Note wedge shaped outline.

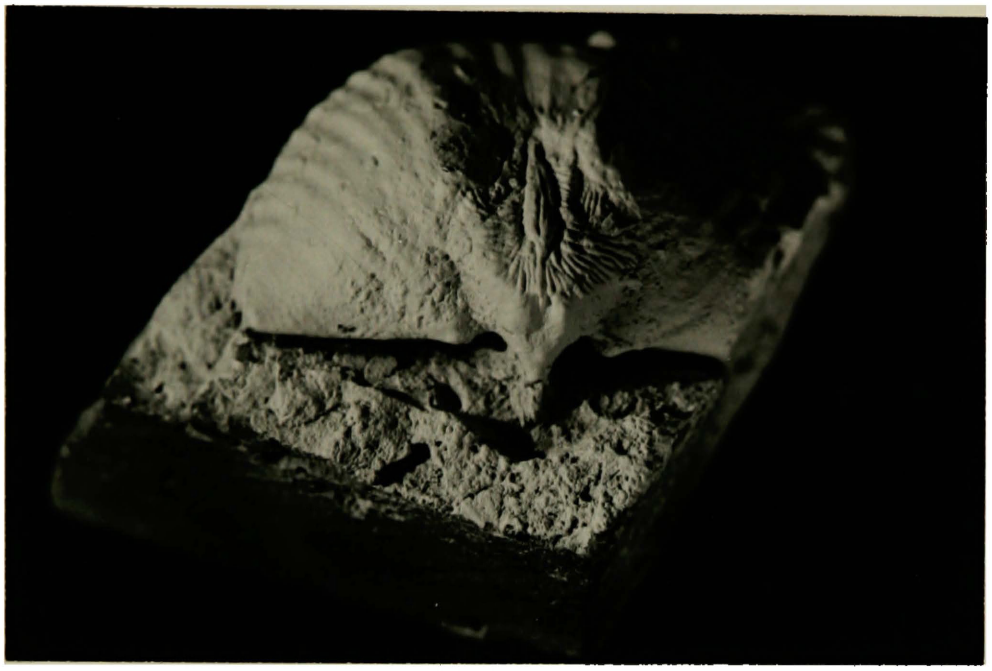

Figure 5. b. Spirifer increbescens, 1.5 X. Internal mold of pedicle valve. Note muscle attachment scars.

All outcrops of Madison carbonates examined in detail are located on domes north of the Little Belt Mountain front and without exception are unconformably overlain by units of the Jurassic Ellis Group. The geologic history section of this work details the evidence for considerable pre-Middle Jurassic erosion. It is quite possible that a substantial part of the upper Madison Group has been removed from the area.

## THE CHARLES PROBLEM

The Charles-Mission Canyon contact is placed by Nordquist (1953), Chamberlain (1955) and Andrichuk (1957) at the base of the lowest massive anhydrite unit in the Madison Group. Anhydrite beds can be expected to thicken or thin over an area as large as that of Montana, and are known to occur at many different stratigraphic positions within the Madison Group (Middleton, 1961). Therefore, a massive anhydrite or solution breccia may not be an ideal marker unit for the base of the Charles. In many cases, rocks termed Charles by one author correlate with Mission Canyon units of another (Table 2).

Some of the problems are illustrated in the following quote from Nordquist (1953):

> "A widespread anhydrite zone in the Mission Canyon is extensively developed throughout southeastern Montana and through most of North Dakota and has caused confusion in the selection of the Charles-Mission Canyon contact in these localities. . . . Since anhydrite may occur in Mission Canyon sediments, the presence of that substance is not a criterion for positive identification of Charles strata."

It seems a contradiction that Nordquist on page 78 of the same paper, indicates, by means of an isopachous map, the presence of 600 feet of Charles in the area of this thesis. He gives no definitive means of recognizing the Charles.

Chamberlain (1955), following the suggestion of Charles Erdmann of the U. S. Geological Survey, retired, introduced the name Sun River Dolomite for a "very light yellowish white dolomitic limestone and limey dolomite with an occasional bed of chert" that is exposed in Hannon Gulch along the Sun River, approximately 90 miles west of Great Falls, Montana. The Sun River Dolomite is given formational rank and is indicated to be correlative with the Charles Formation of eastern Montana (Table 2). Chamberlain presented isopachous maps which indicate a total Madison thickness varying from approximately 1350 to 1900 feet over the thesis area. For the same area, he indicates approximately 300 to 500 feet of the Sun River-Charles Formation.

Like Nordquist, Chamberlain did not clearly define or bound the Sun River Formation. Dolomites of his Sun River-Charles could have been formed from calcareous Mission Canyon units by seepage reflux of highly saline water during the formation of evaporites higher in the section.

Mudge, Sando, and Dutro (1962) studied the Mississippian carbonates of the Sawtooth Range, Montana, and found that Madison terminology of central and eastern Montana is not applicable to Mississippian rocks in the northwestern part of the state. They divided the Madison Group into the Allan Mountain Limestone and the overlying Castle Reef Dolomite. The Allan Mountain Formation consists of three distinct members; the Castle Reef Formation was divided into two members. The Sun River Dolomite, the only member with a formal name, occupies the upper portion of the Castle Reef Formation and is described as a pure dolomite. It is correlated with the Charles Formation of northeastern Montana and is definitely Meramecian in age. The authors summarize their conclusions regarding regional correlation as follows (p. 2009):

> "The Allan Mountain Limestone includes faunal zones A, B, and the lowest part of C (faunal zone terminology of Sando and Dutro, 1960. -- author), whereas the upper part of Zone C and all of Zone D are contained in the Castle Reef Dolomite. This distribution of faunas indicates that the Allan Mountain Limestone is approximately the same age as the Lodgepole Limestone of southwestern and central Montana and that the Castle Reef Dolomite is approximately the same age as the Mission Canyon Limestone of the same area. The Castle Reef also appears to contain beds equivalent to the subsurface Charles Formation in northeastern Montana"

Mudge, Sando, and Dutro state (p. 2017) that "The Sun River Member can be recognized by detailed stratigraphic studies but can not be classified as a formation because it is not a cartographic unit." The Sun River is obviously not traceable into the central Montana area. Use of the term Sun River Dolomite should be restricted to the Sawtooth Range.

At the type Madison section near Three Forks, Montana, the Mission Canyon contains considerable dolomite as does the Mission Canyon at Livingston, Montana (Roberts, 1961). Roberts subdivided the Mission Canyon of the Livingston area into upper and lower members and stated that the upper member correlates with the Charles Formation. It is evident that the presence of a cyclic dolomite-limestone sequence in the Ming Coulee section does not require use of Charles or Sun River terminology.

The presence of a collapse breccia zone in Ming Coulee does not justify application of the term Charles to it and the overlying Mississippian units. Mickelson (1956) and Roberts (1966) have noted similar collapse zones in the Mission Canyon that are attributed to solution and removal of bedded anhydrite. Sando and Dutro (Sando, written communication, 1966) examined the Madison Group near Monarch, Montana, and found no definitive Charles or Sun River lithologies in the Mississippian section. Sando and Dutro noted a LLH algal zone about 160 feet from the top of the Monarch section and placed all Madison units above the Lodgepole in the Mission Canyon Formation.

Middleton (1961), Sando and Dutro (1962) and Roberts (1961, 1966) indicate that the upper part of the Mission Canyon is of Meramecian age. This statement is well documented by paleontologic evidence of two independent investigations and is contrary to the thoughts of many earlier workers who considered the Sun River and Charles to be separate from, and younger than the Mission Canyon. Nevertheless, apparent time correlation between the Sun River Dolomite of Mudge, Sando, and Dutro (1962), the Charles of Seager (1942), Nordquist (1953), Chamberlain (1955), and Andrichuk (1957), and the upper Mission Canyon of Middleton (1961), and Roberts (1961, 1966) does not justify application of the terms Charles or Sun River to upper Madison units in central Montana. They still fail to meet the basic requirement of being recognizable, mapable units in the field.

Because of much confusion in the literature and poor definition of the Charles and Sun River Formations, I conclude that the terms Charles and Sun River should not be applied to upper Madison Group rocks of central Montana. In central Montana, all Madison units above the Lodgepole should be placed in the Mission Canyon Formation.

## Big Snowy Group

Prior to the work of Scott (1935), all strata in central Montana above the Madison Limestone and below rocks of Mesozoic age were included in the Quadrant Formation. Weed (1891, 1899) used the terms Kibbey sandstone and Otter Creek shale for the lower two units of the Quadrant Formation. Because typical Quadrant quartzites of Pennsylvanian age are entirely absent in central Montana sections observed by Scott, he defined the Big Snowy Group to include all strata between the Madison Limestone and the Amsden Formation. Scott included the Kibbey and Otter as the lower and middle formations of the Big Snowy Group and a new unit, the Heath, as the upper formation of the group.

According to Scott (1935), Perry and Sloss (1942), Mundt (1956), Blake (1959), Gardner (1959) and Easton (1962), the Kibbey, Otter, and Heath Formations are of late Mississippian age. After field studies centered in the Big Snowy Mountains, Montana, Gardner (1959) and Easton (1962) include three new Amsden-equivalent formations, the Cameron Creek, Alaska Bench and Devils Pocket Formations, in the Big Snowy Group and thus extend the group into the Pennsylvanian System.

Only the Kibbey and Otter Formations of the Big Snowy Group crop out in the thesis area, hence discussion of the upper four formations of the Big Snowy Group is not necessary.

## KIBBEY FORMATION

In central Montana the Kibbey Formation forms the base of the Big Snowy Group and unconformably overlies the Madison Limestone. Although Weed (1899) named the Kibbey Formation for exposures near the Kibbey School along Little Otter Creek, Cascade County, Montana, the type locality is along Belt Creek near Riceville, Montana. Here the unit consists of 147 feet of yellowish red argillaceous sandstone, red siltstone, and red and maroon shale. Minor calcareous cement is present in the sandier units and the basal portion of the Kibbey contains gypsum as small lenses and irregular disseminations. Measured thicknesses of the Kibbey in central Montana (Easton, 1962) vary from 23 to 282 feet. A well exposed 241 foot section of the Kibbey along the South Fork of the Judith River, 13 miles west of Utica, Montana, is cited by Easton to be representative of the Kibbey for the central Montana region.

In the map area, siltstone and shale dominate the Kibbey section. The sandstones of the Kibbey are friable and poorly indurated. Exposures are generally poor, and grassy valleys follow the Kibbey along strike. Gypsum disseminations are common in the lower portions of all examined Kibbey outcrops. A poorly exposed 7 foot thick gypsum bed of unknown, but probably limited, lateral extent was found on the Martin Ranch (NW$\frac{1}{4}$, Sec 33, T. 17 N., R. 4 E.).

Due to appreciable erosional irregularities in the top of the Madison and because of local differences in intensity of pre-Middle Jurassic erosion, thicknesses of the Kibbey vary considerably in the map area. Because of poor exposures, no section of the Kibbey was measured within the study area. Appendix III contains the 147 foot section of Kibbey measured by Easton along Belt Creek, approximately 10 miles southeast of the map area.

Pre-Middle Jurassic erosion truncates the entire Big Snowy Group just north of the Little Belt Mountains. Consequently, exposures of the Kibbey Formation are limited to the extreme southern portion of the thesis area. The Kibbey Formation is approximately 120 feet thick in exposures along Ming Coulee, one mile southeast of the settlement of Calvert, Montana. Less than a mile northwest of Calvert, along Ming Coulee, the entire Big Snowy Group is absent from the section. See Figure 3 and Plate 1.

No identifiable fossil has ever been collected from the Kibbey Formation, and its precise age is in question. The contrast between the unconformable contact with the underlying Madison units of Meramecian age and the gradational contact with the overlying Otter Formation of Chesterian age suggests that the Kibbey Formation is part of the Chester Series.

OTTER FORMATION

The Otter Formation conformably overlies the Kibbey with a gradational, interbedded contact. It is a thick sequence of green and gray shales and siltstones which contains many intercalated thin, platy, micritic limestones. Many of the limestones are undoubtedly algal in origin. The green shales of the Otter are typically a very bright hue and can be easily recognized from a distance. In most of his measured sections, Easton (1962) placed the base of the Otter Formation at the bottom of the lowest green shale overlying red clastics of the Kibbey.

There is some question regarding selection of the type locality of the Otter Formation. Weed (1892) apparently derived the name from exposures along Otter Creek, Judith Basin County, Montana. Because the Otter is poorly exposed and is intruded by igneous rocks along Otter Creek, most later workers refer to the Riceville section along Belt Creek as the type locality of the Otter Formation. This section is 198 feet thick. Easton designated as type section a 472 foot composite section along the South Fork of the Judith River (Sec. 25, T. 13 N., R. 11 E. and Sec. 19, T. 13 N., R. 12 E.) because he considered it more representative of the Otter Formation for the central Montana region.

The Otter Formation crops out only in the southern portion of the map area and in all exposures is uncomformably overlain by the Sawtooth Formation of the Jurassic Ellis Group. According to Easton, the average thickness of the Otter Formation in the Little Belt Mountain-Big Snowy Mountain area is 410 feet. This contrasts with the 198 foot Belt Creek section and suggests that pre-Middle Jurassic erosion has deeply eroded the upper portion of the Otter Formation. No lithologic change indicating a shallow, near-shore environment of deposition was observed to support a sedimentational thinning of the Otter in and near the map area.

Appendix III contains a measured 211 foot partial section of the Otter Formation on the north side of Ming Coulee, $\frac{1}{4}$ mile southeast of Calvert. This section is included largely to give an impression of the lithology of the Otter Formation present in the thesis area. Total thickness of the Otter in the Ming Coulee section is estimated to be 250 feet, as the contact with the underlying Kibbey Formation is approximately 40 feet down section in a covered zone. The contact between the Otter and the overlying Sawtooth Formation is also covered and is arbitrarily placed at the top of the highest exposed green shale of the Otter. The 198 foot Otter section measured by Easton along Belt Creek is included in Appendix III for comparison. Note that the only striking lithologic contrast between the two sections is the presence of a 16 foot thick, massive, fine grained, calcareous sandstone in the upper part of the Ming Coulee section.

It is important to observe that despite much pre-Middle Jurassic erosion, the Otter maintains a thickness of 200 feet or more across the ten mile wide area from Ming Coulee to Belt Creek. In fact, the thickness of the remaining Otter increases from Belt Creek to near the area of zero Otter in the section. Should the local absence of the Otter be due to non-deposition rather than erosion, one would expect a gradual thinning near the depositional pinchout. The rapid decrease in thickness from 250 feet to zero in less than one mile is not easily attributable to original depositional thinning.

The Otter Formation is of definite Chesterian age. Easton (1962, Plate 5) lists, relative to measured section and stratigraphic position, the occurrence of numerous calcareous algae, forams, corals, crinoids, brachiopods, pelecepods, gastropods, cephalopods, ostracods, and conadonts.

## JURASSIC SYSTEM

### Ellis Group

Marine rocks of Middle and Late Jurassic age unconformably overlie various Mississippian units in the map area. In the southern portion of the area, the Jurassic section overlies units of the Chesterian Big Snowy Group. Further north of the Little Belt Mountains, marine Jurassic rocks rest on progressively older units of the Mission Canyon Formation.

The Ellis Formation was the first formal name given marine Jurassic rocks in Montana. Peale (1893) derived the name from exposures near Fort Ellis southeast of Bozeman, Montana. Cobban, Imlay and Reeside (1945) designated Jurassic exposures located 3.7 miles southeast of Fort Ellis, on the north wall of Rocky Creek Canyon, as the type section of the Ellis Formation. Later, Cobban (1945) elevated the Ellis to group rank and for the Sweetgrass arch area, designated the Sawtooth, Rierdon and Swift as lower, middle and upper formations of the Ellis Group.

Imlay, Gardner, Rogers, and Hadley (1948) found that the Sawtooth Formation east of the Sweetgrass arch shows important changes in lithologic character and proposed the name Piper Formation as the eastern lateral-equivalent of the Sawtooth. Peterson (1957) discussed nomenclature and correlation and presented a regional environmental interpretation of the marine Jurassic of the Northern Rocky Mountains and Williston Basin.

SAWTOOTH FORMATION

The type section of the Sawtooth Formation (Cobban, 1945) is in Rierdon Gulch of the Sawtooth Range (W. $\frac{1}{2}$, Sec. 23, T. 24 N., R. 9 W.). In the type section, the Sawtooth is 137 feet thick and consists of three members, a 20 inch very fine grained calcareous sandstone at the base, an 83 foot middle member of dark gray shale with thin interbeds of dense, dark gray limestone, and a 52 foot upper member of calcareous siltstone that is shaly at the base. The type section of the Piper Formation (Imlay, et al., 1948) consists, from base to top, of 12 feet of massive white gypsum, 6 feet of brittle chocolate gray limestone, 57 feet of green and maroon siltstone and shale, 5 feet of gray silty limestone, 9 feet of gray mudstone and 4 feet of yellow-gray limestone.

Nordquist (1955) defined an arcuate north-south line east of the 112th meridian in Toole County, Montana, that approximates the location of the transition zone between lithologies of the Sawtooth and Piper Formations. He also divided the Piper Formation into lower, middle, and upper members: the Tampico shale, Firemoon limestone, and Bowes member.

Calling the Bowes the "oolite" member, as is sometimes done, may be misleading; as defined, the Bowes shows a wide variety of lithologic types from eastern to central Montana (See Fig. 2, Nordquist, 1955). In the

Williston Basin, the Bowes is a red to varicolored shale. Moving westward to Imlay's type Piper section near Piper, Montana, one finds thin limestone beds near the top of the unit. The Bowes is dominantly a sandy oolitic limestone along the east flank of the northern portion of the Sweetgrass arch. Westward toward the axis of the arch, the oolitic units pass laterally to a section composed entirely of sandstone.

Because of the multiplicity of facies represented by the Bowes, I question its valid member status. The Bowes is best known in the subsurface and comprises an interval between diagnostic marker units, the Firemoon Member and the overlying Rierdon Formation. Recognition of an interval of heterogenous lithologies between key beds is an improper means of defining a member (American Commission on Stratigraphic Nomenclature, 1961, Article 5b). If the Piper Formation is to be subdivided, the Bowes interval should contain at least three members: a sandstone member, a shale member, and a limestone member.

Cobban (1945, p. 1298) described a 90 foot Sawtooth section along Belt Creek, just a few miles east of the map area. For completeness, it has been included in Appendix III. It consists of varicolored shale and siltstone with thin intercalated tan-weathering limestone beds. Peterson (personal communication, 1967) and I agree that the Belt Creek section should be placed in the Piper Formation.

In contrast to the Belt Creek section, the Sawtooth in the western and central portions of the map area is almost entirely oolitic limestone. Along the Smith River, at the western boundary of the area, the Sawtooth is a well bedded oolitic limestone with dark gray shaly partings near the base. A section measured along Ming Coulee (Section 2, Appendix III) consists predominantly of well bedded, sandy oolitic limestone. Quartz sand grains commonly form the nucleus of superficial ooliths.

Upstream (southeast) from the Ming Coulee section, oolitic beds of the Sawtooth occur only in the very upper part of the section. The upper 20 feet of the Sawtooth near Calvert is sandy oolitic limestone which contains at least 10 percent fecal pellets. The oolitic facies gradually thins to the southeast and units from the base of the oolitic zone down to Big Snowy Group strata are everywhere covered (Figure 6). This covered interval is believed to represent shale, perhaps Piper lithology, much like the lower shaly units in the Belt Creek section.

Although Nordquist (1955, Fig. 1 and p. 103) indicates the presence of the Bowes in the thesis area, correlation between oolitic lower Ellis units in the thesis area and the Bowes "oolite" member was not attempted. The reasons are twofold:

1. I question the validity of the Bowes as a member.
2. The Bowes is difficult to distinguish from the underlying Firemoon Limestone on the east flank of the Sweetgrass arch (Nordquist, 1955, p. 103)

Cobban (1966, personal communication) considers the well bedded oolitic limestones along the Smith River to be part of the Sawtooth Formation. This lithology is essentially all that is exposed of the Sawtooth-Piper interval. As distinctive Piper lithologies are not exposed within the area, the interval is mapped as Sawtooth.

The middle Jurassic age of the Sawtooth is well established (Imlay et al., 1948). No identifiable fossils were found from this interval, because the fossils, mostly oyster-like pelecepods, were broken and abraded beyond specific recognition.

Figure 6. View looking northwest along Ming Coulee from near Calvert (Sec. 25, T. 17 N., R. 4 E.). White ledge in right middle distance is oolitic upper portion of the Sawtooth Formation. Swift sandstone forms the red-weathering cliffs above. Note slump in middle distance.

SWIFT FORMATION

A major unconformity marks the base of the Swift, the upper formation of the Ellis Group. Pre-Swift (pre-Late Jurassic) erosion has removed the Rierdon from the map area. The smallest hiatus represented by the unconformity is found in the southern portion of the map area, where the Swift rests unconformably on pelletal oolitic limestone of the Middle Jurassic Sawtooth Formation (See Plate 1). The northernmost exposures of the Swift are found near Centerville, Montana. In the general area of the towns of Centerville, Tracy, Stockett, and Sand Coulee, the Swift unconformably overlies carbonates of the Mission Canyon Formation. In Number Five Coulee, approximately one mile southwest of Stockett, the unconformity has a local relief of about seven feet and Swift sandstone fills a channel cut into the Madison rocks (Figure 7). A pothole structure at the base of this channel is filled with fine grained calcareous sandstone and angular fragments of limestone that are indigenous to the Madison. Elsewhere in Number Five Coulee, the Swift overlies the Madison with no marked erosional relief (Figure 8).

Thomas Walker of the University of Montana (1966, personal communication) reports that remnants of the Sawtooth Formation are present along the erosional unconformity between the Mission Canyon and Swift along Sand Coulee Creek, one mile east of Stockett. It appears that in a north-south distance of four miles, approximately 480 feet of Kibbey, Otter, and Sawtooth strata have been removed from the section.

According to Cobban (1945), the Swift Formation consists of two members at the type locality on the north shore of Swift Reservoir, Toole County, Montana (NE $\frac{1}{4}$, Sec. 27, T. 28. N., R. 10 W.). The lower member is a dark gray shale unit 54.5 feet thick. The upper member, known as the "ribbon sand" to petroleum geologists, is a flaggy, glauconitic sandstone 80 feet thick that contains abundant partings of black-gray fissile shale.

