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GEOLOGY AND GROUND-WATER RESOURCES OF THE CASCADE-ULM AREA, MONTANA

by

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ABSTRACT

The Cascade-Ulm area, approximately 30 miles southwest of Great Falls, includes 415 square miles of semiarid plains that are bounded on the south by the Big Belt Mountains. The area is drained by the Missouri and Smith Rivers.

Exposed rock units include 35 feet of Jurassic and 2, 300 feet of Cretaceous sedimentary strata. The lowest outcropping unit is the upper part of the Morrison Formation (Jurassic) consisting of carbonaceous siltstone. It is overlain disconformably by the Kootenai Formation (Cretaceous), composed of sandstone, limestone, and red siltstone. The Colorado Group, which disconformably overlies the Kootenai, includes the Blackleaf and Marias River Formations. The Blackleaf is composed mostly of bentonitic shale but contains many sandstone beds. The Marias River is predominantly shale. The Montana Group, the upper part of which has been removed by erosion, is made up of the Telegraph Creek and Virgelle Formations. The Telegraph Creek is composed of interbedded sandstone and shale whereas the Virgelle is characterized by massive quartz sandstone.

Surficial deposits include terrace gravel, glacial lake sediment, alluvium-colluvium, dune sand, and alluvium.

Igneous rocks of probable early Tertiary age include the Adel Mountain Volcanics and intrusive dikes and sills.

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Gentle westward dips in the north part of the area reflect uplift of the Sweetgrass Arch. The west-northwest structural trend in the south part of the area resulted from late Eocene diastrophism. There the strata have been folded and faulted into reverse and high-angle faults. These structural features postdate igneous intrusion.

The quality of ground water in the area is generally good. The most productive aquifers are in the Blackleaf Formation, which contains numerous sandstone units that generally yield adequate supplies of water for domestic and stock use; sandstone units in the Flood Member of this formation are the best aquifers in the area. Alluvial deposits along the Missouri River yield adequate supplies of water at shallow depth. The Virgelle Formation is an excellent aquifer, but its small areal extent limits its water yielding capability. Sandstone units in the Kootenai Formation are undeveloped potential aquifers. The Morrison, Marias River, and Telegraph Creek Formations are relatively impermeable and are not regarded as potential aquifers.

Springs commonly issue from the sandstone units of the Blackleaf Formation and from alluvium. A few springs occur in the Kootenai, Telegraph Creek, and Virgelle.

INTRODUCTION

PURPOSE AND SCOPE

This investigation was conducted in hope of determining potential sources of water supply or areas of overuse and to determine whether any potential mineral resources are present. The work, which was done under the sponsorship of the Montana Bureau of Mines and Geology, provides information concerning the quality, quantity, and utilization of well and spring water, with emphasis placed upon the relationship of the water to the areal geology.

The geologic reconnaissance map of the area shows the stratigraphy of the Colorado Group as revised by Cobban and others (1959 b, p. 2786).

Data were obtained through personal communication with residents in the area, measurements of water wells and springs, and reconnaissance mapping.

LOCATION AND ACCESSIBILITY

The map area, which covers approximately 415 square miles, is in Cascade County, about 30 miles southwest of Great Falls (Fig. 1). The map encompasses portions of the Cascade, Simms, and Gore Hill 15-minute quadrangles and portions of the Hardy, Rocky Reef, and Schrammeck Lake $7\frac{1}{2}$-minute quadrangles. It also includes approximately 35 square miles not covered by quadrangle topographic maps. The area investigated lies between long 111° 25' and 111° 50' W. The northern boundary is lat 47° 30' N., and the southern boundary is the northern edge of the Adel Mountain Volcanics, in the foothills of the Big Belt Mountains.

The area is readily accessible via U. S. Highway 91 and Interstate Highway 15, which serve the towns of Cascade and Ulm. County roads, which are kept in excellent condition, give access to most parts of the area and are impassable only during adverse weather. Ranch roads bring even the most remote outcrop within easy reach by automobile.

The Missouri River, which traverses the area, may be crossed by bridges only at the towns of Cascade and Ulm. The crossing at Ulm provides easy access to the eastern and southeastern part of the area via the Smith River road.

PREVIOUS WORK

Previous work in the area has been limited to general reconnaissance. G. H. Eldridge (1886), W. H. Weed (1892), C. A. Fisher (1909), and V. H. Barnett (1916) made early studies of the geology in the eastern part of the area, but their interest was mainly concerned with the development of coal reserves in the Great Falls Coal Field. F. H. H. Calhoun (1906) and W. C. Alden (1932) discussed the physiography of the area and its relation to glaciation. A reconnaissance map of the southwest part of the area was compiled by J. B. Lyons (1944) as part of a study of the igneous rocks of the northern Big Belt Mountains.

C. A. Fisher (1909) was the first to study the possibility of ground-water supplies in the area. E. S. Perry (1933) studied the potential underground-water supply for the town of Cascade. H. C. Elliot (1959) and F. E. Buck (1961) did considerable work in connection with proposed irrigation projects.

The only previous geologic map that covers the entire area is the State Geologic Map of Montana (1955), which for the area under discussion was compiled from the reconnaissance maps of C. A. Fisher (1909) and J. B. Lyons (1944).

Recently, the Vaughn quadrangle, which lies north of the area, was mapped by E. K. Maughan (1961). The U. S. Geological Survey topographic maps of the Hardy and Rocky Reef $7\frac{1}{2}$-minute quadrangles were published in 1964.

PRESENT STUDY

Approximately 65 days during July, August, and September of 1964 were spent in the field mapping and gathering ground-water data. Also two additional days of field work were done in April of 1965.

All ground-water data and part of the geologic data were obtained by auto traverses.

In the southern part of the area, where the geology is more complex, traverses by foot were necessary to determine the geologic structure. Owing to the scarcity of outcrops, and to facilitate mapping, most traverses were made along country roads where road cuts provided the best exposures. Formation and member contacts and faults were inferred between the traverses, which ranged from one to two miles apart.

U. S. Department of Agriculture Commodity Stabilization Service aerial photos (1:20,000 scale), taken in 1954 and 1955, facilitated the planning, locating, interpreting, and plotting of field data.

Water wells and spring data were plotted on a Cascade County highway map (1 inch = 1 mile). The geologic data were plotted on $7\frac{1}{2}$- and 15-minute U. S. Geological Survey topographic maps. These maps were also used for determining elevations and constructing cross sections. In the area without topographic coverage, aerial photos and section corners were used as control points for mapping the geology.

The binocular microscope was used to examine samples of dune sand and glacial lake deposits. Before being studied under the petrographic microscope, thin sections were stained for sodium and potassium feldspar, calcite, and dolomite. The staining technique of Bailey and Stevens (1960, p. 1025) was followed to distinguish the feldspars, and the procedure outlined by Sabins (1962, p. 1184) was used to differentiate between calcite and dolomite.

ACKNOWLEDGMENTS

The writer is grateful to the Montana Bureau of Mines and Geology for suggesting the study and providing financial support.

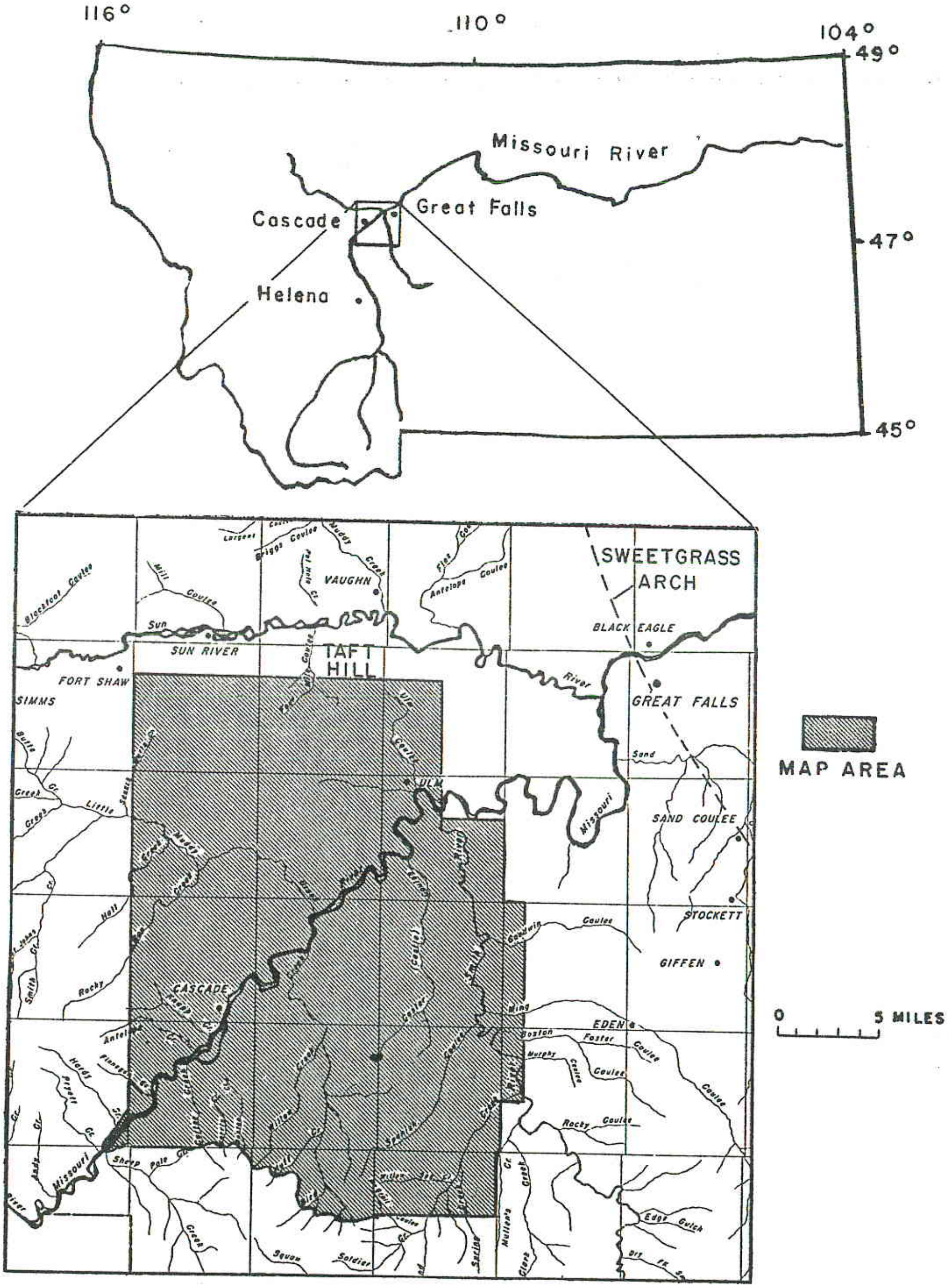

Figure 1.--Index map showing Cascade-Ulm area, and surrounding territory (modified from Buck, 1961).

Appreciation is extended to Dr. S. L. Groff of the Montana Bureau of Mines and Geology for his assistance in the field and for supervision of the study. Special thanks are given to Dr. Robert M. Weidman for supervising the preparation of the thesis. Dr. Donald Winston of the geology department and Dr. Thomas J. Nimlos of the School of Forestry criticized the manuscript.

The work was expedited with the helpful cooperation of several persons to whom the writer is deeply indebted. Special thanks are due to the local residents for their cooperation in supplying information and for allowing access to their property.

PHYSIOGRAPHY

CLIMATE

The climate is characteristic of that found in semiarid high plains. Strong prevailing southwesterly winds are common, especially along the Missouri River from Cascade to the Big Belt Mountains. In the winter months "chinook" winds are common along the Missouri River (locally called Chestnut Valley) near Cascade. Because of these "chinook" winds, Chestnut Valley has relatively warm average annual temperatures. As can be seen from Table 1, the average annual temperature at Cascade is 46° F, whereas Adel (about 18 miles southeast of Cascade) averages 41.4° F, and Sun River (about 18 miles north of Cascade) averages 43.9° F.

Extreme high and low temperatures are occasionally experienced (Table 1), but these temperatures are not enduring. Arctic cold fronts locally give way to the persistent "chinooks", and the summers are moderately warm; only a few days could be classified as hot.

Table 1.--Weather data for area of study and its surroundings (modified from Buck, 1961, p. 10).

	Temperature				Precipitation					
Station	Years record	Avg. Ann.	High	Low	Years record	Avg. Ann.	Wettest year		Driest year	
Cascade	25	46.0	109	-57	25	14.47	19.94	1941	9.28	1935
Ulm					13	15.92	23.05	1953	9.63	1956
Sun River	7	43.9	101	-46	14	13.15	18.08	1951	7.67	1952
Adel	22	41.4	106	-50	22	16.13	23.58	1932	8.42	1935

Precipitation is most frequent in late spring and early summer and some heavy rains fall in May and June. During late summer and early fall the weather is generally pleasant and warm, but according to Buck (1961, p. 10), afternoon showers or thunderstorms may be observed on the average of about one day in four during July and August. Occasionally the thunderstorms are accompanied by hail.

VEGETATION

Vegetation on the semiarid plains commonly consists of prickly pear cactus, sage, thistle, fescue, and timothy. Rushes are abundant in the swampy areas along the rivers, oxbow lakes, creeks, and springs. Cottonwood, alder, and willow trees are found along rivers and creeks, and evergreen trees are almost confined to the Virgelle Formation and the Adel Mountain Volcanics.

TOPOGRAPHY

The map area is characterized by broad, gently sloping plains that border on the edge of the Big Belt Mountains. The plains have been moderately dissected by numerous streams, most of which have their origin in the mountains.

Conspicuous features of the area are the mesas, capped by sills, and the bold narrow ridges that persist along dikes. The dikes extend from the Big Belt Mountains northward across the plains. The most prominent dike is Rocky Reef. The sills are present on Square Butte and Cascade Butte, which have average altitudes of 4, 700 and 4, 200 feet respectively.

Two bench levels in the area are represented by Square Butte and by the flat plains surrounding Cascade and Ulm. Square Butte is a remnant of Alden's Bench Number 1 (1932, p. 17). According to Lyons (1944, p. 448) the plains around Cascade and Ulm are correlated with Alden's Bench Number 2. The series of lower terraces, which are found along the Missouri River, represent minor periods of uplift and are associated with Alden's Bench Number 2.

Dune sand covers a large area southeast of the Missouri River between Cascade and Ulm, which is characterized by hummocky topography. Wind-eroded depressions known as blowouts have depths of 10 to 15 feet. No drainage pattern has developed on the dune sand.

The map area is in general maturely dissected, and relief over most of the area is approximately 500 feet. The highest elevation is at the top of Antelope Mountain (5, 215 feet above sea level) in the southwest part of the map, and the lowest elevation is near Ulm (3, 325 feet above sea level) where the Missouri River leaves the mapped area. The greatest variation in altitude is approximately 1,855 feet in a horizontal distance of $1\frac{1}{2}$ miles between the top of Antelope Mountain and the Missouri River, although most of the maturely dissected area lies between 3,325 and 3,800 feet.

GLACIATION

There is no evidence of mountain glaciation on the north slopes of the Big Belt Mountains nor of continental glaciation on the plains within the map area, but a continental glacier dammed the ancestral Missouri River, resulting in the development of glacial Lake Great Falls. Calhoun (1906, p. 30) states that in Pleistocene time a lobe of the Keewatin ice sheet advanced south out of Canada. Upon reaching the Highwood Mountains, approximately 36 miles northeast of the map area, the ice blocked the Missouri River, thus creating a large glacial lake, which extended southwest into the mapped area along the river channels and inundated areas of lower elevation. The lake discharged eastward through a channel known as the Shonkin Sag, which cuts across the present drainage lines and the gently sloping plain north of the Highwood Mountains.

Conclusive evidence as to the maximum depth of this lake was not found in the map area, but its surface may well have been at least as high as the 3,900 feet assigned it by Calhoun (1906, p. 30).

Maughan (1961) has shown that the lake, after attaining a 3,900-foot maximum level, receded in five successive states, the stage at the 3,800-foot level being most pronounced. At the 3,800-foot contour a terrace along the west side of Rocky Reef in sec. 19, T. 17 N., R. 1 E., is interpreted as evidence of an ancient shoreline. This shoreline is correlated with the well-developed 3,800-foot stage noted by Maughan (1961). Other, less significant shorelines observed near the 3,800-foot contour are interpreted as representing minor variation in the level of the lake. (See discussion under Quaternary Deposits.)

DRAINAGE

The major streams flow northerly and northeasterly except for Little Muddy Creek, which flows east. Minor tributaries may trend in any direction. The drainage patterns are dendritic, but radial patterns have developed locally around Square Butte, Cascade Butte, and Antelope Mountain.

A subtle drainage divide separates the Missouri River from the Smith River. This divide extends north through the center of the area and terminates south of Ulm at the confluence of the Missouri and Smith Rivers. Another drainage divide trends through the northwest corner of the area. This divide separates the Missouri River from Adobe Creek, which flows west and north into the Sun River.

Missouri River

The principal stream is the Missouri River. It enters the mapped area in the southwest corner and provides the major drainage in the western part of the area. Where the river enters the area it flows in a canyon and has a gradient of 15 feet per mile in the vicinity of Halfbreed Rapids. Near the mouth of Hardy Creek it emerges onto the plains and flows in a meandering course through a wide, open valley. Elliot (1959, p. 2) stated that from Cascade to Great Falls the average gradient of the river is 0.44 foot per mile; the Army Corps of Engineers refers to this stretch of the Missouri as the "long pool".

According to Buck (1961, p. 14) the drainage area of the Missouri above Cascade is 18,493 square miles. He reported that the maximum discharge of the river was 54,250 cubic feet per second (cfs) on June 5, 1908, and the minimum discharge was 800 cfs on September 2, 1914.

Several streams enter the Missouri, the largest of which is the Smith River. Lesser tributaries are Bird Creek and Castner Coulee, which enter from the east, and Little Muddy Creek and Hardy Creek, which join from the west. Several intermittent streams, such as Negro Creek, Knapp Creek, Antelope Creek, and Finigan Creek, drain into the Missouri from the west. These streams have their greatest runoff in early spring, but in most years they are dry by late summer.

Before Pleistocene time the Missouri River had cut a deep, wide channel through the area, but during the existence of glacial Lake Great Falls a large amount of debris was deposited in the channel, thus forming the relatively flat valley floor on which the Missouri River now flows. According to Alden (1932, p. 90), a well drilled near Ulm shows that the Missouri River is now flowing on the flood plain about 270 feet above the bottom of the pre-glacial valley, and Lyons (1944, p. 448) stated that a well just east of Cascade reached bedrock at a similar depth.

Smith River

The Smith River (locally called Deep Creek because it flows in a deep valley) enters the map area in sec. 18, T. 17 N., R. 3 E., and flows north to the Missouri River.

Within the map area several tributaries join the Smith River. Hound Creek and Spanish Coulee, which enter the river from the west, are the major drainages in the eastern part of the area. Goodman, Ming, Boston, and Murphy Coulees enter the river from the east, but their drainage area is mainly beyond the map area.

According to Buck (1961, p. 14), above a point approximately 6 miles upstream from its mouth, the Smith River has a drainage area of 2,006 square miles. At that point the maximum discharge observed was 8,800 cfs on June 24, 1907, and the minimum observed was 0.2 cfs on September 10, 1931.

LAND UTILIZATION

The land is used mainly for cattle ranching and farming, the major crops consisting of wheat, hay, barley, and oats. The crops are dry-farmed, except for hay. Most of the agricultural soils have developed from sandstone, shale, and alluvium.

Soil conservation is practiced throughout the area. This involves water and wind erosion control by contour and strip farming, water conservation by dams and irrigation, soil fertility management by fertilization and crop rotation, and controlled stocking of the range land.

IRRIGATION

In the map area most water used for irrigation is diverted from stream flow. The principal sources of water used for irrigation are the Missouri River, Smith River, and Little Muddy Creek.

According to Buck (1961, p. 12), land irrigated from the Missouri River in Cascade County totals 6,039 acres, of which the author estimates 5,500 acres within the map area. On many acres of potentially irrigable land, situated near the Missouri, the available water is not utilized to its maximum capacity. An example of this is the land included in the now dissolved Chestnut Valley Irrigation District in the southern part of the area.

Buck (1961, p. 12) reported that land irrigated from Little Muddy Creek and its major tributary, Rocky Gap Creek, totaled 1,747 acres. In the past, irrigation projects were well developed, and the valley contained several reservoirs for storage of irrigation water, but the dams have been washed out and the projects abandoned.

Smith River irrigation projects have not been developed to a great extent. Buck (1961, p. 13) wrote that land supplied with water from this stream totals only 345 acres.

Many ranchers have private irrigation systems that consist of diversion dams and ditches to distribute the water, thus diverted from creeks. The flood method of irrigation is used exclusively and is commonly employed on the flood plain of the stream.

STRATIGRAPHY

GEOLOGIC SETTING

Rocks in the mapped area consist predominantly of Cretaceous sandstone, siltstone, and shale. Lying disconformably under these strata is shale of the Morrison Formation (Jurassic), and overlying them are unconsolidated Quaternary sediments.

Trachybasalt dikes, sills, and flows are found in the southern and western part of the area. The largest intrusions are the dike of Rocky Reef and the sills of Cascade and Square Buttes. Flows of Adel Mountain Volcanics border the southwestern edge of the map area.