In the study area, thin interbeds of light to dark gray shale are present locally near the base of the Swift section, but the majority of the Swift exposures in the area contain no clastic material finer than fine grained sand. It can be concluded that the lower shaly member of the Swift is absent. Peterson (1957) indicates that the lower member of the Swift is absent in large portions of the Sweetgrass arch area. This absence is probably due to nondeposition rather than erosion.

Figure 7. Swift sandstone over a channelled Mission Canyon surface. (SW $\frac{1}{4}$, SW $\frac{1}{4}$, Sec. 11, T. 18 N., R. 4 E.)

Figure 8. a. Disconformable contact of Swift and Mission Canyon Formations along Number Five Coulee. (SW $\frac{1}{4}$, NW $\frac{1}{4}$, Sec. 11, T. 18 N., R. 4 E.).

Figure 8. b. Same exposure as 7a. Shale above Swift sandstone cliffs belongs to the Morrison Formation. Section 6, Appendix III, was measured up the prominent notch in the cliffs near the center of the photograph.

Most Swift exposures have a basal zone of poorly sorted, black chert-pebble conglomerate that averages one to four feet thick and locally is as thick as 12 feet. The chert pebbles are characteristically well rounded and are up to five centimeters in diameter. Without exception, this conglomerate contains fragments of large oyster-like pelecepods. Locally, in Number Five Coulee, angular limestone and dolomite clasts, derived from the Mission Canyon Formation, are included in the basal Swift and impart a light tan color to the conglomerate (Figure 9).

Figure 9. Basal conglomerate of the Swift Formation at outcrop of figure 7 in Number Five Coulee. Note black chert pebbles, pelecepod fragments, and the light color due to reworked carbonate clasts derived from the Madison erosion surface.

The thickness of the Swift in the thesis area varies from less than 10 to more than 100 feet. The Swift thins to 4 feet in exposures $\frac{1}{4}$ mile north of Stockett. Here the Swift unconformably overlies Madison carbonates on the northwest flank of a dome centered to the east in the Sand Coulee drainage. In contrast, the thickest Swift section measured in the area is the 103 foot section (Appendix III, Sec. 2) on the north wall of Ming Coulee (SW $\frac{1}{4}$, NW $\frac{1}{4}$, Sec. 15, T. 17 N., R. 4 E).

The Swift in the Ming Coulee section consists of clean sandy conglomerate and sandstone. The grain size continually decreases toward the top of the Swift section, with sandy conglomerate and fine grained sandstone the end members of the grain size variation. Calcareous cement is ubiquitous and accessory glauconite was noted at many intervals. Fresh exposures of Swift sandstone are characteristically light gray and are best developed in a road cut along the paved county road as it passes through Stockett. The orange-brown color of weathered Swift exposures is probably due to oxidation of ferrous iron contained in the glauconite.

A 38 foot Swift section was measured by William Harris and the author in the NE $\frac{1}{4}$, SW $\frac{1}{4}$, Sec. 10, T. 18 N., R. 4 E. on the east side of Number Five Coulee (Section 6, Appendix III). The basal 2.5 foot zone of fossil hash contains large fragments of thick-shelled oyster-like pelecepods and minor rounded black chert pebbles and angular carbonate clasts. The relative percentages of fossil fragments, chert pebbles, and carbonate clasts vary greatly over short lateral distances.

At other locations along the same exposure, the base of the Swift contains two thin zones of fossiliferous black chert pebble conglomerate, separated by a one to two foot dark gray carbonaceous silty shale. Immediately west and across the road from the Giffin Coulee section, two dark shale zones, 4 feet in average thickness are present near the base of the Swift. The upper shale unit contains many thin discontinuous beds of micritic limestone. A pelecepod specimen, tentatively identified by Cobban (1967, personal communication) as Pleuromya elongata Goldf was found in one of these small limestone lenses. The specimen was compared with Specimen 7708, University of Montana Paleontologic Collections.

A small lens of what can be termed a brachiopod conglomerate occurs at the base of the Swift in Ming Coulee. This lens contains thousands of well preserved rhynchonellid brachiopods together with scattered chert and quartzite pebbles and is exposed directly to the north side of the Calvert Road as it drops down into the bottom of Ming Coulee (See mile 10, page 23, Goers, 1966.)

Dr. D. V. Ager, Department of Geology, Imperial College, London, examined specimens prepared by the author and indicated (1966, written communication) that the specimens are of an undescribed genus with affinities to the subfamily Cyclothyridinae (Figure 10). Ager commented that the Swift brachiopods are similar to undescribed Late Jurassic brachiopods that were collected under his supervision in the Pyrenees Mountains of Spain. Description of the specimens is in progress and assignment of a formal name is forthcoming.

Figure 10. a. Dorsal view of a small undescribed Upper Jurassic brachiopod with affinities to the subfamily Cyclothyridinae. 8 X. Taken from a brachiopod-conglomerate at the base of the Swift in Ming Coulee.

Figure 10. b. Ventral view. 8 X. Same specimen.

Figure 10. c. Anterior view of same specimen. 8 X.

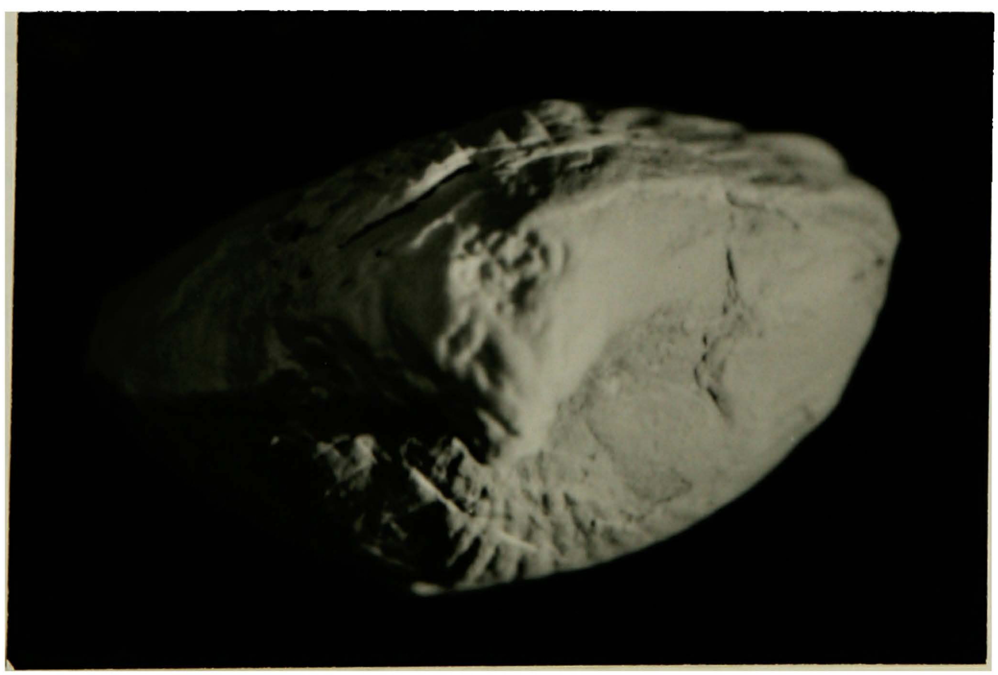

Figure 10. d. Posterior view of same specimen. 8 X.

## Morrison Formation

The Morrison Formation was named by Eldridge (1898) for exposures of nonmarine Jurassic rocks near Morrison, Colorado. Weed (1899) mapped the Little Belt Mountain area, and included units which are presently known as Morrison in the Cascade Formation of Early Cretaceous age. Fisher (1909-a, 1909-b) believed the lower Cascade beds to be correlative with the Jurassic Morrison of Colorado and first used the term Morrison in Montana. Units presently included in the upper part of the Morrison Formation were assigned by Fisher to the Cretaceous Kootenai Formation. The contact of the Morrison with the overlying Kootenai Formation, as it is recognized today, was defined by Cobban (1945) and is placed at the base of a widespread, conglomeratic sandstone. This sandstone is known by a multitude of stratigraphic names and crops out over a vast portion of the western interior of the United States.

The Morrison Formation overlies Swift sandstone across the entire project area and ranges in thickness from 86 to 166 feet. In spite of a change from marine to nonmarine deposition, the formational boundary is apparently conformable in all exposures. With the exception of the northwest quarter of the area, where stream erosion has not penetrated the base of the overlying Kootenai Formation, the Morrison is exposed in canyon walls in all sectors of the map area.

The Morrison is predominantly mudstone and shale with interbedded lenses of freshwater limestone, fine to medium grained calcareous sandstone, and subbituminous coal. Because the Morrison is nonresistant, well exposed sections are rare and are restricted to recent roadcuts.

The upper part of the Morrison is commonly well exposed near portals of coal mines.

The lower part of the Morrison is predominantly light greenish-gray mudstone. According to Harris (1966), the clay-size fraction is composed of mixed layered illite-montmorillonite with minor kaolinite. Locally, thin interbedded micritic limestones occur in the lower part of the Morrison section.

Sandstone lenses commonly found near the middle of the Morrison section are very similar to the fine grained sandstones characteristic of the upper part of the Swift Formation. Sandstones of both formations are calcite cemented and weather yellowish brown. Where the Morrison sandstone lenses are thick and continuous across large outcrops, especially where they form the base of the exposure, they may be mistaken for upper units of the Swift. Such a middle Morrison sandstone is exposed in flaggy, orange weathering outcrops along the east bank of the Smith River, immediately upstream from the Colby Sheep Ranch in the southwest corner of the project area.

Morrison sandstone differs from the Swift in the relative percentages of detrital chert and quartz. Harris (1966) and Ballard (1966) found quartz to compose 80 to 93 percent, and chert from five to eight percent of clastic grains in the Morrison sandstone. Ballard (1966) reports that clastic grains of the Swift Formation are composed of 68 percent quartz and 30 percent chert, with accessory orthoclase and limestone or dolomite fragments.

The following summary of Upper Morrison lithology is taken from

Harris (1966) who investigated in detail the Morrison-Kootenai contact in the Great Falls-Lewistown Coal Field.

> "The upper part of the Morrison, up to 60 feet thick, is a medium to dark gray carbonaceous shale with coal and fine grained sandstone lenses. The coal ranges from a few inches up to 12 feet thick and may be found in one to three benches separated by shale, sandstone or siltstone partings. The siltstone and sandstone beds in the upper part of the Morrison average up to 2 feet thick . . . . Their composition is 80 to 90 percent quartz, a few percent chert and up to 2 percent combined zircon and tourmaline."

Dinosaur bones reported from Wyoming and Colorado establish the age of lower Morrison strata as Late Jurassic. Peck (1957) described gyrogonites of freshwater charophyte algae from Morrison limestones of the Lewistown, Montana, area and indicated a Late Jurassic age for lower and middle units of the Morrison. The age of upper Morrison rocks is much debated. Over the past 70 years the accepted age of upper Morrison strata has fluctuated from Early Cretaceous to Late Jurassic.

The presence of Late Jurassic plant fossils in shales immediately below the coal of the Morrison and the absence of Morrison-like plant fossils in the Kootenai Formation suggested to Brown (1946) that the Morrison-Kootenai contact spanned a major hiatus and represented the Jurassic-Cretaceous boundary. By dating based on freshwater mollosks, Yen (1951, 1952) partially substantiated the ideas of Brown and Cobban. He found that lower Morrison units are of Late Jurassic age and that shales of the middle and upper Kootenai are of Early Cretaceous age. Hansen (1959) placed the Jurassic-Cretaceous boundary at an unspecified horizon in the upper part of the Morrison.

That the upper Morrison of Colorado is of Early Cretaceous age has little bearing on the age of the upper Morrison of central Montana.

Contradictory fossil evidence leaves the stratigraphic position of the Jurassic-Cretaceous boundary still in question. Because some erosion has occurred prior to the deposition of the basal Kootenai sandstones, and because of a major lithologic change recognizable over a large area, the Jurassic-Cretaceous systemic boundary is arbitrarily placed at the formational contact.

## CRETACEOUS SYSTEM

### Kootenai Formation

In central Montana the Kootenai Formation overlies the Morrison with an erosional unconformity. Dawson (1885) first used the term southern British Columbia which contained a Jurassic-Cretaceous flora. Newberry (1891) and Weed (1892) applied the term Kootenie to Lower Cretaceous coal-containing rocks in the Great Falls Coal Field. Weed (1899) discarded the term Kootenie and placed the units in the Cascade Formation.

Fisher (1909) discarded the term Cascade and was first to use the now accepted spelling of the Kootenai Formation. As discussed above, Cobban (1945) placed the Kootenai-Morrison contact at the base of the conglomeratic sandstone overlying coal and carbonaceous shale and Brown (1946) placed the Jurassic-Cretaceous boundary at the Kootenai-Morrison contact.

The basal unit of the Kootenai has many stratigraphic names which relate to individual oilfields. Terms such as Cutbank sandstone, Sunburst sandstone, and Third Cat Creek sandstone are of local significance and their exact correlation is much debated in the literature. The Cutbank sandstone is present only in and near the Cutbank oilfield. The Sunburst is present there as a distinct, stratigraphically higher unit. Because of their limited applicability in the project area, and to avoid confusion, the lower unit is here discussed as the basal Kootenai sandstone.

The Kootenai Formation is approximately 420 feet thick in the map area and can be informally divided into two lithologic entities. Coarse clastics predominate in the lower quarter of the Kootenai section and the upper part of the formation contains red and maroon mudstone and shale with minor, discontinuous sandstone lenses. Another striking contrast is formed by the regional continuity of the sandy conglomerates of the basal Kootenai and the discontinuous nature of the upper Kootenai units.

The lower portion of the Kootenai is very resistant to erosion and supports upland surfaces across a major part of the project area (See Plate 1). In the northwest quarter of the area, Kootenai exposures are restricted to coulee walls, where stream erosion has cut through the sandstones of the basal Flood member of the overlying Blackleaf Formation. Most areas of Kootenai outcrop exhibit a bright red soil derived by erosion of red mudstones and shales of the upper Kootenai.

Because of the nonresistant upper Kootenai, exposures are generally poor and no single outcrop contains a complete Kootenai section that is even moderately well exposed. The thickness of the Kootenai was estimated by marking the upper and lower contacts on a topographic map and calculating the thickness using an appropriate dip value. In this area, immediately north of the settlement of Eden, the dip of the Kootenai is a maximum of five degrees, hence the estimated thickness is reasonably accurate.

Although the basal Kootenai sandstone extends over the entire area, the thickness is quite variable. Section 7, Appendix III, is a composite section of the lower Kootenai in the map area, compiled by Harris and Silverman (1967). The upper Kootenai is best exposed on the south side of Wilson Butte (SE $\frac{1}{4}$, NW $\frac{1}{4}$, Sec. 17, T. 19 N., R. 3 E.) in the northwest corner of the area. The Wilson Butte section contains 198 feet of the upper Kootenai exposed below the Flood sandstones and is presented as Section 8, Appendix III. An exact correlation between the two Kootenai sections is impossible, but together they represent the bulk of the formation.

The basal Kootenai in the map area, like the basal Kootenai across all of north-central Montana is an impure, poorly to moderately sorted coarse sandstone and sandy chert pebble conglomerate. One half mile south of Stockett, the basal unit is as thin as 20 inches but is 30 to 35 feet thick in many other exposures.

Dark brown and black chert pebbles, up to one inch in diameter, are common in the basal Kootenai across the entire project area. Chert pebbles and sand size chert comprize 30 to 40 percent of the basal sandstones and are commonly more angular than the associated quartz grains. Petrified wood and wood impressions are common at the bottom of the basal Kootenai sandstone. Locally, chips of reworked carbonaceous shale are present near the base of the Kootenai. Quartz is the most common cement, but locally interstitial clays are an important lithifying agent. Degree of cementation varies from very poorly to very

very tightly cemented.

Commonly the conglomeratic sandstone at the base of the Kootenai grades upward into white, fine to medium grained, well sorted sandstone which locally reaches 60 feet thick and has small-scale festoon cross-bedding. The white color reflects a diminished chert content; quartz grains compose the majority of the clastics. In the northern part of the area, along the east-west trending portion of Sand Coulee and along the Missouri River south of Great Falls, this finer grained Kootenai sandstone is separated from the basal unit by an interval of dark gray and maroon mudstone that contains lenses of micritic freshwater limestone. Along the Missouri River, the finer sandstone forms massive, blocky weathering cliffs similar to cliffs formed by the basal Kootenai in other areas. Because of the massive sandstone cliffs and the presence of dark gray shales above the basal Kootenai, Cottonwood Coal Company ill-advisedly invested in a coal-exploration adit located about 100 feet above the coal zone of the Morrison Formation.

The upper three quarters of the Kootenai is much finer grained than basal Kootenai units. Individual units of the upper Kootenai are of very limited lateral continuity. Correlation from one upper Kootenai outcrop to another is in most places impossible. Mixed layered illitemont-morillite is the dominant clay mineral of upper Kootenai shales. Puffy weathering beds that appear to be highly bentonitic (relatively pure expandable montmorillonite) are common in the upper 100 feet of the Kootenai (Section 8, Appendix III).

Fine grained discontinuous, cross bedded sandstones are present in the upper portions of the Kootenai and locally may be as thick as 30 feet. They contrast with sandstones of the lower Kootenai in that they contain appreciable feldspar and thin layers rich in unaltered ferromagnesian minerals. Near the top of the Wilson Butte section there is a 9 foot sandstone, notable because of its relatively high content of weathered and unweathered feldspar. On Red Butte, in the eastern part of the area, (NE $\frac{1}{4}$, Sec. 33, T. 19 N., R. 4 E.) the uppermost Kootenai is a fine grained, well sorted, cross bedded sandstone that contains a number of thin layers of unaltered biotite and hornblende, oriented parallel to the bedding. The unit is openly exposed to the prevailing northwesterly winds and wind erosion has carved it into pillar-like hoodoos (Figure 11).

Figure 11. Hoodoos carved by wind erosion of cross bedded upper Kootenai sandstone exposed on the southwest side of Red Butte.

The abrupt change in lithology from carbonaceous shale and coal of the upper Morrison to conglomeratic sandstone of the basal Kootenai, channels cut into the top of the Morrison, and the presence of scattered cobbles up to six inches in diameter at the contact, indicate an unconformity at the base of the Kootenai. The undulatory lower surface of the basal Kootenai sandstone is attributable both to differential compaction of the underlying Morrison shale and to stream-channel cut and fill. (Figure 12). As indicated by the widespread presence of coal in the uppermost Morrison, the erosion was not severe and the hiatus probably of short duration. In the 300 square mile area of this project, little Morrison was removed during pre-Kootenai erosion. Maximum erosional relief observed in the area is in the order of two to four feet.

Figure 12. View of the Morrison-Kootenai contact exposed on the west side of the Smith River Road (NE $\frac{1}{4}$, Sec. 1, T. 17 N., R. 4 E.) The gently undulose bottom of the basal Kootenai sandstone is a result of both channeling and differential compaction.

Peck (1957, p. 10) reports the freshwater charophyte algae, *Atopochara trivolis* Peck and *Clavator harrisi* Peck, from a "nodular limestone and shale zone underlain by red clay in a road cut one mile southeast of Giffin". Together the two species establish an Aptian (Early Cretaceous) age for the limestone unit. Unfortunately Peck did not give exact stratigraphic locations of the sample sites. I believe the sample site is no more than 70 feet above the base of the Kootenai.

## Blackleaf Formation

The Blackleaf Formation overlies the Kootenai with questionable conformity. Stebinger (1918) first mentioned the name as the Blackleaf sandy member of the Early to Late Cretaceous Colorado Formation. As described, the Blackleaf comprised the lower 600 to 700 feet of the Colorado Shale and consists of an alternation of dark marine shale and gray sandstones which are locally up to 75 feet thick. Cobban, Erdmann, Lemke, and Maughan (1959) assigned the Colorado Shale to group rank, elevated the Blackleaf to formational status and named the upper formation of the Colorado Group the Marias River Shale. The Blackleaf and Marias River Formations were each divided into four members. In ascending order the members of the Blackleaf are: Flood sandy Member, Taft Hill glauconitic Member, Vaughn bentonitic Member, and the Bootlegger conglomeratic Member. Exposures of the Blackleaf are restricted to the northwest quarter of the map area and only the basal Flood Member is present.

FLOOD MEMBER

The Flood Member was named for exposures along the north side of the Missouri River near Flood Siding on the Great Northern Railroad, 5 miles southwest of Great Falls. The type section is 4.5 miles west of Great Falls on the south side of the Sun River in the SW $\frac{1}{4}$, NW $\frac{1}{4}$, and NE $\frac{1}{4}$, Sec. 7, T. 20 N., R. 3 E. Here the Flood Member has a thickness of 138 feet and consists of a lower, 16 foot light brown ledge-forming sandstone, a middle dark gray shale approximately 50 feet thick, and an upper massive light brown sandstone about 72 feet thick.

A complete Flood section (Section 8, Appendix III) was measured on the south side of Wilson Butte, (NE $\frac{1}{4}$, Sec. 6, T. 19 N., R. 3 E.) just five miles south of the type section. At Wilson Butte, the Flood member is 110 feet thick and all units of the Flood are thinner than in the type section.

The author found no field evidence for a disconformity at the base of the Flood. Fox (1965), in a composite section from the Cascade-Ulm area, west of the type section, reports the basal sandstone of the Flood member to be 102 feet thick. Fox and Groff (1966) attribute this thickening to scour and fill of the underlying Kootenai Formation and suggest that the contact is disconformable. Cannon (1966) found no evidence for a disconformity at the base of the Flood over an area including the Sweetgrass arch, the Bearpaw Mountains, and the Little Rocky Mountains. Cannon noted that in the Great Falls area, the lower Flood sandstone thins to the northeast and is absent a short distance north and east of Great Falls.

I believe that the thick lower sandstone reported by Fox is better explained as a facies change in the lower part of the Flood. In spite of the change from nonmarine to marine deposition, a disconformity is not yet documented. Because of the discontinuous nature of all upper Kootenai units, a disconformity may not be established on the basis of regional observations of the uppermost Kootenai. Certainly, the lower Flood overlies different Kootenai units across the map area, but this is attributed to abrupt facies changes in the upper Kootenai rather than erosion and fill by the lower unit of the Flood.