The local stratigraphic nomenclature and formation boundaries have been subjected to several revisions. In their coal studies, W. H. Weed (1892), C. A. Fisher (1909), and V. H. Barnett (1916) described the coal beds and placed them in the Kootenai Formation (Lower Cretaceous). These coal measures are now included in the Morrison Formation (Cobban, 1945, p. 1269). After Stebinger (1918, p. 158) defined the lower part of the Colorado Shale as the Blackleaf Sandy Member, the Colorado Group was long thought not to be divisible into smaller units. Cobban and others (1959 b), however, divided the Colorado Group into a lower unit, the Blackleaf Formation (Stebinger's Blackleaf Sandy Member), and an upper unit, the Marias River Formation. Each formation has been subdivided into four members. The historical development of the nomenclature of the Colorado Group is depicted in Table 2.

Table 2.--Historical development of the nomenclature of the Colorado Group (modified from Maughan, 1961).

Meek and Hayden (1861)	Fisher (1909)	Stebinger (1918)	Cobban and others (1959)		
Niobrara Group	Colorado Shale	Unnamed shale member	Colorado Group	Marias River Formation	Kevin Member Ferdig Member Cone Member Floweree Member
Fort Benton Group		Blackleaf Sandy Member		Blackleaf Formation	Bootlegger Member Vaughn Member Taft Hill Member Flood Member

Knowledge of subsurface strata in the map area is based principally on a stratigraphic section from Maughan (1961), which was compiled from the log of a deep well drilled in the SE$\frac{1}{4}$ sec. 12, T. 20 N., R. 1 E., just north of the map boundary (Table 3). The subsurface stratigraphic column southeast of the map area is similar except that Pulju (1964, p. 31) reports the presence of the Big Snowy Group (Mississippian).

JURASSIC SYSTEM

Morrison Formation

The name Morrison was introduced by Eldridge (1896, p. 60) for sedimentary rocks found near the town of Morrison, Colorado. Fisher (1909 b, p. 30) mapped the beds overlying the Swift Formation near Great Falls as Morrison because they contained saurian bones that were dated as being of Jurassic age. This was the first recognition of the Morrison in Montana (Barnett, 1916, p. 221).

Table 3.--Subsurface stratigraphic section (modified from Maughan, 1961).

Jurassic			Morrison Formation		140
			Swift Formation (Ellis Group)		21
			------------------------ Unconformity ------------------------		
Mississippian		Madison	Mission Canyon Limestone		637
			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+

The Morrison conformably overlies the Swift Formation (not exposed in the mapped area) and disconformably underlies the Kootenai (Cobban, 1945, p. 1269). The contact with the Kootenai is exposed in the area along the Smith River valley near Hound Creek, where it is characterized by a wavy surface between massive cross-bedded sandstone of the Kootenai overlying the upper carbonaceous shale unit of the Morrison. I infer, from this single outcrop, that the contact is disconformable.

Only the uppermost part of the Morrison, about 35 feet, is exposed in the map area. Thickness of the formation therefore could not be measured. Maughan (1961), from subsurface data, reported that the Morrison in the SE$\frac{1}{4}$ sec. 12, T. 20 N., R. 1 E., which is just north of the mapped area, is 140 feet thick and thins northward.

The Morrison is composed of continental deposits--siltstone, sandstone, fresh-water limestone, and variegated red, green, and purple shale. Outcrops of the Morrison in the Smith River valley reveal a hackly, well indurated, carbonaceous siltstone that weathers black to dark gray. This shale grades laterally into a bituminous coal. (See discussion under Economic Geology.)

CRETACEOUS SYSTEM

Kootenai Formation

The term Kootenai, derived from the name of a tribe of Indians in the Canadian Rockies, was proposed by Dawson (1885, p. 2) for beds exposed in that part of Canada. Two years later Newberry (1887) correlated the coal-bearing beds of the Great Falls Coal Field with Dawson's Kootenai Formation of the Canadian Rockies. The age of these coal seams has been the subject of much controversy over the years, but they are now judged by Cobban (1945, p. 1269) to be upper Jurassic, marking the boundary between the Cretaceous and Jurassic in the map area.

The bottom of the nonmarine Kootenai Formation is sharp and marked by a surface of erosion previously discussed. The basal bed of the Kootenai is a massive sandstone composed dominantly of quartz grains but containing scattered gray chert pebbles in slightly calcareous clayey cement.

In thin section the sandstone seems to be homogeneous and porous. Little compaction has taken place. The quartz grains, which seem to be from an igneous source, are angular to subrounded and compose 50 percent of the slide. Many contain bubble trains and inclusions of biotite flakes. Most grains have straight extinction, although some grains are strongly undulose.

Outcrops of the Kootenai are characterized by their bright-red shale and siltstone and gray sandstone. A red shale and a prominent yellowish-gray limestone bed are exposed in the Smith River valley. From a distance the limestone seems to be concretionary, but upon close examination the limestone is found to be fractured; weathering accounts for the concretionary appearance.

The upper contact of the Kootenai Formation with the Colorado Group presents a problem. Cobban and others (1959 b, p. 2787) stated that throughout the area of the Sweetgrass Arch the Colorado Group rests on the Kootenai Formation with an obscure disconformity and that the hiatus may be as much as 100 feet, but Maughan (1961) stated that in the type section of the overlying Flood Member of the Blackleaf Formation, that unit seemingly rests conformably upon the red shale of the Kootenai. Thus the Kootenai-Blackleaf contact may either be conformable or disconformable. No exposures in the Cascade-Ulm area shed light upon this problem; the Kootenai-Colorado contact is arbitrarily treated as a disconformity in this paper. (See discussion of Flood Member.)

Measurement of the Kootenai in the map area was impracticable because of poor exposures, but that total thickness as determined from a topographic map is thought to be approximately 400 feet. A section including the lower 200 feet was measured along the Smith River in sec. 36, T. 18 N., R. 2 E. (Appendix 4). Maughan (1961) reported that the Kootenai in the SE$\frac{1}{4}$ sec. 12, T. 20 N., R. 1 E., is 411 feet thick and thins northward.

Because the upper part of the Kootenai was not well exposed, a description by Cobban (1955, p. 109) has been included to acquaint the reader with the stratigraphy.

"The upper unit is chiefly mudstone, siltstone, and greenish-gray sandstone. The mudstone and siltstone are commonly some shade of green, red, or purple, and may be mottled. Brown-weathering silty limestone nodules are locally abundant. The sandstones are fine- to coarse-grained, massive, cross-bedded, highly lenticular, and as much as 100 feet thick. In contrast to the sandstones of the lower part, those of the upper part contain more micas and other grains derived from freshly weathered igneous rocks. Carbonaceous mudstone and siltstone, with macerated fossil plants, are present in some locations."

Cobban's upper unit was not assigned a thickness and cannot be tied to my measured section. Fossils in the Kootenai Formation consist of plants, fresh-water gastropods, and bones of fish, turtles, and dinosaurs. The following plants, representing the only fossils reported from the map area, were found by Fisher (1909, p. 34) on the east side of Spanish Coulee in sec. 11, T. 17 N., R. 2 E.: *Thyrsopteris elliptica* Fontaine, *Chiropteris spatulata* Newberry, *Sequoia gracilis* Heer, and *Zamites apertus* Newberry.

Colorado Group

The Colorado Group, which lies between the Kootenai and Telegraph Creek Formations, comprises strata of both Early and Late Cretaceous age and has a total thickness of about 1,500 feet. It is composed of two major lithologic units of nearly equal thicknesses that have recently been subdivided by Cobban and others (1959 b, p. 2787). The Blackleaf Formation contains much sandstone, siltstone, and shale and some bentonite. In contrast, the overlying Marias River Formation is mainly dark-gray shale. The Blackleaf Formation contains some nonmarine beds, whereas the Marias River Formation is entirely marine.

Blackleaf Formation

The Blackleaf Formation, as previously mentioned, was initially defined by Stebinger (1918, p. 158) as the Blackleaf Sandy Member of the Colorado Group and named for exposures along Blackleaf Creek in sec. 18, T. 26 N., R. 8 W., Teton County. Stebinger wrote: "The lower 600 to 700 feet of the Colorado Shale comprises an alternation of dark marine shales and gray sandstone in beds 20 to 75 feet thick, forming a clearly distinguishable unit from the remaining portion of the Colorado."

The Blackleaf Formation has been divided into four members:

Bootlegger Member (top)
Vaughn Bentonitic Member
Taft Hill Glauconitic Member
Flood Member (bottom)

Flood Member.--The Flood, the bottom member of the Blackleaf Formation, was named for exposures near Flood Siding on the Great Northern Railway 5 miles southwest of Great Falls (Cobban and others, 1959 b, p. 2787). At the type section the member is 138 feet thick and comprises two sandstone units and a middle shale unit. Within the map area a composite section includes a total thickness of 197.5 feet divided as follows: lower sandstone unit, 102± feet thick; middle shale unit, 41.5 feet thick; and an upper sandstone unit, 54 feet thick (Appendix 4). Thicknesses of the upper two units in the mapped area correspond closely to the thicknesses reported for the upper two units in the type section, but the lower unit of the type section is only 25 feet thick as opposed to the 102± feet measured in the map area.

The greater thickness of the lower unit in the Cascade-Ulm area may be accounted for in one of two ways: (1) the section was measured at the crest of a sharply folded anticline where intensive folding may have duplicated the unit, or (2) the greater thickness of this unit could be due to scour and fill of the underlying Kootenai in combination with a possible gradual thickening of the Flood to the south. The latter explanation, offered by C. E. Erdmann

(1964, personal communication), is more plausible in view of the fact that the Flood, a marine deposit, overlies the continental Kootenai. Scour and fill of the Kootenai also suggests a disconformity between the Blackleaf and Kootenai Formations. Folding alone probably could not account for this increased thickness of sandstone, which is not generally subject to plastic flow.

The lower unit of the Flood is a gray to tan-gray coarse-grained sandstone that weathers gray. This slightly calcareous sandstone is distinctly cross-bedded, and contains local massive beds. Ferruginous, calcareous concretions, 1 to 10 feet in diameter, are numerous and range from spherical to discoidal. These concretions readily part along the bedding planes, thus splitting into disks. One concretion contained a small piece of calcareous petrified wood. No animal fossils have been found or reported in this unit.

The middle unit is composed of interbedded siltstone, sandstone, and shale, which slumps extensively. The sandstone is tan and fine grained and weathers light tan gray. Siliceous cement is common, although some beds are argillaceous and friable. The shale beds are dark gray and weather light gray and are generally calcareous. Occasional gypsum crystals and limonite specks were observed in shale outcrops. No fossils were found in the middle unit, but worm borings are common in the sandstone.

In the Cascade-Ulm area the upper unit is a prominent cliff-forming, light-gray sandstone that weathers tan brown. The sandstone is fine to medium grained, and is composed of quartz and chert sand in either a clayey matrix or siliceous cement. Throughout much of the eastern part of the map area the top of the upper sandstone unit forms a stripped erosion surface because it is much more resistant than the overlying Taft Hill Member. This unit thins to the south and east from a maximum of 54 feet in sec. 1, T. 18 N., R. 2 E., to not more than 30 feet in the southeast part of the map area. This thinning is thought to be depositional.

Massive beds showing distinct vertical and horizontal joints characterize the lower 40 feet of this unit. Fossil wood and ferruginous calcareous dark-brown concretions 1 to 4 inches in diameter are widely scattered.

The upper part of the unit contains distinct irregular vertical joints and partings along the bedding planes, which give a flagstone appearance to the outcrop. Dark-brown iron stain is common along fracture planes. The bedding planes are very irregular and mottled, owing to the casts of worm trails.

In a zone 20 to 30 feet below the top of the unit huge epigenitic concretions 1 to 15 feet in diameter were observed throughout the map area. About 2 miles south of Ulm these concretions form the cap rock of several small hoodoos.

No fossils were found in the upper unit, but Maughan (1961) reported that in the uppermost beds the fossils Inoceramus comancheanus Cragin and Anomia n. sp. have been found.

The Flood is gradational with the overlying Taft Hill Member, and the contact is arbitrarily placed at the top of the uppermost sandstone bed.

Taft Hill Member.--To facilitate mapping of a large area on a relatively small scale base map, the Taft Hill and Vaughn Members were grouped together and mapped as an undifferentiated unit. Field distinctions between these members are subtle, and detailed work would be required to map them separately.

The Taft Hill was named by Cobban and others (1959 b, p. 2790) for exposures north of the map area, along the east slope of Taft Hill, which is about 3 miles south of Vaughn; the member includes the strata that lie above the upper sandstone unit of the Flood and below the overlying Vaughn. At the type locality the member is 242 feet thick and is composed of dark-gray marine bentonitic shale containing numerous prominent glauconitic sandstone interbeds. The thickness of the Taft Hill in the map area closely approaches the thickness of the type section.

Approximately 100 feet above the base of the member is a greenish-gray quartz and chert sandstone bed 30 feet thick. Several glauconitic sandstone beds are also present lower in the section. Maughan (1961) reported that these sandstone beds thin to the east and that subsurface data indicate a westward thickening of the member by additional glauconitic sandstone tongues that interfinger in the lower part. Maughan also stated that numerous 1-foot glauconitic sandstone beds are present near the top of the member, but they are neither as green nor as glauconitic as the lower sandstone beds.

Dark-gray shale in the upper 100 feet of the member is slightly calcareous and bentonitic. Commonly it exhibits poorly developed popcorn-weathering surfaces. Salts effloresce where the outcrops form barren slopes. Approximately 50 feet from the top of the Taft Hill the shale is marked by discontinuous brown, tan, and gray laminations and contains numerous lenticular argillaceous concretions. A 6-inch bed of black-chert-pebble conglomerate in a matrix of coarse-grained quartz and feldspar sand was found in sec. 18, T. 20 N., R. 2 E. This conglomerate is similar in composition to that found in the Bootlegger Member. (See discussion on Bootlegger Member.)

The upper contact of the Taft Hill is placed arbitrarily at the top of the highest glauconitic sandstone bed; in the field, however, some confusion may arise as to where the contact is. Maughan (1961) stated that in some places separation of the Taft Hill from the Vaughn Member is difficult because of similar sandstone at the base of the Vaughn. He noted that where both of these sandstones are present they may be distinguished by the presence of Lingula in the bedded glauconitic sandstone of the Taft Hill. The sandstone at the base of the Vaughn is cross-bedded, contains petrified plant fragments, and is devoid of glauconite.

Vaughn Member.--The Vaughn Member is composed of nonmarine sedimentary rocks that lie over the Taft Hill Member and under the Bootlegger Member. This member is named after the town of Vaughn (Fig. 1), and the type section is approximately 3½ miles northeast of the village (Cobban and others, 1959 b, p. 2790).

C. E. Erdmann (1964, personal communication) stated that the Vaughn as defined is not all nonmarine; the lower sandstone unit is marine. He suggested that the lower sandstone unit of the Vaughn should be included in the Taft Hill Member. Such an adjustment of the boundary would alleviate the difficulty of trying to differentiate the sandstone units at the present boundary between the Taft Hill and Vaughn Members. Carbonaceous shale beds mark the top of the Vaughn.

The type section is 97 feet thick. Maughan (1961) reported that the Vaughn gradually thickens to the west at approximately 3 feet per mile, beds at the base of the Bootlegger gradually thinning. This observation is in agreement with Cobban (1951, p. 2180) who noted that the Vaughn thins to the east. An incomplete stratigraphic section of the Vaughn measured in the map area is 94 feet thick, but the total thickness is probably not much greater than at the type section (Appendix 4).

The Vaughn is well exposed throughout the central part of the area. Vaughn outcrops are distinctive, as they form light-gray, green, and pink badlands.

The lower part of the member is generally tuffaceous to argillaceous, cross-bedded gray sandstone, which weathers yellowish gray with local reddish to greenish tints. The unit is friable because of the argillaceous matrix, although dense, hard quartzitic lenses are present. Many of the lenses and beds weather reddish brown.

Near the middle of the member lenses of dense indurated light-greenish-gray tuffaceous siltstone are interbedded with bentonitic shale. The upper part of the Vaughn is composed of greenish to dull-gray bentonitic and tuffaceous beds of siltstone, which exhibit a popcorn-weathered surface. Also present are several beds of thin sandstone, black carbonaceous shale, and rarely a discontinuous seam of lignitic coal of very poor quality. Locally, brownish-orange friable amber may be found in the carbonaceous shale beds.

The upper part of the Vaughn includes the "Red Speck Zone" (Maughan, 1961). This zone is formed by the development of clinoptilolite, which is a brilliant orange-red secondary zeolite. Small crystals and disseminated grains of this mineral give a pinkish to reddish cast to the beds. The mineral forming the "Red Speck Zone" has formerly been reported to be heulandite, but x-ray diffraction patterns of the mineral (procedure outlined by Mumpton, 1960, p. 359) identify the mineral as clinoptilolite, a silica-rich heulandite.

Fossils are common in the Vaughn. In the badlands topography, fragments of petrified wood are numerous. The cherty wood fragments are black on the inside but have developed a tannish-white outer coating or patina, owing to the removal by solution of the organic inclusions. Logs 2½ feet in diameter and as much as 6 feet long were observed, but these are uncommon. Cobban (1951, p. 2180) has identified the following plants: Pinus sp., Araucarioxylon sp., Anemia fremonti Knowlton, and Nelumbites sp., but these were not found in the map area.

Bootlegger Member.--The Bootlegger is the upper member of the Blackleaf Formation and is named from Bootlegger Trail, a secondary road leading from Great Falls north to Canada (Cobban and others, 1959 b, p. 2793). The member is 330 feet thick in the composite type section measured in the Great Falls quadrangle, but it rapidly thins to the west, and in sec. 1, T. 20 N., R. 1 W., it is about 150 feet thick. Most thinning takes place in the upper half of the unit as a result of nondeposition, and the member also may be beveled by a disconformity at the top (Maughan, 1961).

According to Maughan (1961), the Bootlegger just north of the map boundary is 150 feet thick, and this thickness is prevalent through the study area (Pl. 1).

The lower part of the Bootlegger is characterized by bentonite, shale, claystone, siltstone, sandstone, and pebble conglomerate. The bentonite is composed mainly of pale-green or yellowish-green clay, and most of its outcrops, which form gentle slopes, are marked by a white efflorescence of salts. The shale is dark gray to black and slightly fissile, whereas the claystone and siltstone are light gray and thin bedded. Hand specimens indicate that the gray fine-grained moderately well sorted sandstone is composed predominantly of quartz, chert, and fragments of volcanic rock. The black-chert-and-basalt-pebble conglomerate beds have a sandy or silty matrix. All chert pebbles are black on the outside, but they may be gray, tan, or black on the inside.

According to Maughan (1961), these sediments form cyclic deposits in which each cycle began with a fall of ash that has since altered to bentonite. The sediments in each cycle grade vertically from shale through claystone and siltstone into sandstone and pebble conglomerate. Outcrops in the map area are so discontinuous that this cyclic depositional sequence was not noted.

The pebble conglomerate occurs as beds 6 inches to 1 foot thick; internal layering is absent. Locally, lenses 5 feet thick were noted. The conglomerate may have a siliceous, sandy matrix, although a silty, calcareous matrix is more common, as shown by the large quantities of pebbles of chert and basalt that are found weathered out of the conglomerate in contrast to the general scarcity of consolidated conglomerate outcrops.

The pebble conglomerate is dark gray and contains well-rounded pebbles of chert and basalt. The chert pebbles range from $\frac{1}{2}$ to $1\frac{1}{2}$ cm, averaging about 1 cm. The basalt pebbles average about $\frac{1}{2}$ cm in diameter. The conglomerate where silicified is so firmly cemented by the matrix material that it breaks across the grains when fractured.

The chert pebbles indicate two source areas. Microscopic examination of the chert revealed the presence of relict organic spicules or spines and a tannish-brown mineral that may be collophane, indicating a sedimentary origin; this chert probably is derived from the Phosphoria Formation (Permian). Some of the pebbles contain elongate thin "blebs" that were interpreted as glass shards, which imply volcanic origin. The presence of volcanic chert is also suggested by the large percentages of plagioclase and fragments of volcanic rock in the matrix.

The presence of the well-rounded pebbles of chert and basalt in the poorly sorted sandy matrix presents a problem in determining the depositional environment. The roundness of the pebbles suggests a beach line or river environment of deposition where the pebbles would be well abraded. This type of environment, however, is not characterized by the angular, sand-sized grains that are present in the matrix. The high energy of the waves would readily remove such matrix material, producing a well-sorted deposit. Possibly the pebbles were well rounded by strong wave action and were initially deposited in shallow water, but subsequent downslope movement or slump combined with turbidity currents may have mixed them with the sand to produce this conglomerate.

The upper part of the Bootlegger is composed mainly of moderately indurated yellowish-brown sandstone and siltstone interbedded with thin beds of bentonitic clay and shale.

The contact of the Bootlegger with the Marias River Formation was not found exposed in the map area, but Maughan (1961) described it from a nearby area to the north as follows:

"A thin bentonite bed that overlies a very distinctive bed of coarse-grained brown-weathering sandstone marks the top of the member. This sandstone, composed mostly of quartz, is conglomeratic with black-coated, well-rounded chert pebbles and contains abundant fish scales and bone fragments. The bed does not exceed 2 feet in thickness, and locally is absent. In places its distinctive sandstone, which locally is interbedded with light-gray, fine-grained, well-sorted sandstone, is composed of quartz and chert, serves as a marker to separate the Bootlegger Member of the Blackleaf Formation from the overlying Floweree Member of the Marias River Formation. Generally the bentonite bed is no more than 2 feet thick."

Marias River Formation

The Marias River Formation is composed of dark-gray, marine shale that disconformably overlies the Blackleaf Formation and grades upward into the Telegraph Creek Formation; it is approximately 800 feet thick. The formation, which derives its name from the Marias River, along which the exposures of the strata are excellent, was named by Cobban and others (1959 b, p. 2793), as were the four members that it comprises. The four members are:

Kevin Shale Member (top)
Ferdig Shale Member
Cone Calcareous Member
Floweree Member (bottom)

Lack of exposures and similarity of outcrops of these members have necessitated grouping the Floweree and Cone together, and also the Ferdig and Kevin, to form easily mappable units.