Commonly the basal unit of the Flood is entirely sandstone. Locally, as in the Wilson Butte section, fissile dark gray shale beds appear at the base of the unit. In some places, the lowermost Flood shales show a faint maroon cast, indicating that the boundary is locally gradational. No clasts of reworked Kootenai were observed.

The lower sandstone of the Flood is light tan and weathers whitish gray. The sandstone is relatively thin bedded (two to three inches), medium grained, and slightly calcareous (cement). Assymetrical ripple marks with amplitudes averaging one half inch and wavelengths of three to four inches occur on most of the bedding planes. Casts of anastomosing worm trails commonly occur on the troughs of the ripples. Subspheroidal, dolomitic, iron stained concretions up to four feet in diameter are present in the lower Flood sandstone in exposures along the east side of the Smith River. Many of the concretions cross, but do not distort, bedding planes in the sandstone and therefore formed after deposition of the lower Flood sandstone.

The middle unit of the Flood is poorly exposed in the project area and is composed of dark gray calcareous shale with 1 to 6 inch interbeds of gray siltstone and well sorted, fine grained sandstone. Worm trails are very common on bedding surfaces of the interbedded sandstone and siltstone.

The upper sandstone unit of the Flood supports the high benches in the northwest quarter of the project area and is 52.5 feet thick in the Wilson Butte section. The sandstone is buff colored and fine to medium grained. Quartz varies from 60 to 85 percent with fragments of volcanic and metamorphic rock and trace quantities of ferromagnesian minerals comprising the remainder of the clastic material in the sandstone (Fox, 1965). The lower part of the upper sandstone is characteristically massive. The upper part of the unit is moderately well bedded, but because of abundant worm trails on the bedding surfaces, and diversely oriented vertical fractures, the bedding appears somewhat irregular.

## TERTIARY AND QUATERNARY SYSTEMS

Unconsolidated sediments in the project area are divided into three distinct groups, each of which is wholly or in part of Quaternary age. Terrace gravel deposits along the Missouri River and the east-west trending portion of Sand Coulee Creek are pre-Illinoisian in age. The oldest terrace gravel may be older than Quaternary. Glacial deposits include glacial outwash and glacial lake silts and are also restricted to the northern portion of the project area. Alluvium and landslide deposits along the major drainages are recent in age.

### Terrace Gravel Deposits

A number of dissected, gravel covered terraces, formed at successively lower levels of the Missouri River occur in the northern part of the thesis area. Topographic correlation between various remnants is difficult and arbitrary. For discussion in this report, the river terraces are grouped into three levels, each of which progressively decreases in elevation downstream. The highest and oldest terrace, is probably Quaternary in age but may be as old as Late Tertiary (Maughan, 1961). Remnants of QT3 cap Wilson Butte, at an elevation of 3820 feet, about 500 feet above the Missouri River channel. Terrace gravels occur along the lower, east-west portion of Sand Coulee on bluffs which are 170 to 230 feet above the present valley floor. The elevation of this terrace ranges from 3520 to 3580 feet and all its deposits are mapped as Quaternary Terrace 2 (QT2). Terrace deposits at elevations from 3450 to 3420 feet are locally overlain by glacial lake silts and are mapped as

Quaternary Terrace 1 (QT1).

The oldest terrace deposits (QT3) are rather thin and barely cover the underlying bedrock. The younger two terrace deposits are a maximum of 40 feet thick and are locally exploited for concrete aggregate and road metal. The terrace gravels consist of rounded pebbles and cobbles of cross-bedded pink quartzite, green and red argillite, and porphyritic basalt of various types. The quartzite and argillite are identical to Precambrian Belt rock types that crop-out upstream along the Missouri River near Wolf Creek, Montana. The basalt cobbles were derived upstream near Cascade, Montana, where the Adel Mountain Volcanics (Lyons, 1944) crop out in the northern part of the Big Belt Range. All terrace deposits are partially cemented by caliche, which forms on the bottom surfaces of pebbles and cements them to underlying material (Figure 13).

On a bluff overlooking the mouth of Sand Coulee, there is an exposure of the QT1 gravel, which is being quarried. Minor amounts of sand-sized material is segregated into small lenses. The quartzite, argillite, and basalt cobbles are imbricated and indicate a current direction of N. 70°E. (Figure 13). On bluffs situated upstream along Sand Coulee, other gravel pits contain similar pebbles and cobbles, also imbricated in a general west to east direction.

## Glacial and Glaciolacustrine Deposits

During the Illinoisian stage of the Pleistocene, the Montana Lobe of the Keewatin Ice Sheet made its furthest advance to the southwest

Figure 13. View looking north at fresh exposure of imbricated QTl terrace gravel in a pit near the mouth of Sand Coulee Creek (SW $\frac{1}{4}$, Sec. 31, T. 20 N., R. 4 E). Estimated current direction is N. 70° E. Brunton is horizontal. Note caliche cement at bottom of large cobbles.

(Calhoun, 1906). An end moraine marks the limit of this advance and is located less than a mile northeast of the map area. The advancing ice blocked the flow of the Missouri River and created glacial Lake Great Falls. In the Vaughn, Montana area, Maughan (1961) noted five shorelines produced by glacial Lake Great Falls. The altitudes of the shorelines range from 3900 to 3360 feet and were controlled by fluctuations in elevation of the ice dam. The lowest shoreline formed behind the end moraine itself, following retreat of the ice. The glacial lake shorelines are poorly defined in the map area.

Glacial lake sediments are varied and are composed of alternating thin layers of dark gray clay and brownish yellow silt (Figure 14).

According to Fox (1966), the composition of the glacial lake silt is 35% quartz, 30% feldspar, 10% mica, 5% combined magnetite, garnet, and hornblende, and 20% unidentifiable minerals. Small areas of glacial lake sediment occur locally along the Smith River, Missouri River, and Sand Coulee. The exposures are commonly poor and only one outcrop south of Wilson Butte is sufficiently large to be shown on the geologic map (Plate 1).

Two very regular channeled surfaces are exposed in glacial lake silts south of Wilson Butte (NW $\frac{1}{4}$, SE $\frac{1}{4}$, Sec. 17, T. 19 N., R. 4 E.) at an elevation of 3480 feet. The channels are filled by later glacial lake silts which are draped over the entire surface (Figure 14). Individual clay and silt layers can be followed from one channel over the "divide", and into an adjacent channel. The dark clay layers remain of

Figure 14. Glacial lake silts exposed on the south side of Wilson Butte. Note the channelled surface covered by later glacial lake silts.

constant thickness, but the silty layers show appreciable thickening in the troughs.

The absence of foreign clastics from the channeled surface does not support stream channeling and consequent bedload deposition. Some extra-lake material, such as Kootenai shale clasts, would form a residual coating on the stream channel. The erosion was probably by currents developed during sudden drops in the lake level, caused by partial or total failure of the ice dam.

Outwash from the front of the receding glacier was deposited in the northeast portion of the map area. It is in this area that the bluffs above Sand Coulee diminish and spread to a slightly hummocky plain. Fragments of red granite, sandstone, limestone, and nonporphyritic basalt predominate in the glacial outwash material.

Pre-Illinoisian Missouri River alluvium, glacial lake sediment, Sand Coulee alluvium, and glacial lake outwash are present in the east-west portion of Sand Coulee. Because all these materials are unconsolidated and poorly exposed, this area is mapped as undifferentiated Quaternary (Qu).

## Alluvium

The flood plains along the Smith and Missouri Rivers and their tributaries are composed of alluvial gravel, sand, silt, and clay. The large scale of the geologic map (Plate 1) makes it practical to show only the larger occurrences of alluvium. Alluvial fill in the Missouri River channel near Ulm, Montana, was reported by Fox (1966) to be more than 200 feet thick.

## Landslide Deposits

Many small landslides and slumps are present in the map area. Bentonitic units near the top of the Kootenai Formation and fissile shale of the Otter Formation provide suitable slip surfaces for landslides. One large slide in Ming Coulee is shown in Figure 5. It is composed of sandstone and limestone from the Jurassic Swift and Sawtooth Formations that has moved along slip planes developed in Otter shale. The landslide material is only slightly mixed, hence the term slump may be more applicable. Springs issuing from the base of the Jurassic formations may have triggered the slide. Southwest of this slide, across Ming Coulee, (See area of dotted contacts, Plate 1) are many small slumps and landslides that probably moved along slip planes in the Otter Formation.

# STRUCTURAL GEOLOGY

## REGIONAL SETTING

The map area is located near a transitional zone between two major tectonic provinces, the Cordilleran Geosyncline to the west and the Central Stable Platform to the east. Both of these provinces have been elements of the continental framework since the Precambrian. The sedimentational transition zone in which geosynclinal units thin in passing onto the stable platform is now marked by a northwest trending zone of chaotic thrusting and folding. This area is termed the Disturbed Belt and according to Fox (1965) its eastern boundary is approximately 15 miles west of the thesis area. The stable platform is modified by a number of gentle folds and broad isolated uplifts. The major structural features which directly affect the project area are the Little Belt Mountains and the southern part of the Sweetgrass arch.

The Little Belt Mountains were described by Weed (1899) as a broad low arch of batholithic origin which is 60 miles long in an east-west direction and 40 miles wide at its west end. These mountains constitute one of the largest uplifts on the stable platform that expose the basement complex. Precambrian gneisses and schists are overlain by metasediments of the Precambrian Belt Supergroup and a thick Paleozoic sequence is exposed peripheral to the core of the uplift. A large northwest trending fault termed the Smarker fault by Pulju (1964) forms the northern boundary of the Little Belts at the southern border of the study area.

The Sweetgrass arch is a broad north-northwest trending anticlinal structure of major proportions which passes through the northeastern corner of the project area. It lies entirely within the Central Stable Platform and is considered to be an extension of the northwest plunge of the Little Belt Mountains. The arch extends from the Little Belts northward to the Belly River area of Alberta.

## FOLDS

On small-scale geologic maps of central Montana, the Sweetgrass arch is marked by a 200 mile long north-trending outcrop band of the Cretaceous Colorado Group that ranges from 40 to 60 miles wide, and is flanked to the east and west by progressively younger formations. The great length and continuity undoubtedly led early geologists to believe that the Sweetgrass arch was a single broad, gentle anticline which extended from the Little Belt Mountains to near Medicine Hat, Alberta. The arch was thought to be modified only by a large saddle, termed the Marias River syncline, which extends east-northeastward across its central portion, at a right angle to the strike. It is this saddle which provides the southern closure for the Kevin-Sunburst oilfield located on the north part of the Sweetgrass arch.

In more recent work, Alpha (1955) indicates that the continuity of the Sweetgrass arch is broken by normal faulting in the Pendroy fault zone which lies south of, and parallel to, the Marias River syncline. The Sweetgrass arch is now considered to consist of two major segments, the South arch and the Kevin-Sunburst dome. The South arch, the major fold in the project area, is a broad low anticline that extends northwestward from the Little Belt Mountains and plunges to the Pendroy fault zone near Pendroy, Montana.

The extreme southern part of the South arch passes through the northeast corner of the thesis area. This is an area of low dips and the exposed Kootenai sandstones are generally cross-bedded, channeled, and not amenable to accurate strike-dip measurement. Therefore, the location of the axis of the South arch is indicated more by areas of older outcrops than by questionable measurements of the inclination of beds.

This procedure is less than ideal because the outcrop patterns reflect two different periods of deformation. Pre-Middle Jurassic deformation created a number of domes involving the Madison Group in an area directly east and north of Stockett (See geologic history section, this thesis). Evidently an ancestral Sweetgrass arch existed prior to the deposition of the Ellis Group. Because the domal structures are prominent and accurately locate the crest of the Sweetgrass arch as it existed prior to the deposition of the Jurassic, the South arch is shown on the geologic map (Plate 1) to coincide with the areas of Mississippian outcrop near Stockett.

The axial trace of the South arch trends N. 20 W. across the northern part of the area and coincides with exposures of the Morrison Formation along the lower, east-west portion of Sand Coulee and with outcrops of the Mission Canyon Formation north of Stockett. Where it leaves the map in the east-central portion of the area, it curves to a N. 50 W. trend and intersects the large area of Mission Canyon exposures to the east along Sand Coulee Creek.

The shallow dips in the northern portion of the area are generally northwestward and reflect the gentle plunge of the South arch. Minor local folds along the flanks of the arch are difficult to detect because of poor exposures and lack of topographic expression. For example, a small, nearly symmetrical, northeast-plunging syncline (Plate 1) is exposed in a county road cut (NE $\frac{1}{4}$, Sec. 18, T. 18 N., R. 5 E.) but is not reflected in the surface topography. The flanks of the syncline dip approximately 12 degrees and a number of thin lower Kootenai units can be traced continuously from limb to limb along the exposure.

## DOMES

Exposures of the Mission Canyon Formation north of Stockett, in Number Five Coulee, and at the head of Boston Coulee indicate a number of important domal uplifts in the southern and east-central portions of the map area (Plate 1). Only the dome in Boston Coulee, here named Pilgeram dome for Mr. Don Pilgeram, who gave access and cooperation for repeated trips to evaluate the structure, has a distinct topographic expression (Figure 2). Madison carbonates occupy the central portion of the dome and the elevated flanks are capped by the basal sandstone of the Kootenai Formation. The structures in Number Five Coulee and north of Stockett are overlain by relatively flat-lying Mesozoic strata. Here, Madison carbonates are exposed only where streams have cut through the overlying Cretaceous and Jurassic units.

Topographically, Pilgeram dome measures $2\frac{1}{2}$ miles east-west and $1\frac{1}{2}$ miles north-south. The dome structurally influences an area much larger than its topographic expression. In an area northeast of the apex of the dome, Ming Coulee has cut through to Mission Canyon carbonates that dip northeastward off the structure. South dipping units are broken by the Smarker fault about a mile south of the crest. The area influenced by the dome is approximately 12 square miles and the structural closure, estimated from topographic maps, is 800 feet.

All units on Pilgeram dome are involved in the deformation. Dips on the margins of the dome average 25 to 30 degrees and hogbacks are developed on most of the upturned edges of the more resistant units. One, and locally two, lower Kootenai sandstones form ridges. The Sawtooth and Swift formations in some places form individual ridges or elsewhere combine to form a single large ridge.

The stratigraphic column is more complete near the crest of the dome, where thin Kibbey and Otter exposures overlie the Mission Canyon. In Ming Coulee, a structurally lower portion of the dome is exposed and Big Snowy units have been eroded from the section. Here the Jurassic Sawtooth Formation directly overlies the Mission Canyon (Section 2, Appendix III). Thus the Kibbey and Otter Formations were removed from the Ming Coulee section by erosion that occurred before Pilgeram dome became a feature that could influence erosional and depositional trends. The Big Snowy units certainly were removed prior to the deposition of the Jurassic Ellis Group, and the doming could not have taken place prior to the deposition of the Cretaceous Kootenai Formation.

The domes exposed further north, in Number Five Coulee and north of Stockett, contrast with Pilgeram dome in a number of ways. Their lack of topographic expression belies the fact that Mesozoic strata are not involved in the deformation. The stratigraphic column is quite simple in this area as only the Mississippian Mission Canyon Formation, the Jurassic Swift and Morrison Formations and the Cretaceous Kootenai Formation are present. Figure 7 shows the Swift overlying the Mission Canyon in Number Five Coulee. Angular discordance between the Swift and Mission Canyon is minor in Number Five Coulee, but the unconformity is marked by prominent channels cut into the older unit (Figure 6). In the exposure $\frac{1}{4}$ mile north of Stockett, Mission Canyon bedding surfaces are locally sinuous and dips off this small dome range from 15 to 25 degrees. The Swift Formation in this area thins from about 40 feet total thickness on the flanks of the structure to less than five feet at the crest of the dome.

About a mile east of Stockett and outside the map area, the Mission Canyon is exposed for about $4\frac{1}{2}$ miles in a north-south direction along Sand Coulee Creek. This large Paleozoic exposure is also due to gentle doming. At a number of locations in Sand Coulee canyon, Swift sandstone overlying the Mission Canyon is totally unaffected by deformation which produced a series of small monoclines in the older formation. The point to be emphasized is that this deformation occurred prior to the deposition of the Upper Jurassic Swift Formation and is necessarily much earlier than the uplift that produced Pilgeram dome.

The small Mission Canyon exposure north of Stockett is probably part of the major structure in Sand Coulee. Although the Giffin Coulee structure probably formed at the same time, it is considered to be a small isolated flexure, not an integral part of the Sand Coulee structure.

## FAULTS

All faults in the map area are believed to be normal faults. They may be grouped under three headings: the major Smarker fault at the southern border of the map area, minor normal faults near the crests of the domes, and very minor normal faults scattered over the area.

The Smarker fault is a major structure that is marked by a prominent ridge along the southern border of the area. The fault is within the Madison Group except for its end, where it dies out toward Sand Coulee and has Big Snowy units on the downthrown side. It is nearly impossible to follow this fault plane in the massive carbonates of the Mission Canyon. All that can be said regarding orientation of the fault is that it is nearly vertical and strikes generally east-west, curving gently to N. 70° E. near the southeast corner of the map area. Pulju (1964, Plate II) indicates that the fault is vertical. Stratigraphic correlation in the Mission Canyon Formation from the upthrown (south) to downthrown (north) sides of the fault is very difficult. On the basis of topographic evidence, Pulju estimated the displacement of the fault to be about 200 feet.

Where the fault trace crosses the county road in the NE $\frac{1}{4}$, Sec. 6, T. 16 N., R. 5 E., it appears to die out to the east into a gentle anticlinal fold. Here, north dipping Big Snowy units on the downthrown side of the fault are at a slightly lower elevation than south dipping Mission Canyon strata on the upthrown side of the fault. At a number of other locations Madison carbonates dip away from the fault on both sides. Dips in the vicinity of the fault rarely exceed 35 degrees. This relationship prompted Pulju to declare that the fault is a very steep thrust fault that follows and dislocates the crest of an anticline. Pulju also implied that the folding and thrusting were essentially contemporaneous and were associated with the main period of uplift in the Black Butte area, which lies immediately south of the Smarker fault. Pulju suggested that this uplift and the associated intrusion of porphyritic diorites of the Black Butte stock occurred in the early Tertiary.

It is evident from exposures a few miles to the north that Madison carbonates had been appreciably folded prior to the deposition of the Upper Jurassic Swift Formation. This deformation is apparently of a broad regional extent and it is here concluded that the Smarker fault need not be closely related to the formation of an anticlinal structure which only involves rocks of Mississippian age. I agree with Pulju about the Tertiary age of the Smarker fault but am unconvinced that the related anticlinal structure need have formed as a result of the intrusion of the Black Butte stock. It is more reasonable to consider the Smarker fault a relaxation fault formed as a consequence of the uplift of the Black Butte area than to postulate a thrust developed along the crest of a rather gentle anticline. Vertical thrust faults are somewhat rare. Furthermore, one would expect steeper dips, even overturned units, near the crest of a thrust-faulted anticline.

The center of Pilgeram dome is breached by erosion at the head of Boston Coulee, where faults have created chaotic outcrop patterns. Although fault planes are not visible, three intersecting faults have been inferred on the geologic map (Plate 1). The central part of the dome has definitely dropped or collapsed with respect to the topographically higher flanks. The faulting at the crest of the dome is here interpreted to be "hinge" faulting, associated with the doming or with relaxation of stresses after the uplift. The downdropped central part of the dome was hinged on the relatively undisturbed west side of the topographic low.

About six miles east of Pilgeram dome is a larger but similar structure, Tiger Butte. It is topographically and structurally higher than Pilgeram dome and has been intruded by coarse grained quartz-monzonite near the center. Pilgeram dome probably formed by a similar process and the collapse features near the center of the structure resulted from cooling and shrinking of the underlying igneous mass. Indeed, exposures of the basal Kootenai conglomerate on the west side of Pilgeram dome are extremely well indurated and may have been baked by a closely underlying intrusion.

Minor normal faults, with no consistant strike orientation and with displacements less than 30 feet occur widely. In the southwest corner of the area along the Smith River, a normal fault has moved the Mississippian Kibbey Formation up against the base of the Sawtooth Formation. Another normal fault has disturbed units of the lower Kootenai Formation a few miles further north along the Smith River (Plate 1). Smaller faults of displacement less than 10 feet were observed in the Mission Canyon Formation in Ming Coulee near measured section 2, and in the outcrops one-fourth mile north of Stockett. Undoubtedly small normal faults are very common in the area, but few were observed because of poor exposures and lack of topographic expression.

# GEOLOGIC HISTORY

During most of its Precambrian and Paleozoic history, the Sweetgrass arch area was located on or near the western edge of the Central Stable platform. To the west was the eastern limit of the more rapidly subsiding Cordilleran geosyncline. A short distance south, there existed another persistent linear feature, the central Montana trough, which during the Paleozoic connected the Cordilleran geosyncline with the Willison basin to the east. The Central Montana trough also separated two segments of the Central Stable platform, the Alberta shelf to the north, and the Wyoming shelf to the south. The project area is part of the southwest Alberta shelf and is just north of the Central Montana trough. Consequently, the sediments record depositional environments that are predominently shelf marine. Continental and near-shore marine units occur sporadically throughout the section, but are more common in the Mesozoic system.

Inasmuch as the oldest unit described in the map area is of middle Mississippian age, the following data and interpretations of Precambrian and Early Paleozoic history are taken almost entirely from the literature. Recent reviews of Montana stratigraphy by McMannis (1965) and Peterson (1966) were relied upon heavily.

## PRECAMBRIAN

Precambrian sedimentary rocks of the Belt Supergroup are found in depositional troughs that were active during the Paleozoic and are absent in areas of uplift. For this reason, Sloss (1950), Alpha (1955), McMannis (1965) and Peterson (1966) suggest that the paleotectonic elements described above were established during Precambrian time. The pre-Belt basement complex shows a dominant northeast-striking structural configuration and a great range of igneous and metamorphic rock types. According to McMannis (1965), dates of pre-Belt metamorphic events range from 1.5 billion to 2.7 billion years.