Floweree Member.--The basal member of the Marias River Formation was named from the station of Floweree on the Great Northern Railway in Chouteau County. At the type section the member is about 63 feet thick, but in the Vaughn quadrangle, north of the map area, Maughan (1961) reported the Floweree to be 45 feet thick. Within the map area exposures are very poor, consequently a precise stratigraphic thickness could not be measured, but from stratigraphic relations the member is judged to be approximately 45 feet thick.

Lithologically nondistinctive, the Floweree is composed of dark-gray shale, light-gray siltstone, and lenses of sandy siltstone and fine-grained sandstone. The sandstone is composed mainly of quartz but contains abundant dark-gray chert grains.

No fossils were observed, but they have been found in this member elsewhere. Cobban and others (1959 a, p. 91) report the ammonites Calycoceras canitaurinum Hass, Metoicoceras muelleri Cobban, and M. mosbyense Cobban.

The covered contact of the Floweree with the overlying Cone Member is assumed to be similar to that to the north as described by Maughan (1961) who wrote as follows:

> "The top of the Floweree Member consists of a black, very fissile, soft, noncalcareous shale. The base of the overlying member consists of brown-weathering calcareous shale containing limestone concretions. Although this contact is poorly exposed in most places, the abrupt change from dark-gray, noncalcareous soil to pale-yellowish-brown or dark-yellowish-brown very calcareous soil locates the contact approximately."

Cone Member.--The name Cone was proposed for a sequence of beds of calcareous shale and thin-bedded limestone that is well exposed directly south of the U. S. Geological Survey Cone triangulation station in the Vaughn quadrangle. This, the type section, has a thickness of 54 feet. Within the map area the thickness of the Cone is estimated to closely approach that of the type section.

In the map area the lower part of the member consists of a poorly indurated brown calcareous shale that contains yellowish-gray septarian concretions. These concretions are found as float and have veins of either white or brown coarsely crystalline calcite.

About 12 feet above the concretionary bed is a 4- to 6-foot bed of light-gray bentonite, which is overlain by dark-gray shale that is generally covered by surficial deposits of the weathered outcrop.

According to Maughan (1961), the top of the Cone is marked by 10 feet of fossiliferous clastic limestone interbedded with gray calcareous shale that weathers light brown. *Inoceramus labiatus* and *Ostrea* n. sp. are common in the limestone. The conformable contact with the overlying Ferdig Member is characterized by a sharp lithologic change from the clastic limestone of the Cone to the noncalcareous siltstone of the Ferdig.

Ferdig Member.--The Ferdig Member was proposed to include gray noncalcareous shale that lies between the Cone and Kevin Members. It was named from the town of Ferdig in Toole County where it is 225 feet thick. Maughan (1961) reported that in the southern part of the Vaughn quadrangle the Ferdig is about 110 feet thick and that a disconformity within the member accounts for this difference from the type section. Although this disconformity was not observed in the map area, it is probably present, as the thickness of the Ferdig closely approaches that reported in the Vaughn quadrangle.

The lower part of the Ferdig is composed of dark-gray shale containing abundant lenses of sandstone and siltstone. Argillaceous limestone concretions in the shale weather orange yellow and commonly contain cone-in-cone structure. The concretions are very conspicuous and make an excellent stratigraphic marker. The sandstone beds in the lower part of the Ferdig are indurated by siliceous cement.

According to Maughan (1961), the cephalopod Scaphites has been found in sandstone units that have unusual V-shaped markings (chevrons) on the bedding planes. Within the map area, sandstone beds in the middle of the Ferdig contained these unusual V-shaped markings. C. E. Erdmann (1964, personal communication) has interpreted the markings to be tracks formed by Scaphites where they "touched down" on the surface.

The upper part of the Ferdig contains some beds of indurated quartz sandstone, and their resistance to weathering produces the subtle cuestas in the western part of the map area. Near the top of the Ferdig is a sandy shale that grades upward into the poorly indurated shale of the overlying Kevin Member.

The Ferdig-Kevin contact is not exposed in the area, but according to Maughan (1961) the upward change from a predominance of sandstone to shale occurs within a 5 foot interval, and the Ferdig-Kevin contact is placed at the top of the uppermost persistent Ferdig sandstone.

Kevin Member. --The uppermost member of the Marias River Formation is named for the town of Kevin in Toole County.

Where the Kevin crops out in the western part of the map area it is about 590 feet thick and consists of dark-gray shale and siltstone that weather light gray to brown. It contains a few light-gray limestone concretions. According to Maughan (1961), abundant thin beds of bentonite are interbedded with the siltstone. The fossils Lingula and Inoceramus deformis Meek were found and identified by the writer in a road cut southwest of Cascade.

At the upper contact, the Kevin is gradational with the overlying Telegraph Creek Formation of the Montana Group. This contact is arbitrarily placed where the dark-gray shale beds of the Kevin grade into the yellowish-gray interbedded thin sandstone and siltstone beds of the Telegraph Creek.

Montana Group

The Montana Group lies conformably over the Colorado Group. As a result of erosion of the upper part, it is represented in the map area only by the Telegraph Creek and Virgelle Formations. These formations crop out in the southwestern part of the area.

Telegraph Creek Formation

The Telegraph Creek Formation was named by Thom (1922, p. 38) for exposures in south-central Montana, near Telegraph Creek. It may be regarded as a transitional formation lying between the dark shale of the Colorado Group and the overlying massive sandstone of the Virgelle Formation.

In the map area the Telegraph Creek is not well exposed, as it is almost everywhere covered by debris from the overlying Virgelle Formation. A few good exposures may be found in the road cuts along U. S. Highway 91 about 3 miles south of Cascade and along the south side of Square Butte. Surface measurement of the Telegraph Creek was impractical, but as logged in Deep Well no. 4 (Appendix 3) the formation is 320 feet thick.

In the lower part of the formation, 1 inch thick greenish-gray shale beds are interbedded with slightly calcareous, sandy siltstone beds, all of which average about 1 inch in thickness. Abundant sets of symmetrical and asymmetrical ripple marks are found on the bedding planes of the sandstone.

The strata become progressively sandier and thicker near the top of the section, where light-gray, fine-grained sandstone forms beds less than 1 foot thick. Hand specimens indicate that the sandstone is composed mainly of subangular quartz, feldspar, and biotite.

Fossils are scarce in the Telegraph Creek. Cobban (1955, p. 114) lists several pelecypods and cephalopods from this formation.

The Telegraph Creek-Virgelle contact is placed where the sandstone interbedded with shale in the Telegraph Creek grades into the massive sandstone of the overlying Virgelle.

Fossils reported from the formation indicate a marine environment, probably near shore as indicated by the numerous oscillation and current ripple marks. Viele and Harris (1965, p. 408) noted that east of the Sweetgrass Arch the formation grades to tongues of sandstone between marine shale beds, whereas to the west it probably grades to deltaic and continental deposits.

Virgelle Formation

Bowen (1914, p. 97) attributed to W. H. Weed the first use of the name Virgelle for the lower sandstone member of the Eagle Formation on the east side of the Sweetgrass Arch. The unit is named for the town of Virgelle, where there are excellent exposures of the member. Stebinger (1914, p. 62) applied the name to rocks of equivalent stratigraphic level that crop out in the northern part of the Disturbed Belt, but he raised the Virgelle sandstone member to formational status on the west flank of the Sweetgrass Arch.

The Virgelle crops out in the southwest part of the Cascade-Ulm area, but part has been removed by erosion. The maximum exposed thickness is approximately 120 feet, although in Deep Well no. 4 (Appendix 3) the formation was logged as 141 feet thick.

The basal part of the Virgelle is composed of massive sandstone beds 6 to 8 feet thick. Locally it contains small iron concretions 2 to 3 inches in diameter.

Near the top, the Virgelle is composed of cross-bedded grayish-white friable, cliff-forming sandstone beds 25 to 35 feet thick. Southwest of Cascade Butte this sandstone unit contains dark-brown ferruginous calcareous concretions; where eroded they cap small pedestals, forming hoodoos.

Cobban (1955, p. 115) has described large, brown-weathering, calcareous concretions that have yielded a considerable fauna of small pelecypods and a single ammonite fragment identified as <u>Desmoscaphites bassleri</u> Reeside. In sec. 32, T. 17 N., R. 1 E., was found a huge concretion closely resembling those described by Cobban. It contained an abundant pelecypod fauna, but no traces of ammonites were found.

Exact stratigraphic position of beds of lignite 1 to 3 feet thick could not be determined. Lyons (1944, p. 451) reported that the lignite is 10 to 40 feet below the top of the formation. About 1½ miles west of the map area the lignite in these beds was good enough to mine, but the mines are now abandoned.

The presence of both lignite and marine fossils in this formation indicates that part of the Virgelle was deposited in marine environment, part in continental. The cross-bedded sandstone containing marine fossils suggests a near-shore environment whereas the lignite is indicative of a marshy fresh-water environment.

QUATERNARY DEPOSITS

Unconsolidated sediments recognized in the area are terrace gravel, glacial lake deposits, dune sand, alluvium-colluvium, landslide deposits, and alluvium.

Terrace Gravel

Terrace gravel is distributed mainly along the Missouri River although occasional deposits are situated along some of the minor streams. Remnants of these gravel deposits rest upon the underlying planed bedrock approximately 150 feet above the Missouri River and remain as upland terraces. Rejuvenation has resulted in downcutting and removal of sediments adjacent to the remnants of terrace gravel.

The terrace deposits along the Missouri River are composed of well-rounded, poorly sorted pebbles, cobbles, and boulders of argillite and quartzite in a matrix of calcareous sand and silt. Coatings of caliche are commonly found on the underside of the rocks near the top of the deposits, and in some localities this cement is so abundant that the gravel is consolidated into a poorly indurated conglomerate. Thickness of the deposits ranges from 2 to 20 feet.

Deposits 5 to 10 feet thick, located along the minor streams, are composed of sand- to cobble-sized, angular fragments derived from nearby formations. Trachybasalt fragments ranging in size from 1 to 5 cm and thin stringers of clay are also present. Commonly the rock fragments are cemented together by caliche. The most extensive gravel deposit is southwest of Cascade.

The terrace deposits are inferred to be of probable Pleistocene age on the basis of topographic correlation with the terrace deposits of the Vaughn quadrangle, which Maughan (1961) has dated as "probably Pleistocene". Maughan stated that R. W. Lemke (personal communication) has gathered evidence that suggests a Pleistocene age for these terrace deposits.

Glacial Lake Deposits

The glacial lake deposits are directly related to continental glaciation and were deposited in glacial Lake Great Falls. According to Maughan (1961), these lake deposits accumulated during a single period of glaciation as the lake level dropped in five successive stages from a maximum altitude of 3,900 feet to 3,360 feet.

The earliest glacial lake deposits in the area are represented by granitic erratics as large as 5 feet in length. According to Maughan (1961), their random distribution indicates that they were rafted by floating ice that was moved around by wind and water currents. Subsequent melting of the ice resulted in the deposition of these boulders.

Maughan (1961) noted that lacustrine deposits of the first two lake stages are represented only by the granitic erratics. Buff-colored exposures of laminated lacustrine deposits found along the Missouri River were deposited when the lake stood at the lower three levels. These deposits were observed to have a maximum thickness of 40 feet. The lacustrine deposits of this more restricted lake stage consist of finely laminated clay that is interstratified with feldspathic sand.

Mineral percentages of the glacial lake sand are as follows: quartz, 35 percent; feldspar, 30 percent; mica, 10 percent; magnetite, garnet, and hornblende, 5 percent; and unidentifiable minerals, 20 percent.

Under the binocular microscope a sample of well-sorted glacial lake sand was seen to consist of very angular quartz and feldspar fragments that range in size from 0.05 to 1 mm in diameter. Numerous flakes of biotite and muscovite are as large as 1 mm in size. Magnetite occurs in sand- to silt-sized subangular fragments, and two minerals identified as garnet and hornblende averaged 0.25 mm and 0.5 mm respectively in their largest dimension.

The lake deposits are between Cascade and the northern end of the Big Belt Mountains. They occur as remnants next to igneous dikes or in other areas where they have been protected from erosion. Laminated lake deposits next to a dike exposed in a road cut south of Cascade were dipping at an angle of 3 degrees. This is interpreted as a result of differential compaction. Stratigraphically, the lake deposits overlie the terrace gravel.

Small exposures of lacustrine clay occur throughout the lower elevations of the area. Exposures too small to map separately have been mapped with alluvium. Inasmuch as the lacustrine deposits of the highest lake stages are represented in the area only by the scattered erratics, they are not shown on the geologic map. Thus glacial lake deposits are more widespread in the area of investigation than indicated on the map.

Dune Sand

Dune sand deposits between Cascade and Ulm are found predominantly in the Missouri River valley and in the uplands bordering the river to the east.

The sand is derived principally from alluvial deposits of the Missouri River. The dune sands are in part currently active and can be seen migrating over terrace deposits. They are inferred to be of recent origin.

Stabilization of the dune sand is a problem. Along the Missouri River valley, sagebrush and other shrubs retain some of the sandy soil about their roots, but where vegetation is absent the sand is readily picked up by the wind and transported.

The dune areas exhibit the characteristic dune sand swell-and-swale topography. On the west side of the Smith River valley, near the confluence of the Smith and Missouri Rivers, the sand has been blown, but it has not developed a hummocky topography. This may be due to low wind velocity.

Under the binocular microscope the following approximate mineral percentages were determined: quartz, 40 percent; feldspar, 30 percent; mica and magnetite, 5 percent; and unidentifiable minerals, 25 percent. The well-sorted dune sand is mainly of quartz and feldspar. Grains range in size from 0.05 to 1 mm. Some of the quartz grains are frosted. Presence of both angular and well-rounded grains indicates two sources. It is possible that the angular quartz in the dunes was derived from the nearby Virgelle Formation or from glacial lake sediments after first being deposited as alluvium, whereas the well-rounded grains were eroded from sedimentary rocks farther up the Missouri.

Alluvium-Colluvium

Alluvium-colluvium is a heterogeneous unit that includes material deposited by small streams, creep, slope wash, and gravity. These deposits are composed mostly of sand, silt, clay, and trachybasalt fragments, and have accumulated as widespread deposits around the buttes and along the mountain front. The thickest deposits, adjacent to the mountain front, may be as much as 50 feet thick.

Landslide Deposits

One landslide, on the south side of Square Butte, has been recognized in the area. It is composed of chunks of sandstone and siltstone from the Telegraph Creek and Virgelle Formations and huge blocks of columnar-jointed trachybasalt from the overlying sill. The blocks are 6 to 8 feet across and 20 feet long. The debris exhibits a hummocky topography, and drainage is poorly developed. The material is spread over an area of half a square mile. The date of this landslide is unknown; there is no written record of it. Several springs occur in the landslide area, and it is postulated that during an extremely wet year, water from these springs may have provided the lubricant for the slide.

Alluvium

The flood plains and channels along Missouri and Smith Rivers and their tributaries are composed chiefly of alluvial sand, silt, and clay. Gravel lenses are common along Missouri and Smith Rivers; they are poorly bedded deposits of subrounded, moderately well sorted material.

IGNEOUS ROCKS

ADEL MOUNTAIN VOLCANICS

According to Lyons (1944, p. 452), the Adel Mountain Volcanics are 3,200 feet of potash-rich volcanic and related intrusive rocks, which unconformably overlie or intrude the Cretaceous strata in the area. Lyons judged the volcanic rocks to be of Late Cretaceous age on the basis of plant fossils. Viele and Harris (1965, p. 414) indicated that the Adel Mountain Volcanics lie disconformably on the St. Mary River-Willow Creek Formation, and they implied that the time interval of this disconformity is long enough to date the volcanic rocks as possibly Paleocene. The volcanic rocks are herein classed as "Tertiary(?)".

According to Lyons (1944, p. 455), the chief intrusive members of the Adel Mountain Volcanics are trachybasalt, syenogabbro, and monzonite. In the Cascade-Ulm area, trachybasalt has been intruded in the form of dikes and sills. Lyons (1944, p. 455) stated that all the igneous rocks were intruded before the main diastrophism of the Disturbed Belt.

DIKES

The trachybasalt dikes intrude the Adel Mountain Volcanics and predate late Eocene diastrophism, hence are believed to be of early Tertiary age. The dikes, locally known as "reefs", are very conspicuous topographic features in the area. Widths range from 10 to 30 feet, and dips are nearly vertical. The noticeable north-south trend of these dikes may be due to intrusion parallel to prevolcanic axes of folding (Lyons, 1944, p. 455).

The dikes are most numerous in the southwest corner of the area. Near the edge of the Big Belt Mountains a swarm of 13 dikes occurs in a strip about 2 miles wide.

Although the "reefs" are more resistant than the surrounding sedimentary rocks, they erode away readily, and out in the plains in many places the dikes barely protrude above the surface. In two localities, sec. 22, T. 18 N., R. 1 E., and sec. 10, T. 16 N., R. 1 E., dikes were found only with the help of local ranchers, because the igneous rocks were eroded flush with the ground and were expressed only by greener vegetation. Commonly the middle of the dikes is more decomposed than the walls, presumably because of coarser texture of the dike's interior.

The fresh road cuts along U. S. Highway 91 expose the relationship of the dikes to the sedimentary rocks. The strata adjacent to the dikes have been only slightly disturbed by the intrusive flow of the molten rock. Numerous xenoliths of sedimentary rock are incorporated into the dikes. Contact metamorphism is very slight or nonexistent, and the maximum metamorphic effects are nowhere greater than a slightly baked zone 2 inches wide. Any mineral changes in this zone are not megascopically noticeable.

A thin section of quartz-bearing trachybasalt from Rocky Reef is characterized by an aphanitic potash-rich groundmass, which forms 35 percent of the rock. Small unaltered plagioclase laths ranging in size from 0.05 to 1.0 mm occur in the groundmass, and larger plagioclase crystals, 0.75 to 0.105 mm, occur as phenocrysts. The plagioclase phenocrysts form 55 percent of the slide and are moderately zoned. They have a composition between andesine and oligoclase. In the centers of crystals the plagioclase has been strongly altered and is partly replaced with dolomite, but the borders of the phenocrysts have remained fresh.

An opaque accessory mineral, chiefly concentrated around the plagioclase phenocrysts, makes up 5 percent of the thin section. A brown biotite-like mineral forms 2 percent of the rock. It surrounds small, rare vacuities and occurs mostly in radiating fibres, although it is also found unoriented. Subhedral quartz grains are randomly scattered through the rock and form 3 percent of the specimen.

SILLS

Sills at Square Butte and Cascade Butte cover $1\frac{1}{2}$ and $3\frac{1}{2}$ square miles respectively. These sills presumably were fed by the trachybasalt dikes that trend across the plains, because some of the dikes lead into the sills, but no dikes cut the sills or extend beyond them.

The tops of the sills are smoothly undulating, continuous surfaces. Only minor drainage patterns have developed on them.

Strong evidence indicates that the sills were injected into the Virgelle Formation at or near its contact with the Telegraph Creek. Along the western edge of Cascade Butte the sill is overlain by Virgelle sandstone, which is being stripped off the surface. In the bed of Negro Creek, which is flowing at or near the base of the sill, was found a small outcrop of sandstone of the Telegraph Creek Formation. In the slide area, along the south edge of Square Butte, the intrusive contact between the sill and the Virgelle Formation is exposed, and xenoliths of Virgelle were noted in the sill. Approximately 10 feet of Virgelle sandstone lies between the sill and the Telegraph Creek Formation. Although no remnants of sedimentary rock were found on the top of Square Butte, the restricted thickness of the Virgelle beneath the sill indicates that the sill was injected entirely in the Virgelle.

Columnar joints are well developed at Square Butte and less prominently at Cascade Butte. On Square Butte and the north side of Cascade Butte these columns form part of the precipitous cliffs that are so prominent.

An interesting feature of the sills, especially well developed on Square Butte, is the horizontal layering. Lyons (1944, p. 457) counted 28 alternating dark and light-colored layers 8 to 10 feet thick. The dark layers show a concentration of heavy materials. Several theories have been proposed to account for this phenomenon, but none of them have proved completely satisfactory.

In one place along the south side of Square Butte the horizontal layering is disrupted by vertical flow structure. Evidently this was an area where a feeder merged into the sill, and probably it was one of the last places of movement during emplacement.

STRUCTURAL GEOLOGY

STRUCTURAL SETTING

The study area encompasses the margins of two major tectonic provinces, the Cordilleran Geosyncline on the west and the Central Stable Platform on the east. These provinces have been elements of the continental framework since the Precambrian. The structural features that directly affect the area are the Disturbed Belt, which is an area of folds and thrust faults at the front of the belt of orogenic activity, and the Sweetgrass Arch (Fig. 1), which is the northwestward anticlinal plunge of the Little Belt Mountains.

Throughout the plains in the northern part of the Cascade-Ulm area, the structure is comparatively simple. The beds on the western limb of the Sweetgrass Arch dip gently to the west. Moderate dips of from 2° to 5° predominate throughout the plains, and the strata are slightly folded into gentle synclines and anticlines. The few faults show minor amounts of displacement. These folds and faults are difficult to detect, because they have no topographic expression. They can be found only by careful examination of strata that are well exposed along Smith River and its tributaries, in the badlands topography of the Vaughn Member, or in fresh road cuts.

In the southern part of the plains, the strata dip slightly to the south. Near the Disturbed Belt these dips become progressively steeper and the folds are stronger and more pronounced where the sedimentary rocks reflect the strain of compressional forces.