During the late Precambrian, a thick sequence of mudstone, sandstone and limestone was deposited in what is now western Montana. No Precambrian sediments have appeared in the few wells on the Sweetgrass arch that have penetrated below the Cambrian (Peterson, 1966, p. 116), but a prominent east-west bulge of Beltian units extends south of the arch in the general area of the Central Montana embayment. The southern limit of this Belt embayment is fault-controlled (McMannis, 1963) and the northern limit of the trough was in the vicinity of the present-day Little Belt Mountains. In this range and possibly underlying the project area, are quartzites and argillites of the Belt Series. Shallow water deposition is indicated by ripple marks, cross-beds, and mudcracks throughout the Belt section. Algal stromatolites in the Wallace Formation and salt casts in the Missoula Group, high in the Belt sequence, suggest marginal marine deposition and intermittent subaerial exposure.

McMannis (1965, p. 1803) quoted a number of papers which suggest that the age of the upper part of the Belt series is about one billion years. A uranium-lead date from the Coeur d'Alene mining district of northern Idaho indicates that uraninite veins were emplaced in the Ravilli Group of the middle Belt Supergroup approximately 1.25 billion years ago (Eckelman and Kulp, 1957).

Belt rocks characteristically show a slight regional metamorphism to the chlorite subfacies of the greenschist facies. The low grade of metamorphism and the lack of an easily recognizable Precambrian-Cambrian unconformity of regional scale seem to conflict with accepted age dates which indicate that Belt sedimentation must have ceased at least 400 million years prior to the deposition of the earliest Paleozoic unit.

## CAMBRIAN

Cambrian units in central Montana are not regionally metamorphosed. Therefore the presence of an unconformity at the base of the Flathead sandstone is further supported by the fact that Belt units must have been metamorphosed on a regional scale before deposition of Cambrian strata. Erosion or nondeposition continued until Middle Cambrian time when seas transgressing from the west deposited the Flathead sandstone. The lack of a marked unconformity indicates a remarkable stability of the central and western Montana region during the long hiatus.

Little is known of the Cambrian units underlying the thesis area. Green and gray shales of the Woolsey Formation and limestones of the overlying Meagher Formation crop-out along Belt Creek as it emerges from the Little Belt Mountains. As shown in Table 1, the oldest unit penetrated in a deep well near Vaughn, Montana, is the Upper Cambrian Red Lion Formation, which consists of banded silaceous limestone. All Cambrian units mentioned above were probably deposited in relatively shallow water. Cambrian units thin from 3000 feet in western Montana to a maximum of 500 feet in the Sweetgrass arch area (Peterson, 1966).

## ORDOVICIAN-SILURIAN

Units of Ordovician, Silurian, and Early and Middle Devonian age are absent from the Sweetgrass arch. Peterson (1966) indicates that this period of apparent nondeposition must be explained by regional emergence in central and western Montana. Ordovician and Silurian deposition did extend beyond Peterson's zero isopach, as pre-Late Devonian erosion truncates these units east of the Sweetgrass arch. Uplift and erosion was limited, however, as the Devonian-Cambrian unconformity shows little erosion in spite of the long hiatus.

## DEVONIAN

During the Late Devonian, shallow seas transgressed across central Montana and gray shale and dolomitic siltstone and sandstone of the Maywood Formation were deposited. As might be expected of the first unit deposited by a transgressing sea, the Maywood contains more terrigenous material than the remainder of the Devonian strata.

Shallow marine to restricted marine conditions continued through the deposition of the Jefferson dolomite and the basal Potlatch anhydrite member of the overlying Three Forks Formation. Maughan (1961) indicated a very thick anhydrite sequence northwest of the thesis area (Table 1). The nearest Devonian exposures are in the Little Belt Mountains, closer to the axis of the Central Montana trough. Here the Devonian has minimal evaporite deposition and reflects less of a restricted environment. Wilson (1955) described cyclic deposition of silty dolomite, then brown limestone, sucrosic dolomite, and bedded anhydrite in the Devonian of Montana and attributed this sequence to shallow water marine environments of varying restriction, controlled by variations in reef growth in contemporaneous Devonian units of Alberta.

The upper part of the Three Forks Formation consists of interbedded green and red shale, siltstone, and limestone. Wilson attributed this interruption of carbonate-evaporite deposition to a slight transgression which brought fine clastics into the uppermost Devonian depositional basin.

## MISSISSIPPIAN

In the Williston basin of eastern Montana, sedimentation of clastic material continued uninterrupted from the Upper Devonian into the Lower Mississippian with deposition of dark shales of the Bakken Formation. On the Sweetgrass arch and in the Little Belt Mountains, the Bakken is very thin or absent, and a minor unconformity is commonly present at this interval.

The lowermost mapable Mississippian unit in the Little Belt Mountains is the Lodgepole limestone, here considered to be the lowest formation of the Madison Group. According to Chamberlain (1955) the Lodgepole varies from 500 to 700 feet thick beneath the project area and progressively thickens southward toward the Central Montana trough (with respect to Mississippian units, commonly termed the Big Snowy embayment). Lodgepole exposures in the Little Belt Mountains strongly indicate cyclic deposition. Thin to medium bedded limestone and dolomitic limestone alternate with thin dark gray shale beds. Peterson

(1966, p. 121) states:

> "Regionally, the Lodgepole is very widespread, extending southward across northern Wyoming, southeastern Idaho, and northwestern Utah and northward into Canada. The unit appears to be a northern and western basinal facies of the Mississippian seas as it is not developed on the southern Rocky Mountain shelf and apparently grades northward in part into the relatively thick Banff shale of Alberta. The cyclic nature of the Lodgepole may represent an alternation of deepening waters of slightly restricted circulation (dark gray shales) followed by shallower waters and deposition of the fossiliferous limestone beds."

A trend to thicker carbonate and thinner and more scattered dark shale units continues through the upper part of the Lodgepole into the lower portion of the overlying Mission Canyon Formation. The boundary is gradational and difficult to exactly locate. Cyclic deposition in the Mission Canyon of the project area is indicated by the repetitive alternation of thick bedded limey units and thin to medium bedded dolomites. These cycles may be the result of minor changes in depth, circulation, or salinity of the shallow Mission Canyon sea. A solution breccia zone, underlain by a laterally-linked hemispheroidal (LLH) stromatolitic algal sequence, occurs in the uppermost Mission Canyon in the Ming Coulee measured section. According to Logan, Rezak, and Ginsburg (1964), the LLH growth form is produced only in a shallow, intertidal, slightly agitated marine environment. The algal environment probably represents incipient restriction that culminated with evaporite deposition. Solution and collapse may have occurred during the pre-Kibbey hiatus or at an unknown later date. Because most solution breccia zones can be correlated with bedded anhydrite in the subsurface (Roberts, 1966), I believe that brecciation occurred in Tertiary or more recent time.

Near the beginning of the Chesterian epoch, regional uplift exposed the Madison Group and Mississippian seas made a brief retreat from the central Montana area. At this time a well developed karst surface formed on the exposed Mission Canyon over an area that extended from central Wyoming northward into Canada.

Relatively soon after formation of the karst, deposition of the Big Snowy Group commenced. As mentioned earlier in this report, the age of the basal Kibbey is not exactly known. Because of a gradational contact with the overlying Otter Formation of known Chesterian age, the Kibbey is believed to have been deposited during the Chesterian. In any case, the hiatus represented by the unconformity is relatively short, involving only part of an epoch.

Scott (1935, p. 1026) suggested that the Kibbey represents residual material derived from the Madison limestone. Perry and Sloss (1943) noted that quartz comprises at least 90 percent of Kibbey sandstones and siltstones, a concentration not expected for a soil derived from cherty carbonates. Mundt (1956, p. 1919) noted the rounded, frosted nature of most Kibbey quartz grains and their widespread and regular distribution in a fine-grained matrix. He suggested that the quartz grains were wind blown into the area of Kibbey accumulation prior to, or during the transgression of the Chesterian sea.

The characteristic bright brick-red color of the Kibbey is strikingly similar to _Terra Rosa_ soils developed by lateritic weathering of carbonate rocks in a moist tropical climate. The exposed Madison surface was probably of very low relief; hence, favorable for the development and preservation of a thick residuum of _Terra Rosa_ type soil. This compelling similarity of the Kibbey lithology and a Terra Rosa soil suggests that the Kibbey is in part a residual deposit that was formed above sea level and later reworked and modified by transgression of the Chesterian sea. During the initial stages of the transgression, gypsum pods and minor gypsum cement were formed as a result of evaporation of sea water in small shallow basins present only sporadically during deposition of the Kibbey.

The sequence of green and gray shales with intercalated platy limestone that composes the Otter Formation in the project area appears to be of shallow marine origin. The green shale intervals represent deepening water with restricted circulation so that oxidation of the sediment was kept to a minimum. This relatively reducing environment did not prevail throughout the Otter as maroon shale units occur near the top of the Otter section. Formation and preservation of algal mats is greatly assisted by repeated subaerial exposure and subsequent partial desiccation. The algal limestone interbeds present in the Otter probably represent a shallowing to a tidal-flat environment. The source area for the Otter sediments was probably low or lushly vegetated.

In the Bridger Range near Bozeman, Montana, McMannis (1963) noted that where the Big Snowy is thickest, the Mission Canyon is thickest. Conversely, where the Big Snowy beds are thin or absent, the Mission Canyon is also thinner. This indicates that the Big Snowy Embayment subsided throughout the Mississippian and that present limits of the Big Snowy Group partially reflect original depositional trends. The Big Snowy Group is not reported in the subsurface of the Sweetgrass arch and is restricted to the extreme southern part of the map area. For the following reasons, I suggest that the Big Snowy Group was deposited over the southern part of the Sweetgrass arch area:

1. No shoreline facies of the Kibbey or Otter Formations were discerned in the map area.
2. The rapid northward loss of 400 feet of Big Snowy strata in less than a mile is probably controlled by pre-Middle Jurassic erosion.
3. The Otter thickens northward toward the zero Big Snowy isopach.
4. Pre-Jurassic folding of Mission Canyon carbonates required an appreciable overburden. (See the following section.)

## PENNSYLVANIAN-PERMIAN-TRIASSIC

Rocks of Pennsylvanian, Permian and Triassic age are not present in the project area, nor in the entire area of the Sweetgrass arch. Units of the marine Middle and Upper Jurassic Ellis Group overlie Mississippian strata in all of northern Montana, but are underlain by progressively younger units to the south. According to McMannis (1956), this may be due to regional southward tilting of the Paleozoic surface sometime prior to the deposition of the Ellis.

As mentioned in the Structural Geology section of this report, monoclinic folds in the Mission Canyon Formation that are truncated and overlain by undisturbed Swift sandstone are compelling and definitive evidence for post-Middle Mississippian, pre-Upper Jurassic deformation in the southern part of the South arch (Figure 15). It is impossible to document the exact time of deformation, but I suggest that the deformation occurred after deposition of early Pennsylvanian units.

Carbonates are very brittle and competent at surface temperatures and pressures, hence, it is difficult to comprehend folding which locally produced dips up to 40 degrees in the Mission Canyon if these carbonates were not covered by a relatively thick overburden. As mentioned above, the Kibbey and Otter Formations are abruptly truncated by pre-Middle Jurassic erosion a short distance north of the Little Belt Mountains and were probably deposited over the entire map area. Gardner (1959) indicates about 1500 feet of the redefined Big Snowy Group in the Big Snowy Mountains, about 80 miles southeast of the project area. The upper Big Snowy units in the Big Snowy Range are Early Pennsylvanian in age.

Figure 15. Looking north at exposure of folded Mission Canyon carbonates along Sand Coulee Creek (SW $\frac{1}{4}$, NW $\frac{1}{4}$, Sec. 32, T. 19 N., R. 5 E.). The Mission Canyon is unconformably overlain by brown Swift sandstone which is unaffected by the folding.

The nearness of upper Big Snowy strata and the implied necessity for a relatively thick sedimentary cover over the Madison at the time of folding suggest that Early Pennsylvanian and perhaps Permian and Triassic sediments were deposited over the project area and perhaps the entire area of the South arch. It follows that deformation must have been Middle Pennsylvanian or later. It is likely that the domal structures in the map area reflect an early Sweetgrass arch that formed sometime in the interval from Middle Pennsylvanian through Early Jurassic time.

## JURASSIC

The long period of erosion or nondeposition continued through Lower Jurassic time in the project area and over the rest of the Sweetgrass arch. Marine Lower Jurassic rocks have not been identified south of Alberta. During the Middle and Upper Jurassic, seas moved down from the north and covered the Sweetgrass arch area. Thus Middle Jurassic Sawtooth-Piper units represent the first widespread post-Carboniferous marine transgression into central Montana.

Nordquist (1955), Imlay et al., (1948), and Peterson (1957, 1966) noted striking east-west facies changes in the Sawtooth-Piper Formation in central Montana. They indicate that the change from normal or slightly restricted marine deposition on the west side of the Sweetgrass arch (Sawtooth) to restricted marine environments east of the arch (Piper) was controlled by a large low positive area in central Montana. This feature, known as Belt island, profoundly affected the distribution, nature and thickness of all units of the Ellis Group. Observations and conclusions made during the course of this study substantiate the earlier interpretations.

The crest of the present day Sweetgrass arch follows the old Belt island trend that was developed during the post-Early Pennsylvanian deformation postulated above. The unique oolitic texture of the Sawtooth in the project area provides further evidence that Belt island was a barrier to circulation in the Middle Jurassic sea. The oolids represent an agitated shallow water environment that would be expected near the topographic crest of a barrier such as Belt island located at or slightly below sea level.

The Rierdon Formation of the Ellis Group is absent in the project area. Peterson (1966, p. 124) indicates that transgression of the Rierdon sea was a widespread event and suggests that local absence of Rierdon shale on the arch is due to pre-Swift erosion. Along the southern border of the map area, the Swift rests unconformably on the Sawtooth, the Rierdon being absent. In the northern and central portions of the area, the Sawtooth also is absent and the Swift rests directly on Mission Canyon carbonates.

This relatively intense period of erosion was brought to a close by the southward movement of the so-called Sundance sea which extended into Arizona and New Mexico and eastward into western Nebraska and Kansas. The Swift Formation was deposited in Montana by this Upper Jurassic (Oxfordian) sea. The basal shale in the Swift type section in northern Montana does not extend into the project area. Only the upper sandstone unit is present.

Peterson (1966) suggests that the upper Swift sandstone was deposited as a recessive clastic unit during the final withdrawal of the Jurassic seas. This statement seems valid on a regional basis, but other interpretations may be made concerning the deposition of the Swift in the project area. The absence of the lower Swift shale and the presence of a relatively thin sandstone unit in the project area probably represents transgression of the Sundance sea onto what must have been a slightly higher area on the Belt island trend. The ubiquitous presence of a conglomeratic unit at the base of the Swift and the progressive diminution of grain size upwards in the unit support the transgressive nature of the Swift in the project area. It is probable, however, that the uppermost fine grained sandstones of the Swift were reworked during the final regression of the Sundance sea.

Regional regression of Upper Jurassic seas left a terrestrial area of very low relief, barely elevated above sea level. With no apparent break in sedimentation, fluvial and lacustrine strata of the Morrison Formation were deposited on this surface. Varicolored mudstones of the lower Morrison are believed to be flood plain deposits of widely separated streams. Stokes (1944) noted the scarcity of channel sands in the Morrison of Colorado, questioned the alluvial origin of the unit and suggested that the predominantly fine grained Morrison received considerable material by volcanic ash fall.

I saw no volcanic ash beds in the Morrison but did note many small sandstone lenses throughout the formation. Streams flowing from an arid source area to the south and west would become overloaded as they emerged onto the almost featureless plain left by the retreating Sundance sea. Morrison streams continually filled their channels with sediment and spilled over to new locations. Because of the low gradients and possible interior drainage, fine clastics predominated and no record of major streams remains. The hypothesis of an arid lower Morrison environment is supported by the lack of plant fossils in lower Morrison shales and mudstones.

Plant fossils, dark gray shales and coal are common in the upper Morrison and are indicative of a more moist climate. Ephemeral lakes are believed to have been common during the deposition of the upper Morrison. In stagnant lakes with a low influx of clastics, organic material accumulated and formed coal swamps. Bituminous shales and coal are common near the top of the Morrison Formation, but thick coal deposits are restricted to separate, isolated areas within the Great Falls - Lewistown Coal Field.

The coal may have been deposited over the entire Great Falls - Lewiston area and portions of it subsequently removed by pre-Kootenai erosion. Another alternative, favored by Harris (1966), is that the boundaries of present coal fields are largely depositional. Harris stated that at numerous localities the rapid thinning of coal seams indicates the "approach of the coal to the edge of the basin of accumulation." Only slight pre-Kootenai erosion is apparent in the map area and I suggest that both processes were operative but that the coal is restricted more by original deposition than subsequent erosion.

## CRETACEOUS

Data is lacking for the placement of the Jurassic-Cretaceous boundary, but because of a major regional lithologic change and a small but persistant unconformity at the base of the basal conglomeratic sandstone of the Kootenai, it is usually placed at the Morrison-Kootenai contact. Channeling along the unconformity is relatively minor and much of the contact's irregularity is due to differential compaction of the upper Morrison shale and coal (Figure 12).

The basal Kootenai conglomeratic sandstone is present over an immense area from Colorado to southern Alberta. It seems much too thin for an alluvial sandstone that is relatively continuous over such a large area. Stokes (1950) interpreted basal Cretaceous conglomerates in Colorado as desert pavement lag gravels that accumulated in a tectonically quiescent area with an arid to semiarid climate. Peterson (1966) concluded that Stokes' suggestions also apply to the basal Kootenai sandstone in the central Montana area.

The widespread presence of a lag gravel indicates that a marked change in climate toward increasing aridity was largely responsible for the drastic lithologic change at the Morrison-Kootenai contact. Possibly a newly uplifted area to the west caused a rain-shadow belt that instigated the change to an arid climate. This drier climate decreased the vegetative cover in the source area to the west and rare or seasonal heavy rains were quickly channeled to runoff. Thus, the usually dry channels were occasionally flooded by streams overloaded with sediment. These streams flowed eastward to an area of lower relief and dropped the majority of their load. Each resulting flood created a new set of shifting channelways and hence tended to distribute the sediment over a broad area of deposition. Between periods of fluvial sedimentation, wind erosion could have selectively removed much of the finer grained material from the deposit and thus left a poorly sorted residual gravel.

An alternative interpretation, most recently stated by Suttner (1966), is that the basal Kootenai conglomerate is a result of the eastern movement of the Laramide orogeny into the northern Idaho-western Montana area. Uplift of the source area to the west may have been a contributing factor, but it does not explain the widespread deposition of such a thin conglomeratic layer. A tectonic conglomerate is typically a wedge-shaped prism of coarse clastics and can not be expected to maintain a thickness of much less than 100 feet over thousands of square miles.

The depositional environment of the upper part of the Kootenai is difficult to ascertain. Individual sandstone, siltstone, and mudstone units of the upper Kootenai are of very limited lateral continuity and suggest shifting sediment-clogged stream channels on a broad pedimentary surface. The fine grained nature of most of the upper Kootenai suggests that most of the material was deposited on the flood plains of the streams.

Kootenai sedimentation was terminated by the transgression of an Early Cretaceous sea that covered most of the northern interior of the Rocky Mountain region. Deposition of the Blackleaf, basal formation of the Colorado Group commenced at this time. The Blackleaf-Kootenai boundary is apparently conformable.

Only the basal Flood Member of the Blackleaf occurs in the project area. The presence of the Taft Hill, Vaughn, and Bootlegger members of the Blackleaf in the nearby Cascade-Ulm and Vaughn areas strongly suggests that these units were deposited over the study area. The upper members of the Blackleaf have a much lower sand : shale ratio than the Flood, but lithologies of individual sand and shale units are strikingly similar throughout the formation.

Cannon (1966) states that during most of Blackleaf sedimentation, the shoreline of the Early Cretaceous sea was located west of the Great Falls area. Sandy zones in the Blackleaf represent minor eastward regressions that replaced deposition of fine grained clastics with sedimentation of near-shore sands. The sandstones that dominate the Flood Member represent offshore bars or intertidal beach sands.

## TERTIARY

Uplift of the Little Belt Mountains, rejuvenation of the Sweetgrass arch, and epeirogenic uplift of great portions of the Montana plains probably occurred in the Early Tertiary, somewhat coincident with the Laramide orogeny (Lyons, 1944; Wolf, 1964). This is about the time of extrusion of the Adel Mountain volcanics in the northern part of the Big Belt Mountains and the major diastrophism in that portion of the disturbed belt which lies about 15 miles west of the project area. Dissection of the still nearly level land surface probably began during the Late Tertiary.

Up to 300 feet of Kootenai bedrock is exposed in bluffs located on the inside of the large meanders of the Missouri River between Ulm, Montana and the mouth of Sand Coulee. It must be concluded that this segment of the river is superimposed on the Kootenai or flood-capped surface. This may be the result of slow epeirogenic uplift of the area in Tertiary time or a change in the capacity of the river as a result of increased runoff, perhaps from glacial sources.

## QUATERNARY

During Pleistocene time a number of events related to continental glaciation markedly changed the major drainage patterns of the area. The lower portion of Sand Coulee is an abandoned segment of the Missouri River channel that was blocked by the Montana Lobe of the Keewatin Ice Sheet during the Illinoisian advance. Because this east-west segment of the present Sand Coulee drainage is nearly as broad as the present Missouri River valley (Figure 16), and the relief nearly as great, it is concluded that the Missouri River and probably other major drainages of north-central Montana were well established prior to the Illinoisian stage of the Pleistocene. Much of the downcutting probably occurred during the earlier Kansan and Nebraskan stages of Pleistocene glaciation.

An ice dam of fluctuating elevation, together with its associated moraine, blocked Sand Coulee in Secs. 18, 19, and 20, T. 20 N., R. 5 E., just one mile northeast of the northeast corner of the map area and created various levels of glacial lake Great Falls. The moraine consists of unsorted clays, sands, pebbles and cobbles; the coarser grained fraction is composed primarily of fragments of limestone, sandstone and nonporphyritic basalt. Calhoun (1906) provided multiple evidence, recorded below, that the lower Sand Coulee valley is an old channel of the Missouri River:

1. "The topographic relations are such that a broad valley like that now occupied by Sand Coulee Creek could not have been formed by that stream or any other stream flowing westward."

2. Although of a slightly lesser size, the cross-section of Sand Coulee is almost identical to that of the Missouri just below Great Falls.

3. Sand Coulee meanders in a way that closely resembles the Missouri River valley from Ulm, Montana, to the junction of Sand Coulee Creek.

4. "The tributary valleys which join Sand Coulee form acute angles on the downstream side of the junction. They seem to have been formed when the water in the valley flowed in the opposite direction." (It should be noted that the tributary streams have adjusted to the present direction of flow and that it is the tributary valleys that form an acute angle downstream from their junction with Sand Coulee. -- author)

Figure 16. View looking south-southwest across Sand Coulee valley at its junction with the Missouri River. Missouri River in middle distance.

The terrace gravel deposits along Sand Coulee provide conclusive new evidence identifying the drainage as an abandoned channel of the Missouri River. The lithologies of the gravels match those of Precambrian metasediments and Tertiary volcanics which crop out upstream along the Missouri. In fact, it is inconceivable that pebbles with this combination of lithologies could have been derived from a location other than upstream along the Missouri River. Similar terrace gravels are found along the present Missouri River channel between Ulm and Great Falls. Finally, the imbrication of flat pebbles found along Sand Coulee clearly indicates that the stream which deposited them was flowing from west to east (Figure 13).

Glacial lake Great Falls drained to the north of the old Missouri River channel as lake waters followed a portion of the pre-Illinoisian Sun River and eventually cut a new channel, the banks of which were utilized for the city of Great Falls. Abrupt changes in the character of the Missouri River above and below Great Falls indicate that in the vicinity of the city the river is not in its preglacial valley.

The headwaters of the Missouri are in the extreme southwestern portion of Montana. After 300 miles of confinement by mountains, the river escapes to the plain near Hardy, Montana. From this point, the Missouri meanders northward across a wide floodplain and drops only 85 feet along the 75 miles to Great Falls. At Great Falls, the river leaves the wide floodplain and enters a relatively narrow, steep-walled canyon cut into Cretaceous sandstone. The next ten miles of the Missouri's course are marked by numerous falls and rapids as the river drops 512 feet in this comparatively short distance. These cataracts are supported by resistant Kootenai sandstones.

The local relief near the new channel is in excess of 300 feet, hence it is obvious that much erosion has occurred after Illinoisian glaciation. Much of this downcutting may be attributed to torrential runoff during the last glacial advance (Wisconsin stage).

Fluvial sedimentation undoubtedly began as soon as the waters of glacial lake Great Falls receded. Present profiles of major streams and most of the smaller drainages were probably developed fairly early in Recent time. Material deposited since then is mostly landslide deposits and a thin veneer of floodplain alluvium.

# E C O N O M I C   G E O L O G Y

## COAL

Coal occurs in the upper part of the Jurassic Morrison Formation across a broad east-west belt that extends from southwest of Great Falls to southeast of Lewistown, Montana. In the project area, as in the remainder of the Great Falls-Lewistown Coal Field, deposits of potentially economic coal are restricted to local basins. The most important coal producing basin within the map area is centered around the towns of Stockett and Sand Coulee (See coal mine locations, Plate 1). According to Fisher (1909-a), this area was the most important Montana coal producer during the early 1900's. Lesser amounts of coal have been mined along the Smith River near the junction of Hound Creek and in Ming Coulee a short distance upstream from the settlement of Eden.

Coal mining in the area started in 1876 (Buck, 1961) and reached a peak in the early 1940's when 350 men employed in the Cottonwood coal mine near Stockett mined an average of 1800 tons per day. Total production from this mine alone amounted to 5.4 million tons of coal (Silverman and Harris, 1966). Much of the coal mined in the area was used as locomotive fuel by the Great Northern railroad, owner of the Cottonwood Coal Company. The remainder of the coal found use in local smelters and domestic coal furnaces. The introduction of diesel fuel for locomotives in the early 1940's and the use of natural gas for household heating have almost totally eliminated the market for coal produced in the vicinity of Great Falls.

No coal mines are presently operating in the project area.

Total coal thicknesses, the number of individual coal benches and the thickness of shaly partings between coal benches are variable even within local basins. Mines along the Smith River were small compared to adjacent operations along Hound Creek and, due to long abandonment, good coal exposures in this area are presently unavailable. Fisher (1909-a) noted a maximum coal thickness of 4 feet 10 inches in the Rice mine, located on the east side of the Smith River a short distance downstream from the mouth of Hound Creek. The following quotation from Silverman and Harris (1966, p.153) adequately describes coal thicknesses in the Stockett-Sand Coulee and Ming Coulee areas:

> "Coal in the Stockett-Sand Coulee basin occurs in a seam containing three benches and two bone partings. The lower coal bench is one to two feet thick and is separated from the middle bench (four to seven feet thick) by a one-foot coaly shale. The upper coal bench was not mined. The roof rock in this area is composed of Morrison shale and siltstone up to three feet thick, which in turn is overlain by the basal Kootenai sandstone. In Ming Coulee, between Stockett and the Smith River, coal is present in outcrops along the drainage from the town of Eden to the southeast. Although the mines in this area were not extensively developed, the coal seam varies from two and one-half to seven feet in thickness and is commonly overlain by the basal Kootenai sandstone."

Proximate and ultimate chemical analyses of coal from the Smith River and Stockett-Sand Coulee areas are presented in Fisher (1909-a). The data is included as Table 3 of this report. On the basis of physical properties (agglomerating or nonagglomerating) and average B.t.u. values, the coals can be ranked a subbituminous B to high volatile C bituminous (ASTM classification).

Coal reserves in the project area are quite large. According to Silverman and Harris (1966, Table 5), coal reserves in the Stockett-Sand Coulee area (including Ming Coulee) are 163 million tons of coal in beds 36 inches or greater in thickness, 47.4 million tons in beds from 24 to 36 inches thick and 28.0 million tons in beds from 14 to 24 inches thick. These figures amount to 29 percent of the coal reserves in the entire Great Falls-Lewistown coal field and 36 percent of that coal which occurs in beds 36 or more inches in thickness.

Even though large reserves are present in the Great Falls area at depths commonly less than 200 feet, the coal is not being exploited. A number of important factors control the economic potential of the coal.

The nature of the basal Kootenai conglomeratic sandstone, which everywhere overlies the coal, poses two important problems influencing economic extraction. The thickness and hardness of the unit effectively prevent relatively inexpensive removal by strip mining. In addition, the basal Kootenai sandstone is an excellent aquifer and considerable water from it is likely to complicate any underground mining operation as the impermeable coal and carboniferous shale of the Morrison are removed. Conversely, this sandstone makes an excellent, easily supported roof rock for underground mining.

Marketability of the central Montana coals is hampered by their relatively high ash and sulphur contents (Table 3), as well as competition from extensive coal deposits in Utah and Wyoming that are of equal or higher rank and may be strip mined. The old coal markets

Analyses of coal samples from the Stockett-Sand Coulee and Smith River Districts.*

(Note: Proximate and ultimate analyses are in percent.
Ash is included in both proximate and ultimate analyses.)

| | Stockett-Sand Coulee District | | Smith River District | | |
|---|---|---|---|---|---|
| Analysis of sample as received: | (1) | (2) | (1) | (2) | (3) |
| Proximate – Moisture | 6.01 | 7.49 | 4.82 | 6.17 | 4.54 |
| Proximate – Volatile matter | 28.43 | 27.29 | 27.17 | 27.03 | 27.44 |
| Proximate – Fixed carbon | 51.42 | 51.44 | 46.13 | 52.03 | 47.95 |
| Proximate / Ultimate – Ash | 14.14 | 13.78 | 21.88 | 14.77 | 20.07 |
| Ultimate – Sulphur | 2.38 | 2.32 | 2.84 | 4.36 | 4.09 |
| Ultimate – Hydrogen | 4.46 | 4.68 | 4.36 | 4.43 | 4.23 |
| Ultimate – Carbon | 63.61 | 62.61 | 56.98 | 61.62 | 58.66 |
| Ultimate – Nitrogen | .91 | .88 | .72 | .93 | .87 |
| Ultimate – Oxygen | 14.50 | 16.13 | 13.22 | 13.89 | 12.08 |
| Calories | 6,196 | 6,115 | 5,578 | 6,077 | 5,818 |
| British thermal units | 11,153 | 11,007 | 10,040 | 10,939 | 10,472 |
| Loss of Moisture on air drying | 2.40 | 2.60 | 1.90 | 2.20 | 1.70 |
| Analysis of air-dried sample | | | | | |
| Proximate – Moisture | 3.70 | 5.02 | 2.98 | 4.06 | 2.89 |
| Proximate – Volatile matter | 29.13 | 28.02 | 27.69 | 27.63 | 27.91 |
| Proximate – Fixed Carbon | 52.68 | 52.81 | 47.03 | 53.20 | 48.79 |
| Proximate / Ultimate – Ash | 14.49 | 14.15 | 22.30 | 15.11 | 20.41 |
| Ultimate – Sulphur | 2.43 | 2.38 | 2.90 | 4.46 | 4.13 |
| Ultimate – Hydrogen | 4.33 | 4.51 | 4.24 | 4.25 | 4.18 |
| Ultimate – Carbon | 65.17 | 63.88 | 58.08 | 63.02 | 59.66 |
| Ultimate – Nitrogen | .92 | .89 | .73 | .95 | .88 |
| Ultimate – Oxygen | 12.66 | 14.19 | 11.75 | 12.21 | 10.74 |
| Calories | 6,348 | 6,278 | 5,678 | 6,213 | 5,918 |
| British thermal units | 11,427 | 11,300 | 10,244 | 11,185 | 10,654 |
| Fuel ratio | 1.81 | 1.88 | 1.70 | 1.93 | 1.75 |

*Modified from Fisher, 1909-a.

are no longer available, thus renewal of coal production in the Great Falls area is dependent upon the development of new outlets. A coal burning steam-electric plant in the Great Falls area could provide this new outlet. As power demands for domestic and industrial use increase, local steam generated electricity may be needed. The Missouri River supplies the necessary water and the Stockett-Sand Coulee Coal Field could provide large tonnages of coal with low to medium B.t.u. content, provided the mining could be done cheaply and efficiently.

## GRAVEL

A number of gravel deposits are present along the east-west portion of Sand Coulee, and four gravel pits are currently in production. The largest is worked by the Montana Sand and Gravel Company of Great Falls and is located on the north side of Gibson Flat, a meander of the preglacial Missouri River (SE $\frac{1}{4}$, Sec 16, T. 20 N.,R. 4 E.). Smaller pits are located on a bench on the south side of Sand Coulee, near the junction with the Missouri River (NW $\frac{1}{4}$, Sec. 6, T. 19 N., R. 4. E.) and along Sand Coulee in Secs. 34 and 35, T. 19 N., R. 4 E.). Refer to gravel pit locations on Plate 1.

The gravels and sands in all of the Sand Coulee pits are believed to have been deposited by the Missouri River. The gravel and sand in the Montana Sand and Gravel Company pit is more than 30 feet thick and in the other operating pits is more than 10 feet thick.

Minor amounts of caliche cement coat the undersurfaces of pebbles in all of the pits along Sand Coulee. This cement poses no problem as disaggregation during mining and size-classification is nearly complete. The gravels of the smaller pits are directly at the surface and easily removed. A thin mantle of varved glacial lake silts overlies the alluvial gravels at the Montana Sand and Gravel pit.

Most of the gravels are used as concrete aggregate and road metal. Their nearness to the city of Great Falls allows them to compete with larger operations that work alluvium of the Sun River west of the city. As U. S. Interstate Highway 15 is extended east of Great Falls, away from the Sun River deposits, their economic potential will surely increase. Possibly a number of the inactive pits along Sand Coulee will then come into operation.

## OTHER ECONOMIC DEPOSITS

Construction of houses, highways and "defence" installations provides a market for minor amounts of limestone and sandstone for building stone or riprap. Until recently, the Great Northern railroad used lower Kootenai sandstone from a quarry in lower Sand Coulee as riprap for railroad beds. This sandstone is the fine-grained unit immediately above the basal Kootenai sandstone and its flaggy nature made removal relatively inexpensive. The quarry is ideally located adjacent to a Great Northern spur which extends from Great Falls to Sand Coulee and Tracy. If the need develops, the quarry could be inexpensively reopened. Kootenai sandstone is locally used in small amounts for lining dug wells, decorative stone, and riprap for small stock-pond dams.

Gypsum lenses in the lower part of the Kibbey Formation were noted during the geologic mapping, but are of uncertain lateral continuity. The presence of large gypsum reserves near Heath, Montana, may limit the funds available for trenching and detailed gypsum exploration in the project area.

# G R O U N D W A T E R

## INTRODUCTION

A supply of good quality water is necessary for almost every domestic, agricultural and industrial pursuit of all men who live or work within the project area. Certainly this water is the most valuable resource that is extracted from the rocks that underlie the project area. The following discussion is concerned only with those stratigraphic units which are found to contain usable amounts of good quality water. Detailed lithologic descriptions are found in the Stratigraphic section of this thesis and are not restated in the following discussion.

Well and spring water in the project area is largely derived from the upper part of the Madison Group, lower Kootenai sandstones, and the basal Flood member of the Blackleaf Formation. A number of dug and shallow drilled wells obtain water from recent and preglacial alluvium of the Missouri River and alluvium of the Smith River and smaller streams. A few wells produce water from the Swift Formation.

Most of the project area is underlain by one or more of the major aquifers and because of this multiplicity of potential sources, areas in which water may not be obtained are exceptional. Near the front of the Little Belt Mountains and along certain stretches of some of the drainages, most of the potential aquifers have been removed or transected by erosion and water may be difficult to obtain.

Other local problems are a result of geological phenomena such as variation in the cementation of a sandstone, irregularities in the bottom surface of a sandstone aquifer, and massive solution zones in carbonates. These phenomena and the difficulties they present to the water-well driller will be discussed in detail as individual aquifers are considered.

At present there is no sustained areal water-table depression as wells are widely dispersed across the project area. The city of Great Falls, located a few miles north of the area, derives water from the Missouri River and no town within the project area is of sufficient size to significantly influence the regional drawdown. One-hundred forty-three wells, about half of those in the map area, are described in Appendix I of this report. The density of wells is estimated to be little more than one well per square mile. The average annual precipitation (precipitation is greater toward the Little Belt Mountains) is adequate to sustain present rates of water consumption for an unlimited period of time.

Because of the overlying aquicludes, and the gentle, sustained regional dip off the Little Belt Mountains and the west flank of the Sweetgrass arch, artesian pressures commonly develop in a number of the aquifers. Sandstones in the lower part of the Kootenai Formation are relatively continuous over the project area, are bound above and below by impermeable shales, and almost everywhere carry water under artesian pressure. To a lesser extent, artesian conditions exist in the Swift Formation and the Flood Member of the Blackleaf. The artesian conditions are reflected in the fact that water levels in many of the wells are elevated above the top of the source aquifer. Pressure in very few of the artesian wells is sufficient to force water to the surface, but above average precipitation during the spring of 1965 caused a number of wells to flow.

# AQUIFERS

## Madison Group

Large quantities of water are locally produced from the upper part of the Madison Group, but many expensive attempts to derive water from this unit have been totally unsuccessful. This problem is clarified by an understanding of the nature and distribution of the porosity and permeability of the Mission Canyon Formation.

With the possible exception of minor oolite beds, unaltered Mission Canyon carbonates are low in primary porosity and permeability. Local zones of high permeability are due to the effects of solution, both within and at the top of the Mission Canyon. As suggested by the Swift-filled channels cut into Mission Canyon carbonates exposed in Number Five Coulee, the upper surface of the Madison is probably uneven. Permeable zones of solution debris can be expected to be distributed somewhat irregularly over the top of the Mission Canyon in the project area.

Near the head of Ming Coulee, close to the front of the Little Belt Mountains, the stream sporadically disappears into sinkholes formed in the upper part of the Mission Canyon Formation. Presumably this water enters solution channelways within the Madison Group. Except for local domes in the vicinity of Stockett, the Madison has a gentle regional dip to the north. Consequently, water that enters solution zones south of the project area may be expected to move northward into the Madison strata that underlie the project area. These channels are present only under a limited portion of the study area. Wells such as the Tracy Water Users Corporation well no. 122 and General Mills well no. 123

fortunately intersected such channelways and derive almost unlimited amounts of good quality water from the Madison.

Most wells to the Madison in the Tracy area can draw air down their casings with such force that leaves and other debris are carried along. On other days, the same wells will, in unison, expell air from the casing. According to Charles Entsminger, manager of the General Mills elevator at Tracy, (personal communication, 1965) 14 wells within the settlement of Tracy were completed at depths varying from 165 to 200 feet. All of these wells yield tremendous volumes of water from the Madison. Running water may be heard in all of these wells. These curious phenomena suggest that: (1) solution channelways are present in the upper part of the Madison Group; (2) that these channelways interconnect and allow the passage of air; (3) that the channelways are open to the surface, probably in or near the Little Belt Mountains.

Where no secondary permeability is developed, the Madison can be expected to yield little water. Cavernous areas are present which contain no water and present great problems to the water well driller. The Mapston well no. 59 is located in a part of Number Five Coulee where the Mission Canyon is the only available aquifer. The well driller penetrated the Mission Canyon to a depth of 474 feet, found no water, and repeatedly lost drill bits into dry caverns (Mrs. Rose Mapston, personal communication, 1965).

The Mission Canyon Formation crops out over a broad area in the Little Belt Mountains (an area with average annual precipitation as high as 40 inches) and gains water that enters sinkholes along the minor drainages that leave the mountains. Hence, those wells that derive water from the Mission Canyon Formation can be expected to be most stable with respect to drawdown during heavy usage or an exceptionally dry year. As shall be seen in the following discussions, all of the other bedrock aquifers in the area have a much smaller area of recharge.

## Swift Formation

Fine to coarse grained calcareous sandstones of the Swift Formation maintain a fairly uniform thickness of from 40 to 60 feet across most of the project area. The porosity and permeability of the Swift is generally high; the sandstone interstices are not completely filled by calcareous cement. Paradoxically, this formation is not an important aquifer in the project area. Only a few wells are believed to derive water from the Swift and only the Gruel no. E spring (Appendix II) yields large quantities of water from the unit.

The Swift Formation is not a major productive aquifer because it has no large up-dip area of recharge and because little of the precipitation that falls on the area underlain by the Swift ever percolates down to the unit. The Swift's area of recharge is greatly limited by up-dip truncation along the front of the Little Belt Mountains. The Swift is present under most of the thesis area, but the impermeable shales of the overlying Morrison Formation limit the acquisition of downward moving meteoric water.

## Kootenai Formation

The basal Kootenai conglomeratic sandstone is by far the most utilized aquifer in the project area. Fifty-four percent of the wells examined during the course of this investigation derive water from the Kootenai Formation. Most of the Kootenai well descriptions (Appendix I) list the aquifer as lower Kootenai sandstone rather than directly citing the basal conglomerate.

Exact identification of the lower Kootenai aquifer in wells distant from outcrops is difficult due to the local presence of a separate, fine-grained well-sorted sandstone above the basal conglomerate. This unit is locally separated from the basal conglomerate by up to 40 feet of freshwater limestone and red and black shale. Commonly, the basal conglomeratic unit grades upward into the fine grained sandstone and the shale and limestone interval is absent. In many of the deeper wells it is almost impossible to determine the number of lower Kootenai sandstones or to ascertain which one supplies the water. Well-drillers' reports are generally sketchy, of questionable accuracy, and provide scant assistance toward solving the problem. Because most Kootenai springs issue from the basal sandstone, it is concluded that many aquifers described as lower Kootenai are actually the basal unit.

Rarely, wells sunk to the base of the Kootenai are unproductive. This is mostly due to local tight cementation or excessive amounts of interstitial clay. These local decreases in permeability are responsible for isolated dry holes and are unfortunately difficult to anticipate. A special problem confronts landowners on the interdrainage between Number Five Coulee and Cottonwood Coulee. Great amounts of sulphur and iron laden water emerge from abandoned coal mines and greatly reduce the water content of the basal Kootenai conglomerate.

The up-dip extension of the Kootenai Formation is terminated at the front of the Little Belt Mountains, therefore its area of recharge is confined to the project area. Lower Kootenai sandstones are consistantly good aquifers because they eventually receive most of the downward moving meteoric water that infiltrates the surface. Because of a restricted recharge area, Kootenai-derived water supplies may be vulnerable to severe drought.

## Blackleaf Formation

Moderate amounts of ground water are obtained from wells into either or both of the sandstone units of the Flood member of the Blackleaf Formation. Springs issue from both the upper and lower sandstones of the Flood where they are exposed by stream erosion along gullies and coulees. Most noteable springs issuing from the Flood are the Hensler no. H and the Horan no. J, which are located on small tributaries of Goodwin Coulee and yield 50 to 60 gallons per minute, respectively, from the thin-bedded lower sandstone. Most springs in the Flood are fracture-controlled and only minor amounts of water seep from the unbroken sandstone.

The Flood crops out only in the northwest quarter of the project area (plate 1). As it is present only at the top of a high bench, its only possible source of groundwater recharge is the rain and snow which falls directly on this limited surface. The area that can provide water to a given well drilled or dug into the Flood is also limited by Goodwin Coulee, which nearly bisects the area of Flood outcrop. Because of the limited, local area of recharge, wells and springs which tap the Flood may be expected to be quite sensitive to an extended period of drought.

## Alluvium

Varying amounts of alluvium are present along the valley bottom of almost every stream in the area. The alluvium that is found along many of the smaller drainages occupies a relatively narrow belt and is not shown on the geologic map. As a result, a number of wells, such as the C. Konesky no. 23 well, which tap alluvial sources (See Appendix I), are located on the geologic map in areas mapped as bedrock. All alluvial deposits large enough to be included on the map are fairly reliable sources of abundant, good quality water at shallow depth.

The alluvium consists of unconsolidated to slightly consolidated gravel, sand, silt, and clay deposited in the channel and on the floodplain of recent and Pleistocene streams. Sorting is relatively good, hence the gravels and sands are relatively permeable and are the best potential water carriers in the alluvium.

Along the floodplains of the major streams, the water table is generally within 10 to 20 feet of the surface. Fluctuations of the water table parallel, but lag behind, changes of the water level in the streams. Many wells along the lower course of Sand Coulee derive water from alluvium. Most of the dug wells are shallow and had to be deepened during the summer of 1963 after a long dry period. The F. Vining no. 142 well bottoms in alluvium at a depth of 135 feet and probably derives water from preglacial Missouri River alluvium.