Cretaceous strata in the area are composed predominantly of siltstone and shale and may be regarded as incompetent. This may account for the rapid dying out of folds and faults away from the Disturbed Belt and toward the plains.

Within the Cascade-Ulm area the Disturbed Belt deviates from its regional north-northwest trend and assumes a west-northwest trend along the northern edge of the Big Belts. Thus the rocks of the area were subjected to north-south compressional stresses, which folded the Cretaceous strata into a general structural trend of approximately N. 75° W.

The Adel Mountain Volcanics, which lie south of the area, have been folded and faulted. The intensity of this deformation increases to the west and has been dated by Viele and Harris (1965, p. 414) as late Eocene.

FOLDS

In the southern part of the area are several small folds and one major fold, which are parallel and trend west-northwest, concordant with the general structural pattern of the area.

The most prominent structure is in the southeast part of the area in sec. 4, 5, 9, 10, and 11, T. 16 N., R. 1 E., where a large asymmetrical anticline seems to develop from the Carter Ranch Fault at its northwest end. (See section under Faults.) This structure, named the Carter Ranch Anticline, may be traced for nearly 2 miles in a northwesterly direction before it plunges westward in sec. 5, T. 16 N., R. 1 E. From this point westward, alluvial-colluvial cover made it impossible to determine the structure of the anticline in detail, but it is thought to be complicated by smaller folds. Sandstone of the Flood Member crops out along the crest of the anticline except where inliers of the Kootenai Formation are exposed. Dips on the south limb of the fold range from 5° to 25°; dips on the north limb range from 53° to slightly overturned.

South of the Carter Ranch Anticline several anticlines and synclines on which the dip is as great as 30° deform Taft Hill-Vaughn sandstone layers. These structures were too small to be mapped, and their areal extent could not be determined, because exposures are incomplete.

Parallel to the Carter Ranch Anticline and about 1½ miles north of it lies a broad syncline, named the Willow Creek Syncline after Willow creek, which flows across the structure. As the syncline plunges west it becomes broader; it is about 3 miles wide where it plunges under the alluvium of the Missouri River. The trough exposes mostly poorly indurated shale of the Marias River Formation; the more resistant sandstone of the Blackleaf Formation crops out on the flanks. To the west, rocks of the Telegraph Creek and Virgelle Formations become prominent as the syncline plunges. In sec. 1 and 2, T. 16 N., R. 1 E., an inlier of Taft Hill-Vaughn is exposed in the core of the syncline. This inlier may be explained by the presence of a minor cross fold, although proof for this interpretation could not be found, owing to poor exposures.

It is easier to detect the Willow Creek Syncline by observing the outcrop pattern of the rocks than by measuring strikes and dips, because the structure is so broad (cross section B-B', Pl. 1). Dips on the south flank were difficult to measure, owing to poor exposures and to the numerous "crinkles", which tend to give erroneous interpretations. The north limb dips gently to the south.

The southern limb of Willow Creek Syncline, which is the northern limb of the Carter Ranch Anticline, is modified by numerous minor anticlines and synclines and a few faults. Faults are probably more numerous than indicated on the map, as scarcity of exposures has prevented their detection. Those which could be located were mapped and their attitudes determined.

It was not possible to obtain continuous delineation of the folds, because of vegetative and soil cover, but in sec. 31, T. 17 N., R. 1 E., and sec. 6, T. 16 N., R. 1 E., a set of folds in sandstone beds of the Taft Hill-Vaughn could be followed for nearly a third of a mile. The axial traces are approximately 400 feet apart. The dips of the flanks of these folds range from 18° to 53°. Folds of this type, and occasional minor folds, seem characteristic of the area between Carter Ranch Anticline and the Willow Creek Syncline.

An asymmetrical anticline in sec. 26 and 27, T. 17 N., R. 1 E., is nearly $1\frac{1}{2}$ miles long. At the eastern end it trends west, but about 1 mile from where it dies out in the west it curves gently to the northwest. The fold plunges gently and dies out to both the east and west. Dips on the northern flank average 10°; those on the slightly steeper south limb range from 5° to 37°. Rocks of the Taft Hill-Vaughn are exposed in the core of the fold in its eastern part where the anticline has been breached by a small stream, but elsewhere the Bootlegger crops out on the flanks and crest of the fold.

An asymmetrical anticline in sec. 19 and 20, T. 17 N., R. 1 E., has been named Cherry Coulee Anticline for its proximity to Cherry Coulee. This structure is flanked on both sides by Bootlegger rocks, and its core exposes the Taft Hill-Vaughn section. The north flank dips slightly to the north whereas the south flank has dips of 15° to 20°. The anticline trends east for about 2 miles before it dies out. To the west the fold is covered by deeply weathered Floweree-Cone and Ferdig-Kevin shale, and its west-plunging nose is covered by Missouri River alluvium.

The north flank of the Cherry Coulee Anticline is common with the south flank of the northwest-trending west-plunging Cherry Coulee Syncline. This shallow structure was detected by outcrop patterns. In the trough is exposed Marias River shale; on the flanks Bootlegger and Taft Hill-Vaughn rocks crop out. The syncline is truncated on the north by a reverse fault. (See discussion under Faults.) South of the axis the dip is 5°.

FAULTS

Four longitudinal reverse faults and four longitudinal high-angle faults were mapped. The actual fault planes are not exposed; criteria for their recognition were (1) stratigraphic separations, (2) change in dips, (3) topographic breaks, and (4) physiographic anomalies.

In this paper the term "high-angle fault" is applied to faults that have nearly vertical fault planes. Reverse faults are faults in which the hanging wall has apparently moved up relative to the footwall. The terms are not mutually exclusive.

Reverse Faults

The fault with the greatest amount of displacement is the northwest extension of the Carter Ranch Fault, named by Barnett (1916, p. 227). This fault was traced by Barnett for approximately 6 miles through the Hound Creek Coal District and it may be followed for an additional 3½ miles in the Cascade-Ulm area, a total length of 9½ miles. Barnett reported that the beds south of the fault have been displaced upward about 700 feet at the point of its maximum stratigraphic throw. Where the fault enters the Cascade-Ulm area it is striking N. 45° W., and from its topographic expression the fault plane is judged to be dipping southwest.

In sec. 7, T. 16 N., R. 2 E., the fault turns sharply to the west and bifurcates. The southern segment trends S. 80° W., and may be traced for nearly three-quarters of a mile before it gradually dies out. Kootenai strata dipping 15° to 22° southward on the south side of this segment of the fault have been raised upward approximately 180 feet relative to sandstone in the Flood on the north, which dips 25° S. The arcuate trace and the overturning along the north segment suggest that the fault plane also dips south at a low angle. A small intermittent stream flows along the trace of the fault.

The northern segment of the Carter Ranch Fault strikes westward in an arc for 2 miles. Sandstone beds in the Flood on the southern upthrown block of the fault dip 70° N. to slightly overturned, whereas the Bootlegger rocks on the north side of the fault dip at a much smaller angle of 25° to the north. The steep to overturned dips may be the result of drag.

The dip of the fault plane could not be determined, owing to lack of exposures; but the attitude of the strata on the south side of the fault and the syncline on the north suggest that the fault plane dips steeply south. The stratigraphic throw diminishes westward along the fault. Cross section A-A' (Pl. 1) shows a displacement of 300 feet on this segment of the Carter Ranch Fault, but as the fault is traced westward its displacement becomes less and it dies out in the steep north limb of the previously discussed Carter Ranch Anticline.

Another reverse fault is in sec. 4, T. 16 N., R. 1 E. This short fault is closely associated with the Carter Ranch Anticline and resulted when the folding of this structure became so intense that sandstone beds in the Flood on the south limb were raised upward and northward nearly 400 feet over the Vaughn. The fault plane dips to the south at an angle estimated at 30° and the fault trace is exposed for about 1 mile in a tight arc, concave to the south. The stratigraphic displacement becomes gradually less toward both the east and west extremities of the fault trace, which eventually dies out.

Willow Creek Fault, near the head of Willow Creek in sec. 31 and 32, T. 17 N., R. 1 E., strikes northwest. The fault can be traced for slightly more than half a mile on the east side of the creek for which it is named, but beyond this stretch the fault cannot be distinguished. The Bootlegger and Floweree-Cone on the north side of the fault dip 25° N.; the Taft Hill-Vaughn beds south of the fault dip 50° S. The fault plane is not exposed. The Taft Hill-Vaughn beds on the southern, upthrown, block are brought into contact with the Floweree-Cone, indicating a stratigraphic throw of approximately 160 feet. Along the western half of the fault, the Bootlegger has been faulted out.

It is probable that a fault three-quarters of a mile farther west is a continuation of the Willow Creek Fault, but lack of exposures in the area of alluvium prevents verification. The fault in sec. 36, T. 17 N., R. 1 W., was mapped as a diagonal-slip fault. It seems to displace Rocky Reef dike 600 feet in a right lateral sense. There is a possibility that the igneous rock forming the dike shifted from one fracture to another during intrusion, thus giving the illusion of being offset; examination of the outcrop was inconclusive. A stratigraphic throw of approximately 100 feet (up on the south side) is indicated by a cross section prepared from the scanty data available. The fault trace was followed for about 2,400 feet between areas of alluvium-colluvium on the east and on the west. The Taft Hill-Vaughn strata south of the fault dip north at 55°. Attitudes north of the fault surface were impossible to measure. The fault plane is not exposed anywhere throughout the length of the structure, but slickensides were found on Bootlegger conglomerate float. A small spring-fed stream originates along the fault trace and flows through the gap in the dike.

High-Angle Faults

An east-west fault in sec. 17 and 18, T. 17 N., R. 1 E., can be traced for $1\frac{1}{2}$ miles. The fault plane is believed to dip north. The north side has moved up relative to the south side, and the amount of displacement is on the order of 250 feet. To the west this fault is covered by alluvium, hence its true length cannot be measured. The fault gradually dies out to the east. Attitudes in the poorly consolidated Floweree-Cone and Ferdig-Kevin shale south of the fault could not be determined. Dips of the Taft Hill-Vaughn strata north of the fault range from 25° S. to 45° N. Two interpretations could account for these erratic attitudes: (1) they could indicate a fault zone comprising numerous secondary faults and slices, or (2) the locality may be characterized by numerous small folds. A combination of these two possibilities probably accounts for this structure.

In sec. 16 and 17, T. 17 N., R. 1 E., an east-west-trending fault may be traced for roughly three-quarters of a mile before it disappears to the west under Missouri River alluvium and to the east under the alluvium of Willow Creek. A small spring-fed creek flows along the fault trace. Vaughn shale expressed in badlands on the south side of the fault is in contact with Floweree-Cone shale on the north side, indicating that the south block has moved upward. Rocks on both sides of the structure dip north. Stratigraphic relationships indicate displacement of approximately 140 feet. The direction of dip of the fault plane could not be determined, but the linear trace of the fault pattern indicates that it is nearly vertical. Scattered pieces of sandstone float contain poorly developed slickensides.