Almost all wells which bottom in alluvium are considered adequate water sources by the ranchers in the area and produce ample water for domestic, stock, and garden use. Robert Klasner, who bought the entire townsite of Stockett from the Cottonwood Coal Company, developed a low-production well in Cottonwood Coulee so that it provides over 90 percent of the town's water supply (Klasner, personal communication, 1965). In 1963 the existing well went dry. Klasner diverted the creek channel and dug a trench 3 feet wide, 12 feet deep, and 200 feet long into the alluvium. The trench was filled with washed gravel and cobbles and 200 feet of perforated four-inch pipe was installed. The pipe is always full and continually empties into a catch-basement. Water then moves by gravity to a reservoir tank near Stockett. This modified well (well no. 73, Appendix I) provides excellent quality water for 79 of the 86 families in Stockett. According to Klasner, this well could provide for the entire water needs of a town many times the size of Stockett.

## QUALITY OF WATER

Most of the groundwater in the area is of good to excellent taste, satisfactory chemical composition, and sufficiently free of biologic contaminants. It is, therefore, usable for all domestic and stock purposes. A large number of wells yield water that is sufficiently hard to necessitate water-softening treatment for domestic supplies. Chemical analyses by the Montana State Board of Health from a few of the representative wells are presented in Table 4.

Water from the R. Vining no. 141 well has a value of 1900 parts per million (ppm) for total dissolved solids; triple the values expected from water derived from the Madison Group, Kootenai Formation, Flood member or the alluvium. The extraordinary sulphate content of 995 ppm is difficult to explain other than by contamination by downward percolation of sulphate rich water that enters Sand Coulee Creek upstream.

The F. Vining well no. 142 is situated less than 100 yards from the R. Vining well no. 141. This well has only 560 ppm total dissolved solids and has a greatly reduced sulphate content (Table 4). In lower Sand Coulee, the presence of better quality water at depth may be due to natural purification during downward movement, but it is possible that deeper alluvium in Sand Coulee receives water from a completely different source, such as seepage from the Missouri River into the old preglacial channel.

Analyses of the General Mills no. 122 well and the Lyman no. X spring are believed to be representative of water from the upper part of the Madison and the basal Kootenai sandstone, respectively. The

Table 4

Chemical analyses of well and spring water in milligrams per liter.*

| Map Mumber | 141 | 142 | 122 | X |
|---|---|---|---|---|
| Iron (Fe) | 0 | 2.96 | 0 | 0.10 |
| Calcium (Ca) | 280 | 66 | 185 | 48 |
| Magnesium (Mg) | 119 | 66 | 38 | 71 |
| Sodium and Potassium (Na-K) | 105 | 68 | 15 | 75 |
| Carbonate ($CO_3$) | 0 | 0 | 0 | 0 |
| Bicarbonate ($HCO_3$) | 372 | 412 | 210 | 396 |
| Sulphate ($SO_4$) | 965 | 212 | 420 | 174 |
| Chloride (Cl) | 52 | 10 | 8 | 37 |
| Fluoride (F) | 1.4 | 2.0 | 0.8 | 1.1 |
| Nitrates ($NO_3$) | 34 | 8 | 25 | 20 |
| [illegible] | [illegible] | .94 | 1.00 | .93 |
| Total Hardness (as $CaCO_3$) | 1188 | 435 | 615 | 512 |
| Total Dissolved Solids | 1900 | 560 | 850 | 610 |

*Determined by the Montana State Board of Health.
Map numbers refer to Appendices I and II.

taste of the water is excellent, but sulphate present in the Madison water is in excess of the 250 ppm recommended by the U.S. Public Health Service for municipal use.

In general, water wells located in alluvium are most susceptible to surface pollution. Contaminants introduced to the ground surface near or upstream from a well in alluvium may quickly pollute the water supply.

Because of unfavorable chemical analyses and a strong petroliferous odor associated with water from the Swenson no. 51 well, the Cascade County Board of Health declared the water unfit for consumption at a small country school that uses water hauled from neighboring ranches. The Swenson well was sunk in alluvium and it is doubtful that the Kootenai formation was penetrated. Source of the petroleum taint was most likely leakage or spillage around a gasoline tank located a short distance from the well. Another rancher reported difficulties resulting from the location of a cattle feed-lot too close to his domestic well sunk in alluvium.

## SUGGESTIONS TO WATER WELL DRILLERS

As noted in the description of individual aquifers, local adverse changes in the nature of the rock may cause a dry well to be located in what is regionally a good aquifer. Changes in the cementation and interstitial clay content of the basal Kootenai sandstone, for example, may be observed in exposures along the coulees, but are almost impossible to predict beneath the broad benches that characterize the majority of the project area. The following suggestions, therefore, are a guide to evaluating the possibilities of finding water in a given sector of the area and determining which aquifer is the most reasonable target for a proposed well. In no case can the author definitely say that water can be derived from a particular aquifer at a given well site.

The basal Kootenai conglomerate is present in the subsurface across almost the entire area (Plate 1). Its water carrying capacity is so well documented that it should be a prime target for water well drilling in all but the northwest quarter of the project area. Here shallower Flood sandstones may carry abundant water. Along coulees where the Flood has been removed, it is evident that water sources in the Kootenai Formation should be developed. If the target sandstones of the Flood provide insufficient water, the landowner should be given the option of abandoning the hole. The upper 200 feet of the Kootenai Formation are predominantly shale and mudstone and are thus unlikely to bear water (See Sec. 8, Appendix III). Depth to the lower Kootenai sandstone, the next potential aquifer, is approximately 350 additional feet.

After reading the stratigraphy section of this report, an observant well driller can determine when he has drilled through the basal Kootenai sandstone. Unfortunately, as exemplified by the Takala no. 75 dry well, a driller may pass through a Kootenai sandstone above the basal conglomerate and upon encountering black shales and freshwater limestone in the lower Kootenai, conclude that the best potential aquifer has been tested and therefore abandon the well.

As long as the well cuttings show a predominant red or maroon color, the driller may be certain that the bottom of the well is still above the basal Kootenai conglomerate. An interested driller might examine the dark gray shales and freshwater limestones of the lower Kootenai that are well exposed and easily accessable along the Missouri River Road, one-quarter mile from its junction with the Eden Road at the Trailer Terrace corner (SE $\frac{1}{4}$, Sec. 36, T. 20 N., R. 3 E.). The dark shales of the lower Kootenai should not be confused with the carbonaceous shale and coal that occupy the upper part of the Morrison Formation and underlie the basal Kootenai conglomerate. It should be emphasized that the problematic lower Kootenai sandstone is fine grained, free of interstitial clay, and contrasts with the poorly sorted basal Kootenai conglomeratic sandstone.

In portions of the area where the basal Kootenai conglomerate is not present (Plate 1), the Swift Formation and the upper part of the Mission Canyon Formation are the remaining potential targets. In areas north of the Little Belt Mountains, the Swift directly overlies the Mission Canyon and the two units should be considered as a single drilling target. The Swift does produce abundant good-quality water for a number of wells (Appendix I), but as mentioned in the discussion of individual aquifers, attempting to obtain water from the Mission Canyon is a risky proposition and many drilling problems may be encountered.

Alluvium along all of the valley bottoms should be seriously considered as a potential source of water. Wells in alluvium should be located so that they are not near or immediately downstream from a potential source of contamination, such as a cattle feed-lot or a leaking gasoline tank. As exemplified by the efforts of R. Klasner (See discussion of alluvium, aquifer section), it may be possible to develop a large dependable water supply from alluvium along smaller drainages. If the individual landowner contemplates using this water for large-scale irrigation, he must take care not to drastically deplete the source and violate the vested water rights of landowners downstream.

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# APPENDIX I

## WATER WELLS

| Well no. | ¼ ¼ | Sec. | Twp. | Rge. | Owner | Depth (feet) | Static Level (from surface) | Date measured | Aquifer | Use*** | Amt. gpm |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | SW, SE | 6, | 16 N., | 5 E. | L. Anderson | 36.2 | 15.9 | 7-10-65 | Madison Gp. | D.S. | 5 |
| 2 | SE, SE | 7, | 16 N., | 5 E. | T. Westerland | 20 R** | Flows | 7-5-65 | Madison Gp. | D.S. | 10 |
| 3 | NW, NW | 8, | 16 N., | 5 E. | D. Umphres | 65 R | 10 R | 7-5-65 | Madison Gp. | S. | Sm |
| 4 | NE, NE | 18, | 16 N., | 5 E. | D. Umphres | 28 R | 8 R | 7-5-65 | Madison Gp. | D.S. | Sm |
| 5 | SW, SE | 19, | 16 N., | 5 E. | J. Gasvoda | 25 R | 4 R | 7-5-65 | Madison Gp. | S. | Sm |
| 6 | NW, NW | 29, | 16 N., | 5 E. | D. Gasvoda | 22.1 | 1.2 | 7-8-65 | Madison Gp. | S. | Sm |
| 7 | SE, SE | 30, | 16 N., | 5 E. | T. Westerland | 38 R | 14 R | 7-5-65 | Madison Gp. | S. | 20 |
| 8 | SE | 1, | 17 N., | 2 E. | W. Meer | ---- | 18 R | 7-17-64* | Alluvium | D.S. | Sm |
| 9 | NE, NE | 4, | 17 N., | 3 E. | L. Smiley | 30.2 | 13.75 | 6-22-65 | basal Kootenai Fm. | D. | Sm |
| 10 | SW, NW | 8, | 17 N., | 3 E. | G. Marko | 30 R | 8 R | 6-22-65 | Alluvium | D.S. | Sm |
| 11 | NE, NW | 11, | 17 N., | 3 E. | L. Smiley | 26 R | 18 R | 6-22-65 | basal Kootenai Fm. | D. | Sm |
| 12 | NE, SW | 11, | 17 N., | 3 E. | E. Marxer | 60.2 | 15.88 | 6-22-65 | basal Kootenai Fm. | None | Sm |
| 13 | SE, NE | 11, | 17 N., | 3 E. | E. Marxer | 220 R | 145 R | 6-23-65 | lower Kootenai Fm. | S. | Sm |
| 14 | NE, NW | 12, | 17 N., | 3 E. | L. Reardon | 212 | 115 | 6-23-65 | lower Kootenai Fm. | D.S. | Sm |
| 15 | SW, SW | 12, | 17 N., | 3 E. | E. Marxer | 25.8 | Flows | 6-22-65 | basal Kootenai Fm. | D.S. | 8 |
| 16 | NE, SE | 15, | 17 N., | 3 E. | J. Maurer | 135 R | ---- | 6-23-65 | lower Kootenai Fm. | D. | Sm |
| 17 | NE, NW | 25, | 17 N., | 3 E. | J. Staigmiller | 95 R | 25 R | 6-23-65 | lower Kootenai Fm. | D. | Sm |
| 18 | NE, NE | 26, | 17 N., | 3 E. | J. Staigmiller | 72 | 57.1 | 6-23-65 | Kootenai Fm. | D.S. | Sm |
| 19 | SE, NW | 2, | 17 N., | 4 E. | W. Jacobs | 120 R | 30 R | 7-6-65 | lower Kootenai Fm. | D. | Sm |
| 20 | SW, SE | 5, | 17 N., | 4 E. | A. Baehler | 187 R | 30 R | 6-30-65 | lower Kootenai Fm. | S. | Sm |
| 21 | NW, NE | 7, | 17 N., | 4 E. | L. Marxer | 44 R | ---- | 6-24-65 | Kootenai Fm. | D.S. | 4 |
| 22 | NW, SW | 8, | 17 N., | 4 E. | S. Bell | 88 R | 10 R | 6-25-65 | lower Kootenai Fm. | D.S. | Sm |
| 23 | NW, NW | 12, | 17 N., | 4 E. | C. Konesky | 20 R | 14 R | 7-5-65 | Alluvium | D. | Sm |
| 24 | NW, SE | 14, | 17 N., | 4 E. | W. Jacobs | 125 R | 30 R | 7-6-65 | lower Kootenai Fm. | S. | Sm |
| 25 | NW, NW | 14, | 17 N., | 4 E. | D. Jacobs | 78 R | 48 R | 7-6-65 | lower Kootenai Fm. | S. | 7 |

* All Wells dated 1964 were measured by Fox (1965)

** R=Reported

*** D=Domestic
S=Stock
I=Irrigation

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 26 | NE, SW 16, 17 N.,4 E. | T. Konesky | 158.3 | 92.5 | 6-30-65 | lower Kootenai Fm. | S. | 5 |
| 27 | NE, NE 17, 17 N.,4 E. | T. Konesky | 94 R | 69 R | 6-30-65 | lower Kootenai Fm. | None | Sm |
| 28 | SW, NW 17, 17 N.,4 E. | Meisenbach School | 90 R | 40 R | 6-24-65 | lower Kootenai Fm. | D. | Sm |
| 29 | NE, NE 18, 17 N.,4 E. | J. Pilgeram | 83 R | 40 R | 6-25-65 | lower Kootenai Fm. | D.S. | 10 |
| 30 | SW, NW 20, 17 N.,4 E. | J. Pilgeram | 52.1 | 9.4 | 6-24-65 | lower Kootenai Fm. | D | 5 |
| 31 | NW, NE 20, 17 N.,4 E. | T. Konesky | 48 R | 20 R | 6-30-65 | lower Kootenai Fm. | D.S. | 10 |
| 32 | NW, NE 29, 17 N.,4 E. | D. Pilgeram | 185 | 60 | 6-30-65 | lower Kootenai Fm. | D.S. | 20 |
| 33 | NE, NE 29, 17 N.,4 E. | D. Pilgeram | 92 R | 60 R | 6-30-65 | lower Kootenai Fm. | S | 150 |
| 34 | SE, NW 6, 17 N., 5 E. | F. Schott | 150 R | 50 R | 7-10-65 | lower Kootenai Fm. | D.S.I. | Sm |
| 35 | NW, SW 6, 17 N., 5 E. | F. Schott | 150 R | 105 R | 7-10-65 | lower Kootenai Fm. | D.S.I. | Sm |
| 36 | NE, NW 6, 17 N., 5 E. | J. Kohut | 89 R | 20 R | 7-10-65 | lower Kootenai Fm. | D | 6 |
| 37 | NW, SW 7, 17 N., 5 E. | F. Schott | 136 R | 116 R | 7-10-65 | Swift-Madison Fm. | S | 10 |
| 38 | NE, NE 22, 17 N.,5 E. | F. Schott | 195 R | 165 R | 7-10-65 | lower Kootenai Fm. | S | 18 |
| 39 | NW, SW 1, 18 N., 2 E. | D. Roehm | 155 R | 125 R | 7-17-64 | Alluvium | D.S. | 20 |
| 40 | NE, SW 1, 18 N., 2 E. | D. Roehm | 205 R | 190 R | 7-17-64 | Alluvium | S | Sm |
| 41 | SW, NW 13, 18 N.,2 E. | J. Hocevar | 18 R | 7 R | 7-31-65 | Alluvium | D.I. | 5 |
| 42 | SE, SE 14, 18 N.,2 E. | R. Gruel | 60 R | 52 R | 7-21-64 | Alluvium | S. | Sm |
| 43 | NW, NW 24, 18 N.,2 E. | R. Gruel | 15 R | 10 R | 7-21-64 | Alluvium | D.S. | Sm |
| 44 | SW, SE 36, 18 N.,2 E. | F. Murphy | 26.30 | 2.05 | 7-17-64 | Alluvium | D. | Sm |
| 45 | SE, NW 36, 18 N.,2 E. | A. Young | 72 R | 40 R | 7-21-64 | Alluvium | D.S. | Sm |
| 46 | SE, SW 1, 18 N., 3 E. | F. Kruse | 100 R | 60 R | 8-12-65 | Kootenai Fm. | S. | 7 |
| 47 | NW, NW 5, 18 N., 3 E. | L. Dickman | 95 R | 50 R | 8-24-65 | lower Flood Mm. | none | 3 |
| 48 | NW, NE 10, 18 N.,3 E. | M. Bruneau | 18.6 R | 14 R | 8-12-65 | Alluvium | D.S.I. | Sm |
| 49 | SE, NE 10, 18 N.,3 E. | H. Pederson | 10 R | 1.9 R | 8-12-65 | Alluvium | D.S. | 5 |
| 50 | SE, NE 13, 18 N.,3 E. | A. Borgstrom | 6.8 | 0.8 | 7-15-65 | lower Kootenai Fm. | D.S. | 18 |
| 51 | SE, SE 14, 18 N.,4 E. | N. Swenson | 22 R | 6 R | 8-12-65 | Alluvium or lower Kootenai Fm. | D. | Sm |
| 52 | NW, NE 21, 18 N.,3 E. | J. Yuhas | 70 R | ---- | 7-15-65 | Flood Mm. | S. | 20 |
| 53 | NE, NW 23, 18 N.,3 E. | J. Lorang | 240 R | very low | 7-15-66 | Kootenai Fm. | none | none |
| 54 | NE, NE 23, 18 N.,3 E. | J. Kohut | 7.9 | 2.0 | 7-15-65 | Kootenai Fm. | D.S.I. | 8 |
| 55 | SE, NW 29, 18 N.,3 E. | E. Maxell | 72 R | 52 R | 8-11-65 | Flood Mm. | D.S.I. | .75 |
| 56 | NE, SW 9, 18 N., 4 E. | M. Halko | 11.2 | Flows | 7-23-65 | Kootenai Fm. | D.S.I. | Sm |
| 57 | SE, NW 10, 18 N.,4 E. | M. Halko | 18 | 10 R | 7-5-65 | Kootenai Fm. | D. | Sm |
| 58 | SW, NE 10, 18 N.,4 E. | M. Dusinko | 23 R | 15 R | 7-22-65 | Swift Fm. | D.I. | 3.5 |
| 59 | NE, NE 10, 18 N.,4 E. | R. Mapston | 474 R | dry | 7-5-65 | Madison Gp. | none | none |
| 60 | NE, NE 10, 18 N.,4 E. | R. Mapston | 38.3 | 6.0 | 7-5-65 | Swift Fm. | none | Sm |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| [illegible] | [illegible] | L. Hatcher | 20.6 | 9.8 | 7-2-65 | Kootenai Fm. | D.S. | Sm |
| 62 | NE, SW 14, 18 N.,4 E. | R. Klasner | 55 R | 20 R | 6-29-65 | Swift Fm. | D.S. | 10 |
| 63 | SW, SE 16, 18 N.,4 E. | G. Borgstrom | 18 R | 3.5 R | 7-2-65 | Kootenai Fm. | D.S. | Sm |
| 64 | SE, SW 18, 18 N.,4 E. | J. Yuhas | 48 R | 7.5 R | 7-15-65 | Kootenai Fm. | D. | 3.5 |
| 65 | NW, NE 19, 18 N.,4 E. | E. Lorang | 210 R | 150 R | 7-15-65 | lower Kootenai Fm. | S. | 20 |
| 66 | NE, NE 25, 18 N.,4 E. | E. Dennis | 20 R | Flows | 7-8-65 | lower Kootenai Fm. | D. | Sm |
| 67 | SE, SE 29, 18 N.,4 E. | C. Van Horn | 19 R | 5.9 R | 7-2-65 | Kootenai Fm. | D.S. | 5 |
| 68 | SE, NW 31, 18 N.,4 E. | R. Mikelson | 43.2 | 23.28 | 6-17-65 | basal Kootenai Fm. | D. | Sm |
| 69 | NE, SW 31, 18 N.,4 E. | R. Mikelson | 12.76 | 3.04 | 6-17-65 | Alluvium | D. | 8 |
| 70 | NW, NW 34, 18 N.,4 E. | A. Borgstrom | 60 R | 30 R | 7-2-65 | Kootenai Fm. | none | Sm |
| 71 | NW, NW 35, 18 N.,4 E. | W. Steyaert | 236 R | 221 R | 7-2-65 | lower Kootenai Fm. | D.S. | 6 |
| 72 | NW, NW 35, 18 N.,4 E. | W. Steyaert | 35 R | 20 R | 7-2-65 | Kootenai Fm. | D. | Sm |
| 73 | NW, NW 6, 18 N., 5 E. | R. Klasner | 12 R | 10 R | 7-6-65 | Alluvium | D. | 200 |
| 74 | SW, NW 6, 18 N., 5 E. | A. Dolena | 38 R | 28 R | 7-13-65 | Swift Fm.-Alluvium | D.S. | Sm |
| 75 | SW, SE 7, 18 N., 5 E. | W. Takala | 80 R | dry | 7-13-65 | lower Kootenai Fm. | none | none |
| 76 | SW, NE 8, 18 N., 5 E. | F. Raunig | 55 R | 16.8 R | 7-14-65 | Swift Fm. | S.I. | 10 |
| 77 | NE, SE 19, 18 N.,5 E. | J. Kornowsky | 22 R | 8 R | 7-13-65 | Kootenai Fm. | D.S.I. | 10 |
| 78 | SE, SW 20, 18 N.,5 E. | A. Goette | 16.2 | 3.7 | 7-13-65 | Kootenai Fm. | S.I. | 10 |
| 79 | NE, SW 27, 18 N.,4 E. | J. Kornowsky | 160 R | 94 R | 7-13-65 | Swift Fm.-Madison Gp. | none | 0.1 |
| 80 | SW, SW 28, 18 N.,5 E. | J. Tesinsky | 54 R | 44 R | 7-13-65 | Kootenai Fm. | D.S.I. | 15 |
| 81 | SE, SW 29, 18 N.,5 E. | M. Swartz | 38.1 | 13.4 | 7-10-65 | Kootenai Fm. | D.S. | Sm |
| 82 | NW, NW 29, 18 N.,5 E. | J. Knaup | 39.2 | 3.9 | 7-13-65 | Alluvium-Kootenai | D.I. | 5 |
| 83 | SW, NW 31, 18 N.,5 E. | C. Gerke | 85 R | 75 R | 7-8-65 | Kootenai Fm. | D. | 8 |
| 84 | NE, NE 32, 18 N.,5 E. | M. Swartz | 45 R | 20 R | 7-14-65 | Kootenai Fm. | D.S. | 2 |
| 85 | SE, SW 23, 19 N.,2 E. | D. Marxer | 144 R | 40 R | 7-17-64 | Alluvium | D.S. | Sm |
| 86 | NE, NE 23, 19 N.,2 E. | J. Marxer | 145 R | 50 R | 7-17-64 | Kootenai Fm. | S. | 20 |
| 87 | NE, NW 26, 19 N.,2 E. | D. Marxer | 150 R | 25 R | 7-17-64 | Alluvium | D.S. | Sm |
| 88 | NE, SW 26, 19 N.,2 E. | Truly Sch. District | 147 R | 85 R | 7-17-64 | Alluvium | D. | 46 |
| 89 | NW, SE 35, 19 N.,2 E. | H. Hastings | 21.10 | 14.70 | 7-17-64 | Alluvium | D. | Sm |
| 90 | NE, NE 1, 19 N., 3 E. | G. Wilson | 95 R | 1.0 | 8-6-65 | Kootenai Fm. | D.I. | -- |
| 91 | NW, SE 6, 19 N., 3 E. | A. Polich | 35 R | 15 | 8-11-65 | Alluvium | D.S.I. | 10 |
| 92 | NW, SW 13, 19 N.,3 E. | R. Hahn | 22 R | 6.2 R | 8-5-65 | basal Kootenai Fm. | D.S. | 3 |
| 93 | SE, SW 14, 19 N.,3 E. | R. Stanich | 38 R | 27 R | 8-12-65 | Alluvium | D.S.I. | 16 |
| 94 | SE, NE 22, 19 N.,3 E. | R. Duggan | 65 R | 25 R | 8-28-65 | Alluvium | D.S.I. | 50 |
| 95 | NE, SE 23, 19 N.,4 E. | C. Reid | 126 R | Flows | 8-6-65 | lower Kootenai Fm. | D. | 20 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 96 | NW, NE 24, 19 N.,3 E. | S. Enott | 70 R | --- | 8-6-65 | lower Kootenai Fm. | D.S.I. | 10 |
| 97 | NW, NW 32, 19 N.,3 E. | C. Young | 96 R | 46 R | 8-24-65 | Flood Mm. | D.S.I. | 4 |
| 98 | NE, NW 34, 19 N.,3 E. | J. Kuki | 50 R | 22 R | 8-5-65 | Kootenai Fm | D.S.I. | 8 |
| 99 | NE, NW 36, 19 N.,3 E. | S. Lassila | 12 R | Flows | 8-5-65 | Flood Mm. | D.S. | 1½ |
| 100 | SW, NW 3, 19 N., 4 E. | C. Nolde | 20 R | 15 R | 8-29-65 | Alluvium | D.I. | Sm |
| 101 | SW, NE 5, 19 N., 4 E. | P. Elespuru | 50 R | 20 R | 8-1-65 | lower Kootenai Fm. | D. | 10 |
| 102 | SW, SW 6, 19 N., 3 E. | J. Gendreau | 265 R | --- | 8-2-65 | lower Kootenai Fm. | D.I. | 100 |
| 103 | NE, NE 7, 19 N., 4 E. | P. Elespuru | 125 R | --- | 8-12-65 | lower Kootenai Fm. | D. | 5 |
| 104 | NE, SW 9, 19 N., 4 E. | T. Gillespie | 403 R | 100 R | 7-31-65 | Madison Gp. | D. | 3 |
| 105 | SW, NW 10, 19 N.,4 E. | L. Franzich | 24 R | Flows | 7-23-65 | Kootenai Fm. | none | Sm |
| 106 | NE, NW 13, 19 N.,4 E. | Sand Coulee Water Assoc. | 210 R | 134 R | 7-22-65 | basal Kootenai Fm. | D.I. | 85 |
| 107 | SE, NW 14, 19 N.,4 E. | H. Franzich | 133 R | --- | 7-23-65 | lower Kootenai Fm. | D.S.I. | 12 |
| 108 | SW, NW 15, 19 N.,4 E. | C. Franzich | 193 R | 55 R | 7-23-65 | lower Kootenai Fm. | D.I. | 4½ |
| 109 | SW, SW 19, 19 N.,4 E. | G. Dutt | 7.9 | 0.8 | 8-24-65 | Alluvium | S. | Sm |
| 110 | SW, SE 21, 19 N.,4 E. | T. Pettyjohn | 108 R | 11 R | 8-24-65 | lower Kootenai Fm. | D.S. | 7 |
| 111 | NW, NW 23, 19 N.,4 E. | E. Hakola | 7.2 | 0.2 | 7-23-65 | Kootenai Fm. | D.S.I. | 5 |
| 112 | SW, SW 23, 19 N.,4 E. | H. La Rogue | 9.9 | 0.9 | 7-22-65 | Kootenai Fm. | S. | Sm |
| 113 | SE, SW 23, 19 N.,4 E. | E. Chartier | 60 R | 5.4 | 7-23-65 | lower Kootenai Fm. | D.S. | 7 |
| 114 | SE, SE 23, 19 N.,4 E. | E. Chartier | 22.8 | 10.8 | 7-23-65 | Kootenai Fm. | none | 2 |
| 115 | SW, NW 28, 19 N.,4 E. | G. Konesky | 12 | 1.3 | 8-28-65 | Alluvium | S.I. | Sm |
| 116 | NW, SW 28, 19 N.,4 E. | G. Konesky | 60 R | --- | 8-28-65 | Kootenai Fm. | D. | 1½ |
| 117 | NE, SW 33, 19 N.,4 E. | L. Wirtala | 185 R | 180 R | 7-22-65 | basal Kootenai Fm. | D. | 2.5 |
| 118 | SW, NW 34, 19 N.,4 E. | N. Young | 165 R | 16 R | 7-22-65 | lower Kootenai Fm. | D. | 5 |
| 119 | SW, SE 36, 19 N.,4 E. | R. Klasner | 18 R | 12 R | 7-6-65 | Alluvium | D. | 25 |
| 120 | SE, SE 36, 19 N.,4 E. | M. Frisnegger | 48.6 | 30.9 | 7-13-65 | Swift Fm. | none | Sm |
| 121 | NW, SW 7, 19 N., 5 E. | Tracy Water Users Corp. | 190 R | 100 R | 7-23-65 | Madison Gp. | D.S.I. | large |
| 122 | NW, NW 18, 19 N.,5 E. | General Mills Inc. | 265 R | 165 R | 7-22-65 | Madison Gp. | D.S.I. | 50 |
| 123 | NW, SE 18, 19 N.,5 E. | R. De Michielli | 187 | 160 | 7-22-65 | Madison Gp. | D. | 12 |
| 124 | SE, NW 19, 19 N.,5 E. | D. Yatsko | 227 R | 187 R | 7-22-65 | Madison Gp. | D. | Sm |
| 125 | SE, SE 29, 19 N.,5 E. | C. McCafferty | 12 R | 6 R | 7-5-65 | basal Kootenai Fm. | none | Sm |
| 126 | NE, SE 23, 20 N.,3 E. | J. Kostohris | 215 R | 25 R | 7-31-65 | Alluvium | D. | 20 |
| 127 | SE, SW 25, 20 N.,3 E. | W. Jordan | 18 R | 9 R | 8-29-65 | Alluvium | D.I. | 190 |
| 128 | SE, NE 25, 20 N.,3 E. | Ayrshire Dairy | 193 | 54 | 7-31-65 | lower Kootenai Fm. | D.S.I. | 30 |
| 129 | NW, SE 36, 20 N.,3 E. | C. Hagen | 229 R | 154 R | 7-29-65 | lower Kootenai Fm. | D.I. | 26 |
| 130 | SW, SE 36, 20 N.,3 E. | G. Chamberlain | 95 | 70 | 7-31-65 | Alluvium | D. | 12 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 131 | NW, NW 16, 20 N., 4 E. | J. Butler | 435 | 170 | 7-31-65 | Madison Gp. | D. | 10 |
| 132 | SE, SE 26, 20 N., 4 E. | R. Lyman | 56 R | 5 R | 9-3-65 | Alluvium | D.S.I. | Sm |
| 133 | SW, SW 30, 20 N., 4 E. | Ayrshire Dairy | 153 | 60 | 8-22-65 | lower Kootenai | D.S.I. | 80 |
| 134 | NW, NE 31, 20 N., 4 E. | R. Brandt | 21.45 | 15.45 | 8-22-65 | Alluvium | D.S.I. | 10 |
| 135 | NE, SE 31, 20 N., 4 E. | M. Hortick | 90 R | 20 R | 8-29-65 | Alluvium | D.S.I. | 10 |
| 136 | SW, NE 32, 20 N., 4 E. | R. Anderson | 105 R | 25 R | 8-29-65 | Alluvium | D.I. | 10 |
| 137 | NW, NW 33, 20 N., 4 E. | N. Weaver | 250 R | 12 R | 8-29-65 | Alluvium-Swift- | D.S.I. | 5 |
| 138 | NW, NW 33, 20 N., 4 E. | R. Weaver | 18 R | 14 R | 8-29-65 | Madison Gp. Alluvium | D.I. | 8 |
| 139 | NW, SE 33, 20 N., 4 E. | E. Lyman | 80 R | 20 R | 8-29-65 | lower Kootenai | D.S.I. | Sm |
| 140 | SE, NW 33, 20 N., 4 E. | R. Ball | 105 R | dry | 8-29-65 | Alluvium | dry | dry |
| 141 | NE, NW 36, 20 N., 4 E. | R. Vining | 51 R | 23 R | 9-3-65 | Alluvium | D.S.I. | 15 |
| 142 | NE, NW 36, 20 N., 4 E. | F. Vining | 105 R | 23 R | 9-3-65 | Alluvium | D.S.I. | 10 |
| 143 | SE, NE 36, 20 N., 4 E. | D. Todd | 135 R | --- | 9-3-65 | Kootenai-Swift | D.S. | -- |

# APPENDIX II

## SPRINGS

| Spring no. | Location ¼ Sec. Twp. Rge. | Owner | Est. Flow (gpm) | Temp. F. | Use* | Aquifer |
|---|---|---|---|---|---|---|
| A | NW 11, 17 N., 3 E. | L. Smiley | 8 | --- | S | basal Kootenai Fm. |
| B | SW 12, 17 N., 3 E. | E. Marxer | 10 | 43 | S | lower Kootenai Fm. |
| C | NW 13, 17 N., 3 E. | E. Pribyl | 20 | 43 | D.S. | basal Kootenai Fm. |
| D | NW 10, 17 N., 4 E. | G. McIntyre | 2 | 43 | D.S. | Kootenai Fm. |
| E | SW 25, 17 N., 4 E. | R. Gruel | 20 | 43 | D.S. | Swift Fm. |
| F | NW 2, 18 N., 3 E. | M. Iverson | 20 | 43 | D.S.I. | basal Flood Mm. |
| G | NE 7, 18 N., 3 E. | C. Young | 10 | 51 | D.I. | basal Flood Mm. |
| H | NW 15, 18 N., 3 E. | B. Hensler | 50 | 46 | D.S.I. | basal Flood Mm. |
| I | NW 16, 18 N., 3 E. | R. Volk | 15 | 46 | D.S.I. | basal Flood Mm. |
| J | SE 17, 18 N., 3 E. | F. Horan | 60 | 48 | D.S.I. | basal Flood Mm. |
| K | SW 17, 18 N., 3 E. | A. Anderson | 5 | 50 | D.S. | Flood Mm. |
| L | SW 29, 18 N., 3 E. | R. Dimke | 10 | 50 | D.S.I. | Flood Mm. |
| M | SE 15, 18 N., 4 E. | W. Hooker | 3 | 43 | D. | Flood Mm. |
| N | NE 18, 18 N., 4 E. | F. Cereck | 10 | 42 | D.S.I. | Flood Mm. |
| O | SW 21, 18 N., 4 E. | W. Jacobs | 25 | 42 | D.S.I. | Kootenai Fm. |
| P | SW 22, 18 N., 4 E. | J. Kohut | 20 | 42 | D.S. | lower Kootenai Fm. |
| Q | SE 29, 18 N., 4 E. | C. Van Horn | 3 | 42 | S. | Kootenai Fm. |
| R | C 31, 18 N., 4 E. | R. Mikelson | 5 | -- | D. | basal Kootenai Fm. |
| S | NW 25, 19 N., 2 E. | J. Lord | --- | -- | S. | Flood Mm. |
| T | NE 13, 19 N., 3 E. | T. Rada | 3 | 52 | D.S.I. | basal Kootenai Fm. |
| U | SW 23, 19 N., 3 E. | G. Sorenson | 3 | -- | D. | Kootenai Fm. |
| V | NE 26, 19 N., 3 E. | J. Donnelly | 10 | 48 | D.S.I. | Kootenai Fm. |
| W | SW 30, 19 N., 3 E. | A. Polich | 10 | 52 | S. | basal Flood Mm. |
| X | NW 2, 19 N., 4 E. | R. Lyman | 15 | 49 | D.S.I. | basal Kootenai Fm. |
| Y | NW 3, 19 N., 4 E. | C. Nolde | 1 | 49 | D.S.I. | basal Kootenai Fm. |

| | | | | | | |
|---|---|---|---|---|---|---|
| Z | NW 7, 19 N., 4 E. | C. Young | 10 | --- | D.S.I. | basal Kootenai Fm. |
| AA | SW 7, 19 N., 4 E. | K. Porro | 20 | 46 | D.S.I. | basal Kootenai Fm. |
| AB | NE 21, 19 N., 4 E. | T. Pettyjohn | 50 | 48 | S. | Kootenai Fm. |

# APPENDIX III

## Section I

## MEASURED SECTION AT TOP OF MISSION CANYON FORMATION

Location: NE $\frac{1}{4}$, NE $\frac{1}{4}$, Sec. 36, T. 19 N., R. 4 E.,

$\frac{1}{4}$ mile north of Stockett, Montana

Covered grassy slope - - - - - - - Swift Formation

| Unit Number | | Thickness (feet) |
|---|---|---|
| 12 | Limestone: tan, thick bedded (1'-5'), granular. Nine and one-half feet above the base, there is a small dark gray lens that measures 8" by 12'. It consists of clasts of dolomicrite as large as 3 mm. that have been replaced and coated by mega-quartz. The secondary quartz crystals interlock, are as large as 0.5 mm., comprise 50% of the rock and replace both clasts and fossil fragments. Numerous endothyrids. | 12 |
| 11 | Dolomite: white, thin bedded, fine grained. | 1 |
| 10 | Dolomitic limestone: tan, one foot bedding, fine grained. Gradation from 5% dolomite near the base of the unit to 30% dolomite rhombs in a micrite matrix near the top of the unit. | 6 |
| 9 | Oosparite: light tan, massive, slightly recrystallized, fossiliferous. Ooliths average 0.8 mm. and are in grain support. The base of this bed is channeled, with relief of one foot, into the underlying algal limestone. Good specimens of _Syringopora_ sp., _Vesiculophyllum_ ? and _Spirifer_ sp. | 7.5 |
| 8 | Algal? limestone: light tan, finely laminated, domomitic. Dolomite rhombs concentrated in very fine laminae. | 3 |
| 7 | Limestone: light gray, massive very fine grained. | 2.5 |
| 6 | Dolomite: light tan, thin bedded, fine grained. | 1 |

| | | |
|---|---|---|
| 5 | Dolomitic limestone: light tan, dolomite in thin patches and stringers; weathers pink, chert lenses to top. | 1.5 |
| 4 | Dolomite: white, thin bedded extremely fine grained (All rhombs less than 0.05 mm.). | 1.5 |
| 3 | Dolomite: light gray, fine grained, slightly granular | 1 |
| 2 | Limey dolomite: massive, granular. | 1 |
| 1 | Dolomite: white, thin bedded, fractured, very fine grained. (All rhombs less than 0.1 mm.). | 2 |
| | Base of cliff | |

NOTE: This section is painted at 5 foot intervals. The location is at mile 0, Goers, 1966.

## MEASURED SECTION OF SWIFT FORMATION, SAWTOOTH FORMATION, AND UPPER PORTION OF MISSION CANYON FORMATION

Location: North wall of Ming Coulee; SW $\frac{1}{4}$, NW $\frac{1}{4}$, Sec. 15, T. 17 N., R. 4 E.

| Unit Number | | Thickness (feet) |
|---|---|---|
| 28 | Long covered slope - - - Morrison Formation | |
| 27 | Sandstone: light gray, weathers tan; fine grained, well sorted, calcareous, quartz with minor black chert, thin to medium bedded (2" - 8") thinner bedded to top. | 31.0 |
| 26 | Sandstone: tan to gray, weathers with scattered red patches; fine to medium grained, calcareous, glauconitic, thin bedded, 2"-6"; small scale cross-bedding, amplitude 1". Numerous $\frac{1}{4}$" shaly partings, dark gray, calcareous. | 36.5 |
| 25 | Sandstone: tan to gray, weathers brick-red; coarse grained: calcareous, regular medium beds, 6" - 12". | 23.5 |
| 24 | Conglomerate and conglomeratic sandstone: well rounded pebbles and cobbles of dark gray chert, in tan, poorly sorted, fine to coarse grained calcareous sandstone. Many oyster-like pelecepods. Chert pebbles concentrated in numerous thin layers. Small, poorly preserved wood prints common near base. | 12.0 |
| | TOTAL THICKNESS SWIFT FORMATION | 103.0 |
| | Unconformity - - - Rierdon Formation absent. | --- |
| 23 | Limestone: light tan, weathers light gray; thick regular beds, oolitic, fossil oyster and smooth pelecepods fragments common near top. Thin section - - -recrystallized oomicrite. Many oolites coat rounded quartz grains. | 24.0 |
| 22 | Limestone: light gray, weathers same; 1" - 2" beds, very fine grained, slightly oolitic, poorly exposed. | 11.0 |
| 21 | Limestone: light tan, weathers light gray; thick regular beds, 2'-4'; oolitic, minor sand, oolites in grain to grain support. | 35.0 |
| 20 | Conglomerate: light gray fine sandstone matrix with well rounded, smooth chert pebbles, black to dark brown; contains numerous fragments of large oyster-like pelecepods. | 1.0 |

| | | |
|---|---|---|
| | TOTAL THICKNESS SAWTOOTH FORMATION | 71.0 |
| | TOTAL THICKNESS ELLIS GROUP | 174.0 |

UNCONFORMITY

MISSION CANYON FORMATION

| | | |
|---|---|---|
| 19 | Limestone breccia: large (4"-2') blocks of dark micritic limestone in a fine grained red-brown sandstone matrix. Chaotic arrangement of blocks to base. Fracturing decreases upward. Limestone contains brachiopod fragments. | 8.5 |
| 18 | Sandstone: weathers dark red-brown; poorly indurated; calcareous, ferrugenous; quartz, minor plagioclase; fine grained, structureless. Thickness varies along strike, 6"-20'. | 2.6 |
| 17 | Limestone: light tan mottled with whitish gray, weathers light blue-gray; massive. Lower 3 feet contains large unoriented blocks of the underlying algal limestone (Unit 16). Thin section---recrystallized pelmicrite. | 10.8 |
| 16 | Limestone: light gray weathers same; very thin beds, 1/10"; LLH algal growth form. Bedding surface irregularity marked by algal nodules $\frac{1}{2}$"-3/4" in relief. Individual nodules carry vertically through many beds. | 20.1 |
| 15 | Covered interval | 13.0 |
| 14 | Limestone: light tan, weathers same; cliff former, 5'-8' massive beds; fine grained, commonly pelletal. Local concentrations of fossil fragments, thin section of biosparite near middle of unit contained forams, echinoid spines and punctate brachiopods. | 37.0 |
| 13 | Covered interval | 16.5 |
| 12 | Limestone: light tan, weathers tan to gray; massive, badly fractured and silicified, fine grained. Limestone is cut by a fine irregular network of dark brown chert. | 1.8 |
| 11 | Limestone: tan, weathers same; finely laminated, pelletal. Thin section---laminated alternation of pelsparite and pelmicrite, pellets rounded and micritic; 1% rounded, fine grained, well sorted quartz sand, overgrown with sparry calcite. | 1.4 |

| | | |
|---|---|---|
| 10 | Limestone: light gray, 18"-30" beds; fine grained, mottled with sparry patches. Thin section---Dismicrite: 40% spar, apparently filling burrows or other open-space in micrite. | 10.3 |
| 9 | Limestone: light gray, weathers light tan; massive bench former, fine grained; contains numerous thin, discontinuous chert stringers. | 9.1 |
| 8 | Dolomitic limestone: light tan to gray, weathers whitish gray; 6"-18" beds, fine grained. Thin section---Dismicrite, slightly dolomitic; contains small scattered sparry patches, probably burrows; dolomite rhombs are concentrated in and around the burrows; slightly fossiliferous (miliolids). | 9.8 |
| 7 | Dolomite: light gray, weathers same; 8"-12" beds, granular. Thin section---dolomicrite with 50% large (up to 6 mm.) rounded irregular dolomicrite interclasts. Interclasts and matrix contain irregular spar filled vacuities. | 3.0 |
| 6 | Dolomitic limestone: dark gray, weathers light gray; massive, prominent cliff former; fine grained, recrystallized, faintly laminated. | 32.6 |
| 5 | Limestone: light gray, weathers same; thin regular beds, 1"-3"; very fine grained. Upper two feet of unit contains numerous discontinuous dark gray chert stringers, parallel to bedding, $\frac{1}{2}$ inch thick. Thin section---micrite: contains less than 5% fossil fragments, recrystallized; 5% dolomite as scattered rhombs, 0.3 mm. | 13.4 |
| 4 | Dolomitic limestone: light tan, weathers brownish gray; very fine grained, contains recrystallized brachiopod fragments. | 1.5 |
| 3 | Dolomitic limestone: dark gray, weathers light gray; 8"-12" beds, fine grained. Thin section ---Intramicrite: dolomitic, slightly fossiliferous, contains 45% rounded irregular micrite interclasts in a dolomite microspar matrix. | 3.5 |
| 2 | Dolomite: dark gray, weathers light gray; massive, fine grained. Petroliferous odor when struck with hammer. Thin section---Dolomicrite: silicified, slightly fossiliferous, (Endothyrids, Brachiopod fragments). Recrystallized, 30% chert as small irregular patches, 0.1---2 mm. | 4.0 |

| | | |
|---|---|---|
| 1 | Limestone: light gray, weathers same; massive oolitic. Ooliths in grain support in upper two feet of unit. | 19.1 |
| | TOTAL THICKNESS OF MISSION CANYON FORMATION MEASURED | 218.0 |

## Section 3

## MEASURED SECTION OF THE BIG SNOWY GROUP

From Easton (1962, p. 114)

Location: along Belt Creek, Secs. 1 and 11, T. 17 N., R. 6 E.

| | | |
|---|---|---|
| Jurassic System - ELLIS GROUP | | |
| | | Feet |
| 18 | Sandstone, yellowish, fine-grained, slump. MESOZOIC OR PALEOZOIC ROCKS | --- |
| 19 | Covered, probably shale (estimate) | 25 |
| Mississippian System - BIG SNOWY GROUP | | |
| Otter Formation: | | |
| 16 | Shale; mostly greenish-gray, some purple, blocky, in part fissile and calcareous; lower 6 ft. with limestone (algal?) nodules, nonresistant. | 49 |
| 15 | Limestone: light-gray, fine-grained; wavy laminations: algal(?) in part. | 1 |
| 14 | Limestone: saccaroidal, dolomitic, gray, calcareous, slightly resistant, medium-grained; and conglomerate. | 1 |
| 13 | Limestone: light-gray, argillaceous, resistant, platy-weathering: wavy laminations. | 4 |
| 12 | Shale: greenish-gray, some reddish and purplish, some calcareous: nonresistant. | 49 |
| 11 | Limestone: light-gray, very fine grained, argillaceous, vugular, resistant; wavy laminations. | 6 |
| 10 | Shale: reddish, some greenish and purplish, calcareous, nonresistant. | 8 |
| 9 | Limestone: buff to gray, very fine grained, vugular, heavy-bedded, resistant: ostracodes. | 8 |
| 8 | Shale: reddish-brown, some green-speckled, calcareous; some very calcareous streaks or limestone nodules are very fossilliferous. | 18 |

| | | |
|---|---|---|
| 7 | Limestone, very argillaceous, gray, very fine grained, platy-weathering, resistant bluff-maker, algal (?) in part: 3-in. dark-brown chert band near base; ostracodes. | 12 |
| 6 | Shale: mostly gray-green, nonresistant; 20 per-cent of the lower half contains limestone beds 2-in. to 2-ft. thick limestone; some reddish beds of shale with rounded sand grains overlie lower half and are succeeded by strata which grade into unit 7. | 42 |
| | Total Otter Formation | 198 |
| Kibbey sandstone: | | |
| 5 | Conglomerate and sandstone, gray-green, coarse- and round-grained with some limestone clasts, massive, resistant; rounded outcrops. | 2 |
| 4 | Siltstone; maroon with green specks, calcareous, nonresistant. | 6 |
| 3 | Sandstone: siltstone, and shale, interbedded. mostly reddish with some green beds; beds as thick as 1 ft; calcareous, slightly resistant: weathers platy to hackly. | 38 |
| 2 | Mostly sandstone, reddish, fine-grained, rather resistant; some gypsum present in beds; basal portion shaly and very poorly exposed; thickness computed to make total thickness equal to the figure of 153 ft. given by Weed (1899-a) | 101 |
| | Total Kibbey sandstone | 147 |
| | Total Big Snowy Group | 345 |
| | MADISON GROUP | |
| Mission Canyon limestone: | | |
| 1 | Limestone: blue-gray, fine-grained; massive beds, resistant cliff-maker. | --- |

Section 4

# PARTIAL MEASURED SECTION, OTTER FORMATION

Location: North side of Ming Coulee, ¼ mile above Calvert, Montana.
SW ¼, SE ¼, Sec. 25, T. 17 N., R. 4 E.

| Unit Number | | Thickness (feet) |
|---|---|---|
| **SWIFT FORMATION** | | |
| 26 | Conglomerate: red weathering, massive, calcareous, contains black rounded chert pebbles, and water worn oyster fragments. | |
| **SAWTOOTH FORMATION** | | |
| 25 | Limestone: light gray, weathers same; thick regular beds, 1'-4'; pelletal, oolitic, contains oyster fragments. | 25.0 |
| 24 | Covered interval. (Sawtooth-Otter unconformable contact may lie within this interval.) | 88.0 |
| | Approximate Total Thickness Sawtooth Formation | 113.0 |
| **OTTER FORMATION** | | |
| 23 | Limestone: light gray, weathers same; thin bedded, undulose bedding surface, (algal?); contains small pods of dark gray to black chert. | 4.0 |
| 22 | Shale: light gray, weathers same; calcareous. | 2.3 |
| 21 | Covered interval. | 5.3 |
| 20 | Claystone: drab olive green, thin bedded to massive, slightly silty, slightly calcareous. | 12.2 |
| 19 | Shale: yellowish tan, weathers same, thin bedded, faintly calcareous. | 3.2 |
| 18 | Covered interval. | 5.0 |
| 17 | Limestone: dark gray, weathers tan; thin bedded, ¼"-1"; micritic. | 2.0 |
| 16 | Mudstone: dark red, weathers same; silty. Poorly exposed; holes dug in talus every 5 feet, consistantly same lithology. | 36.0 |

| | | |
|---|---|---|
| 15 | Sandstone: light gray, weathers same; massive, minor planar cross-beds; fine grained, well sorted, well rounded, calcareous. Very friable, crumbles in hand. | 16.0 |
| 14 | Covered interval; presumed to be shale. | 21.0 |
| 13 | Shale: poorly exposed, mostly green fissile shale with scattered thin (1") black shale layers; widely scattered thin (2"-6") massive dark gray lithographic limestones. | 35.0 |
| 12 | Shale: gray-green, weathers same with brick red mottling; thin bedded, fissile, calcareous. | 17.0 |
| 11 | Shale: black, weathers with faint purple cast; thin bedded, fissile; contains 2" stringer of dark gray micritic limestone near the base. | 2.2 |
| 10 | Shale: gray-green, weathers same; thin bedding, 1/8"-1"; slightly calcareous. | 16.0 |
| 9 | Limestone: dark gray, weathers tan to gray; contains thin green shale partings, contains internal casts of high-spiral gastropods. | .9 |
| 8 | Shale: bright green, platy. | .4 |
| 7 | Limestone: dark gray, weathers tan; micritic, brecciated in top 6". | 3.5 |
| 6 | Shale: black, very fissile, very thin, ¼" beds. | 2.5 |
| 5 | Shale: bright olive green, weathers brown; bedding varies from 1/8"-2"; nodular weathering. | 11.5 |
| 4 | Shale: drab olive green, thin bedded. | 7.1 |
| 3 | Sandstone: tan, weathers same; fine grained, calcareous, friable, contains thin discontinuous carbonaceous partings. | .8 |
| 2 | Limestone: black, weathers tan; thin bedded, 1"-3"; micritic, forms small ledge. | 1.1 |
| 1 | Shale: dark charcoal gray, thin bedded, calcareous, upper 3 feet poorly exposed. | 7.0 |
| | Covered slope. Kibbey-Otter contact is approximately 40 feet down-section in covered area. | |
| | TOTAL OTTER FORMATION MEASURED* | 212.0 |

*Note: Upper contact with Ellis Group is believed to be in the lower part of covered interval (Unit 24). Estimated total thickness of Otter Formation 250'-260'.

Section 5

## MEASURED SECTION OF THE ELLIS GROUP

From Cobban (1945, p. 1298)

Location: E. ½ Sec. 2, T. 17 N., R. 6 E. and SE ¼ Sec. 36, T. 18 N., R. 6 E. Along Belt Creek

| | | Feet | Inches |
|---|---|---|---|
| SWIFT FORMATION | | | |
| 22 | Sandstone: tan weathering, fine-to medium-grained, thick-and thin-bedded, locally cross-bedded; contains wood impressions. Finer-grained and thinner-bedded toward the top. Composed chiefly of angular to sub-angular colorless quartz grains and minor amounts of medium to dark gray chert. Joint faces in middle of unit coated with dark desert varnish displaying many colors. Massive, forms bluffs. | 55 | |
| 21 | Sandstone: tan weathering, fine-to very fine-grained; contains wood prints. Ripple-marked bedding surfaces contain micaceous shale films. | 13 | |
| 20 | Sandstone: tan weathering, coarse-grained; contains lenses of conglomerate and scattered pebbles as much as 1.5 inches in diameter. Some prints of wood and partings of very fine-grained sandstone and siltstone. | 10 | |
| 19 | Conglomerate: rounded to subrounded pebbles and cobbles of tan and gray quartzite and medium to dark gray chert as much as 5 inches in diameter, in tan fine-to coarse-grained hard calcareous sandstone. Contains some water-worn oyster shells. | 1 | |
| | Total thickness of Swift formation | 79 | |
| Unconformity. Rierdon Formation Absent | | | |
| SAWTOOTH EQUIVALENT | | | |
| 18 | Limestone: yellowish, dense, chalky; weathers brown. | 1 | |
| 17 | Limestone: buff, soft, chalky, shaly. Few fossils | 2 | |
| 16 | Shale: light gray weathering bluish gray; contains some fossils and tiny green clay galls. | 1 | |

| | | | |
|---|---|---|---|
| 15 | Limestone: light gray, dense, poorly bedded, highly fossiliferous; contains some sand grains and tiny green clay galls. | 5 | |
| 14 | Limestone: medium gray, dense to finely crystalline, sandy, hard; in wavy beds averaging 2 feet in thickness; weathers brownish; contains a few thin green shale parting. Upper part contains abundant fragments of Pentacrinus. | 14 | |
| 13 | Shale: medium green, limy. | | 6 |
| 12 | Limestone: light gray, dense, massive; weathers yellowish tan. | 2 | |
| 11 | Shale: medium green, limy. | 1 | 6 |
| 10 | Limestone: medium gray to slightly reddish gray, very finely crystalline to coarsely crystalline. | 2 | 2 |
| 9 | Limestone and shale: yellowish and green, soft, poorly bedded. Much limestone and shale conglomerate. | 2 | 2 |
| 8 | Limestone: creamy buff, dense, hard; weathers yellowish. | | 9 |
| 7 | Shale: medium green, limy. | 3 | 6 |
| 6 | Limestone: medium gray, dense, fossiliferous; in beds 6"-2' thick; weathers yellowish tan. | 5 | |
| 5 | Shale: medium green, limy. | 6 | |
| 4 | Shale and siltstone: maroon, green, and yellow, sandy, calcareous, gypsiferous. Some thin yellowish oolitic limestones in lower part. | 26 | |
| 3 | Siltstone and limestone: massive, pale gray calcareous siltstone grading up into creamy buff oolitic limestone. | 6 | |
| 2 | Siltstone: light gray to buff, calcareous, hard and soft; contains a few sand grains. | 6 | |
| 1 | Siltstone: light gray to buff, calcareous, massive, poorly bedded to non bedded; contains scattered colorless quartz grains. Basal part contains large fragments of limestone derived from Otter formation. | 7 | |
| | Total thickness of Sawtooth equivalent | 90 | 7 |
| | Total thickness of Ellis group | 169 | 7 |

Section 6

## MEASURED SECTION OF SWIFT FORMATION

Location: East wall of Number Five Coulee, SW ¼, NW ¼, Sec. 11, T. 18 N., R. 4 E.

| Unit Number | | Thickness (feet) |
|---|---|---|
| LOWEST MORRISON FORMATION | | |
| 12 | Shale: greenish gray, calcareous. | 4.0 |
| SWIFT FORMATION | | |
| 11 | Siltstone: tan, weathers with iron stain; thin bedded, 1/10"-¼"; calcareous, interbedded thin layers of silty shale, dark gray. | 4.0 |
| 10 | Sandstone: tan to light gray, weathers brown; massive, small scale cross bedding at scattered intervals; medium grained, well sorted; forms prominent bench. | 23.0 |
| 9 | Sandstone: medium gray, thin bedded, very fine grained to silty, calcareous; contains thin, 1"-2", light gray limestone lenses. | 2.2 |
| 8 | Sandstone: tan, weathers olive gray; massive, small scale planar cross beds; medium-coarse grained, calcareous. | 2.1 |
| 7 | Sandstone: light gray, thin bedded with many tiny carbonaceous shale partings; fine grained, calcareous. | 1.5 |
| 6 | Sandstone: dark gray, massive, medium grained, glauconitic, calcareous; sparry calcite crystals fill small vacuities. | 1.0 |
| 5 | Shale: dark gray, thin bedded, carbonaceous, silty. | 1.7 |
| 4 | Sandstone: tan to brown; massive with smallscale cross beds, fine grained with scattered chert pebbles, calcareous. | .5 |
| 3 | Fossil hash: light to medium gray; broken thick-shelled oyster-like pelecepods, minor rounded black chert 1-20 mm.; sandy calcareous matrix. | 2.5 |
| | Total Thickness Swift Formation | 38.5 |

Unconformity

MISSION CANYON FORMATION

| | | |
|---|---|---|
| 2 | Limestone: medium gray, weathers same; dolomitic, massive. Fractures common in upper part of unit. Hematite staining along fractures. | 5.0 |
| 1 | Limestone: tan, weathers light gray; thin regular beds; 1/8"; micritic. | 2.0 |

Covered Talus Slope To Base Of Cliff.

Section 7

## MEASURED SECTION OF THE LOWER HALF OF THE KOOTENAI FORMATION AND UPPER PART OF THE MORRISON FORMATION

From Silverman and Harris, 1967, p. 18-19.

Location: NE $\frac{1}{4}$ Sec. 27, NW $\frac{1}{4}$, Sec. 26, T. 19 N., R. 6 E., along the road that enters Belt from the west, just north of U. S. Highways 87 and 89.

KOOTENAI FORMATION (CRETACEOUS)

| | | Feet | Inches |
|---|---|---|---|
| 41 | Sandstone: fine grained, to siltstone interbedded with mudstone, calcareous, weathers purplish brown and fissile. | 4 | 0 |
| 40 | Mudstone: conchoidally fractured, light gray, weathers light green. | 0 | 3 |
| 39 | Mudstone: | 0 | 1 |
| 38 | Shale: contains carbonaceous chips. | 0 | 8 |
| 37 | Shale: light gray, weathers to light green clay. | 0 | 6 |
| 36 | Shale: gray, weathers light brown. | 2 | 0 |
| 35 | Limestone: light brownish gray, weathers red and orange brown; contains calcareous clasts and carbonaceous chips. | 2 | 2 |
| 34 | Mudstone: arenaceous, poorly indurated, light gray, weathers red. | 3 | 0 |
| 33 | Sandstone: medium to fine grained, massive, well indurated, partly cemented by calcite, gray, weathers dark red spotted; contains chert and muscovite; fluting and load casts on bottom. | 5 | 5 |
| 32 | Shale: fissile, gray. | 0 | 3 |
| 31 | Sandstone: medium to fine grained. | 1 | 11 |
| 30 | Mudstone: nodular and fissile, gray, weathers red. | 4 | 3 |
| 29 | Sandstone: weathers red. | 3 | 7 |
| 28 | Mudstone: gray, weathers red. | 0 | 8 |

| | | | |
|---|---|---|---|
| 27 | Sandstone: fine grained, weathers red; contains shale intraclasts and carbonaceous chips. | 0 | 8 |
| 26 | Shale and mudstone: gray, weathers red and yellow. | 3 | 6 |
| 25 | Sandstone: fine grained, massive, gray and white, weathers red; grades upward into siltstone. | 7 | 11 |
| 24 | Mudstone: arenaceous; contains fragments of rock and mafic minerals. | 2 | 0 |
| 23 | Sandstone: quartzose, fine grained to sugary, weathers red. | 10 | 5 |
| 22 | Interbedded, sugary sandstone and mudstone. | 13 | 4 |
| 21 | Sandstone: medium to fine grained, massive, light gray to white, weathers red; 90 percent quartz, 10 percent chert. | 4 | 8 |
| 20 | Mudstone: shaly, gray, showing deformation structure around calcareous nodules of mudstone. | 2 | 0 |
| 19 | Mudstone: indurated with calcite cement. | 5 | 8 |
| 18 | Siltstone: greenish gray; contains fragments of red mudstone. | 2 | 6 |
| 17 | Mudstone: red; contains large clasts of greenish-gray siltstone. | 0 | 5 |
| 16 | Siltstone: greenish gray, weathers orange brown, grades into fine-grained massive sandstone at base. | 5 | 6 |
| 15 | Limestone: contains limestone intraclasts. | 1 | 0 |
| 14 | Mudstone: shaly, red, weakly resistant. | 2 | 2 |
| 13 | Siltstone: indurated; contains chert grains and calcite cement. | 3 | 7 |
| 12 | Mudstone: red, nonresistant; contains yellow calcareous concretions. | 3 | 4 |
| 11 | Siltstone: massive, calcareous, brownish gray, stained red; grades downward into medium-grained sandstone. | 10 | 6 |

| | | | |
|---|---|---|---|
| 10 | Mudstone: calcareous, concretionary, tan. | 0 | 10 |
| 9 | Mudstone: dark red. | 8 | 0 |
| 8 | Limestone: light gray, weathers purple; contains calcareous intraclasts; interbedded with light-gray mudstone containing calcareous concretions. | 30 | 4 |
| 7 | Mudstone: conchoidally fractured, gray, weathers yellow, orange, and red. | 10 | 0 |
| 6 | Mudstone: arenaceous, light gray, weathers white. | 3 | 0 |
| 5 | Sandstone: clean, white, grading downward into gray, chert-bearing, cross-grained sandstone; basal surface gently undulating. | 16 | 0 |
| | Total Thickness of Kootenai Formation Measured | 176 | 1 |

MORRISON FORMATION (JURASSIC)

| | | | |
|---|---|---|---|
| 4 | Coal. | 0 | 6 |
| 3 | Shale: dark brown, stained yellow. | 3 | 6 |
| 2 | Bentonite: white, nonresistant, interbedded with siliceous, light-gray porcelaneous shale. | 3 | 2 |
| 1 | Shale: dark gray. | 1 | 2 |
| | Total Thickness of Morrison Formation Measured | 8 | 4 |

Section 8

MEASURED SECTION OF FLOOD MEMBER OF BLACKLEAF FORMATION AND UPPER PORTION OF KOOTENAI FORMATION

Location: Southside of Wilson Butte; SE $\frac{1}{4}$, NW $\frac{1}{4}$, Sec. 17, T. 19 N., R. 3 E.

| Unit Number | | Thickness (feet) |
|---|---|---|
| 37 | Sandstone: light tan, massive toward base, irregular thin 4" beds to top, slightly calcareous, contains quartz, plagioclase, minor chert. UPPER UNIT OF FLOOD. | 52.5 |
| 36 | Shale: dark gray with interbedded thin, medium grained sandstone, 1"-6". Shale slightly calcareous. Sandstones commonly contain worm trails. MIDDLE UNIT OF FLOOD. | 27.5 |
| 35 | Sandstone: tan to gray, thin bedded, 2"-3"; fine to medium grained. Small assymetrical ripple marks. Worm trails ubiquitous on bedding planes. Quartz, minor plagioclase and chert. | 20.0 |
| 34 | Shale: dark gray, medium gray toward base, weathers whitish gray; at intervals contains isolated maroon streaks. Probably represents minor reworking of Kootenai. | 10.0 |
| | TOTAL THICKNESS LOWER UNIT, FLOOD MEMBER | 30.0 |
| | TOTAL THICKNESS FLOOD MEMBER | 110.0 |
| KOOTENAI FORMATION | | |
| 33 | Mudstone: dark red, mottled with pale green; massive. | 9.0 |
| 32 | Siltstone: dark red, thin bedded, slightly argillaceous. | 2.0 |
| 31 | Sandstone: light gray, weathers same; thin bedded to base, 1"-2"; massive with small-scale festoon crossbeds in upper 5 feet, amplitude 6"; fine grained, moderately well sorted, non-calcareous; feldspathic, 75% quartz, 20% feldspar, 5% black chert. | 9.5 |
| 30 | Covered interval. | 11.5 |

| | | |
|---|---|---|
| 29 | Shale: drab olive. | 4.5 |
| 28 | Alternate intervals of drab olive and red shale in bands 6"-18". Only apparent difference between lithologies is oxidation state of iron. Montmorillonitic. Puffy. Weathering makes unit resistant to erosion; forms steep slopes. | 14.0 |
| 27 | Shale: dark red, montmorillonitic. | 2.0 |
| 26 | Shale: drab olive green, montmorillontic. | 1.0 |
| 25 | Siltstone: dark red, massive, slightly argillaceous. | 8.0 |
| 24 | Shale: drab olive green. | 3.5 |
| 23 | Shale: dark red. | 6.5 |
| 22 | Shale: drab olive green, red stains on surface, probably from above. | 3.0 |
| 21 | Shale: dark red. | 2.5 |
| 20 | Sandstone: tan, massive, medium grained, subangular, well sorted. | 1.4 |
| 19 | Shale: drab olive green, weathers light gray. | 5.9 |
| 18 | Shale: gray, mottled with irregular maroon patches. Maroon patches not parallel to bedding. | 5.0 |
| 17 | Shale: dark red, montmorillonitic. | 9.2 |
| 16 | Sandstone: dark red, bottom 4' massive, top 1' very thin bedded, $\frac{1}{4}$"; very argillaceous. | 5.0 |
| 15 | Shale: maroon. | 10.0 |
| 14 | Shale: light gray, montmorillonitic. | 3.0 |
| 13 | Mudstone: dark red, massive. | 1.2 |
| 12 | Limestone: medium gray with purple mottling; massive, lithographic, contains numerous small 1"-2" lens shaped siliceous concretions. | 2.1 |
| 11 | Mudstone: dark red, massive, slightly montmorillonitic. | 5.3 |
| 10 | Shale: light gray, popcorn weathering, probably contains abundant montmorillonite. | 5.5 |

| | | |
|---|---|---|
| 9 | Shale: dark red, fissile | 4.9 |
| 8 | Siltstone: dark red, massive, slightly sandy. | 2.2 |
| 7 | Shale: gray green, weathers light gray. | 12.9 |
| 6 | Siltstone: dark red, argillaceous, very thin bedded, 1/8"-¼". | 5.5 |
| 5 | Siltstone: dark red, sandy, two massive beds 1' thick. | 2.0 |
| 4 | Shale: dark red, silty. | 2.0 |
| 3 | Covered interval. | 10.5 |
| 2 | Sandstone: light tan, massive, small festoon cross-beds; fine to medium grained, subangular, moderately sorted; mostly quartz, minor chert, feldspar and ferromagnesians. | 9.0 |
| 1 | Shale: dark gray, weathers drab olive; contains iron rich clay nodules, scattered tiny carbonaceous specks, poorly preserved leaf impressions near base. | 9.0 |
| | Covered slope | |
| | TOTAL THICKNESS OF KOOTENAI FORMATION MEASURED | 188.6 |