At the southeast end of Cascade Butte a fault was mapped that trends northwest for a distance of $1\frac{1}{2}$ miles. To the southeast the fault disappears under the alluvium of the Missouri River and toward the northwest it terminates in the igneous rock of Cascade Butte. No evidence of displacement could be found on the butte.

A road cut across the structure reveals excellent exposures of the fault plane, which dips south at 55°. Rocks on both sides of the fault are Ferdig-Kevin shale. The strata on the north are nearly horizontal and the strata on the south dip away at 5° to 15°. Similar shale of the Ferdig-Kevin prevails on both sides of the fault zone, hence the stratigraphic throw could not be determined, but on the basis of drag, the fault is judged to have normal displacement.

A high-angle fault trending west-northwest intersects the northwest corner of Cascade Butte. An intermittent stream originates in a depression and flows westward along the projected strike of the fault. The fault lineament is about $1\frac{1}{2}$ miles long. Nearly vertical slickensides on a dike crossing the structure suggest that the fault plane is almost vertical, as does the linear trace of the fault across the topography. There was no lateral displacement of the dike; movement on the fault is dip slip. Difference in altitude of the igneous rocks on the two sides of the structure indicate that the south side of the fault has moved upward not less than 150 feet relative to the north side.

It is possible that eastward extension of the fault along the entire north side of Cascade Butte accounts for the sharp escarpment of the north face of the sill. No proof could be found to verify this suggestion.

STRUCTURAL INTERPRETATION

Folding within the area seems to have occurred at different times and possibly by different mechanisms. The gentle westward dips on the plains owe their origin to uplift of the Sweetgrass Arch, a northward offshoot of the anticlinal Little Belt Mountains. Wolf (1964, p. 496) stated that uplift was intermittent in the Little Belts from Late Cretaceous to Pliocene and probably is continuing today.

In the structurally complex portion of the Disturbed Belt it is difficult to determine the exact sequence and date of the folding. Lyons (1944, p. 452) noted that folding prior to extrusion of the Adel Mountain Volcanics structurally disturbed the Late Cretaceous sedimentary rocks, but that the major diastrophism of the Disturbed Belt postdated the volcanism.

In the Disturbed Belt portion of the mapped area no evidence was found to indicate prevolcanic folding; all folds and faults are thought to be related to late Eocene diastrophism. Faults cut folds, therefore the faults are younger. The youngest rocks that display deformation are the Adel Mountain Volcanics.

ECONOMIC GEOLOGY

GRAVEL

Gravel pits are widespread throughout the area, although most of them are small and have supplied only the local market. Of the several pits in alluvium along the Missouri River only one pit, operated by the Mortensen Sand and Gravel Company about 6 miles south of Cascade, is currently being worked. Crushed and sized sand and gravel are produced for use in the surrounding area.

Terrace deposits provide a source of gravel used for road metal by the county highway department. Much of this material was used in construction of U. S. Interstate Highway 15. Gravel from terrace deposits along smaller tributary streams has been utilized for graveling private roads.

COAL

In the map area bituminous coal occurs in the upper unit of the Morrison Formation. Fisher (1909, p. 50) noted that coal beds of workable thickness are not continuous. In places the coal zone is only a thin seam embedded in carbonaceous shale.

In the Smith River and Hound Creek canyons the coal-bearing zone has been mined intermittently for approximately 80 years. According to local ranchers two mines are now operated on a part-time basis; the Carville and Gibson mines, located respectively on the west and east sides of Hound Creek near the Smith River.

Fisher (1909, p. 66) described the coal-bearing zone and Carville mine as follows:

"The main entry extends 375 feet west from the outcrop, with a side entry to the south 75 feet long and 40 feet wide, branching from the main entry 90 feet from its mouth. On the north side of the main entry there is another side entry with four large rooms. This mine is not operated in an extensive way, but it is worked continuously, the total annual output being about 1, 800 tons. It supplies coal to ranchmen throughout a considerable territory to the south and west. The bed mined is 5 feet 6 inches thick with no appreciable partings. The lower 6 inches of coal is dull looking and in places bony, but it is firm and as a fuel gives good satisfaction. Above this bed there is a bright coal said to be suitable for blacksmithing, which contains numerous iron-pyrite nodules. The thickness and character of the bed remain relatively uniform throughout the workings."

The Gibson mine is similar to the Carville mine. Fisher (1909, p. 67) stated that the coal bed worked is slightly thicker than that exposed in the Carville mine and measures 5 feet 10 inches thick. He noted that the upper 2 feet is a bright, firm-looking coal whereas the lower part of the bed has a dull appearance. Table 4 shows the chemical composition of the coal taken from the Smith River locality. From the analyses, the coal of the Smith River district is classified as medium-grade bituminous (Fisher, 1909, p. 81).

OTHER ECONOMIC DEPOSITS

Numerous bentonite beds occur in the Vaughn and Bootlegger Members, but they are either too poor in quality, too thin, or too deeply covered by overburden to have economic value.

Sandstone in small amounts has been used for foundations, well linings, decorative stone, and riprap for facing on small stock dams. Most stone for riprap comes from the massive sandstone in the middle of the upper unit of the Flood but some comes from the massive sandstone in the lower part of the Vaughn. Some sandstone from the Bootlegger is utilized.

The sandstone commonly used for building foundations and well linings is an easily quarried flaggy sandstone from the top of the Flood Member. It was used extensively in the foundations of older buildings in the area, but because these flagstones are poorly cemented, the foundations have not held up very well. This flatstone serves as excellent linings for dug wells.

According to D. Jones (1964, personal communication), some of the alluvial clay in the Missouri Valley has ceramic properties, although impurities impart an undesirable terra cotta color. These clay beds are about 4 to 6 inches thick and are not continuous. They are not present in sufficient quantity to be of economic importance.

Several deep wells have been drilled for oil in the map area and surrounding territory, but no discoveries have been made (Appendix 3). The probable reservoir objective is the Madison Limestone.

Table 4.--Analyses of coal samples from the Smith River district (modified from Fisher, 1909, p. 81).

Analysis of sample as received:		1	2	3
Proximate	Moisture	4.82	6.17	4.54
Proximate	Volatile matter	27.17	27.03	27.44
Proximate	Fixed carbon	46.13	52.03	47.95
Proximate / Ultimate	Ash	21.88	14.77	20.07
Ultimate	Sulfur	2.84	4.36	4.09
Ultimate	Hydrogen	4.36	4.43	4.23
Ultimate	Carbon	56.98	61.62	58.66
Ultimate	Nitrogen	.72	.93	.87
Ultimate	Oxygen	13.22	13.89	12.08
Calories		5,578	6,077	5,818
British thermal units		10,040	10,939	10,472
Loss of moisture on air drying		1.90	2.20	1.70
Analysis of air-dried sample:				
Proximate	Moisture	2.98	4.06	2.89
Proximate	Volatile matter	27.69	27.63	27.91
Proximate	Fixed carbon	47.03	53.20	48.79
Proximate / Ultimate	Ash	22.30	15.11	20.41
Ultimate	Sulfur	2.90	4.46	4.13
Ultimate	Hydrogen	4.24	4.25	4.18
Ultimate	Carbon	58.08	63.02	59.66
Ultimate	Nitrogen	.73	.95	.88
Ultimate	Oxygen	11.75	12.21	10.74
Calories		5,678	6,213	5,918
British thermal units		10,244	11,185	10,654
Fuel ratio		1.70	1.93	1.75

GROUND WATER

The main aquifers in the map area are in the Blackleaf Formation and alluvial deposits. Several sandstone units in the Blackleaf yield moderate amounts of water, the most important are the upper and lower sandstone units of the Flood Member. The alluvial deposits yield small quantities of water of good quality. Other aquifers of minor importance are the Virgelle and Kootenai Formations.

TERMS

Ground water as defined by Tolman (1937, p. 559, 563) is the water in the zone of saturation. This is distinct from gravity or vadose water, which is in the zone of aeration above the water table. The characteristics governing the ability of an aquifer (water-yielding material) to yield water to wells are porosity and permeability. Porosity is the ratio of pore space to total volume of rock and is commonly expressed as a percentage. The permeability of a rock is its capacity for transmitting a fluid. The degree of permeability depends upon the size and shape of the pores and the size, shape, and extent of their interconnections. Permeability can also result from joints and fractures in solid rock.

Ground water in an aquifer may occur in a free (unconfined) or artesian (confined) environment. Free ground water occurs under water-table conditions. The water table is a subdued reflection of the land surface, and ground water moves slowly in the direction of slope of the water table. The water table is not constant but fluctuates up and down with wet and dry seasons. Artesian conditions result if an aquifer is overlain by a relatively impermeable material (aquiclude), such as shale or clay, which limits or prevents upward movement of water from the aquifer. An artesian well is one wherein the water rises above the level where it was tapped by the drill. A flowing artesian well is a well that flows at the surface. The difference in elevation to which artesian pressure can raise water is called the head, and an imaginary surface connecting such elevations is the piezometric or pressure surface. The pressure surface is affected by the elevation of the aquifer intake or recharge area and the friction within the aquifer.

PRINCIPAL AQUIFERS

Only those materials and stratigraphic units, members, or formations capable of adequate yields to wells are considered here. Details of stratigraphy and petrography are given under Stratigraphy.

Kootenai Formation

The Kootenai has a basal and an upper sandstone unit, each of which is capable of supplying moderate to large amounts of water. The basal sandstone (known as the Third Cat Creek or Sunburst sandstone) is one of the best aquifers in Montana (S. L. Groff, 1964, personal communication), but in the Cascade-Ulm area it is generally beyond economic drilling depth. Only one well in the area, Brattain well no. 28 (Appendix 1) is producing from the basal sand of the Kootenai, and its water is good.

Flood Member

The Flood, the basal member of the Blackleaf Formation, consists of an upper massive to thin-bedded medium-grained jointed sandstone, a middle unit of thin-bedded black shale and tan silty sandstone, and a lower unit of massive to thin-bedded coarse- to medium-grained sandstone. The unconfined ground water of the upper unit supplies numerous wells and springs with water of fair quality (Anderson well no. 30, Eller well no. 81). These wells yield water a the rate of $3\frac{1}{2}$ to 4 gallons per minute (gpm).

The artesian wells in the central part of the map area were judged to be producing from the lower sandstone unit of the Flood on the basis of well depths and stratigraphic thickness. The aquifer is underlain and overlain by relatively impermeable shale, and it is one of the few sandstone units in the area that has sufficient continuity to be capable of supplying numerous artesian wells. All of the artesian wells are closely associated, as is indicated by reports that when the Cascade School District artesian well no. 58 was completed, several of the other artesian wells stopped flowing (J. Nicholls, 1964, personal communication).

The pressure head of the artesian wells may be formed as a result of a structural water trap created by an igneous dike that has truncated the aquifer (Fig. 2). This hypothesis is supported by the fact that a north-south trending dike crops out in the locality and no artesian wells produce from the Flood sandstone west of the projected strike of this dike. The quality of water from the artesian wells is very good (Ferguson artesian well no. 59, Table 5).

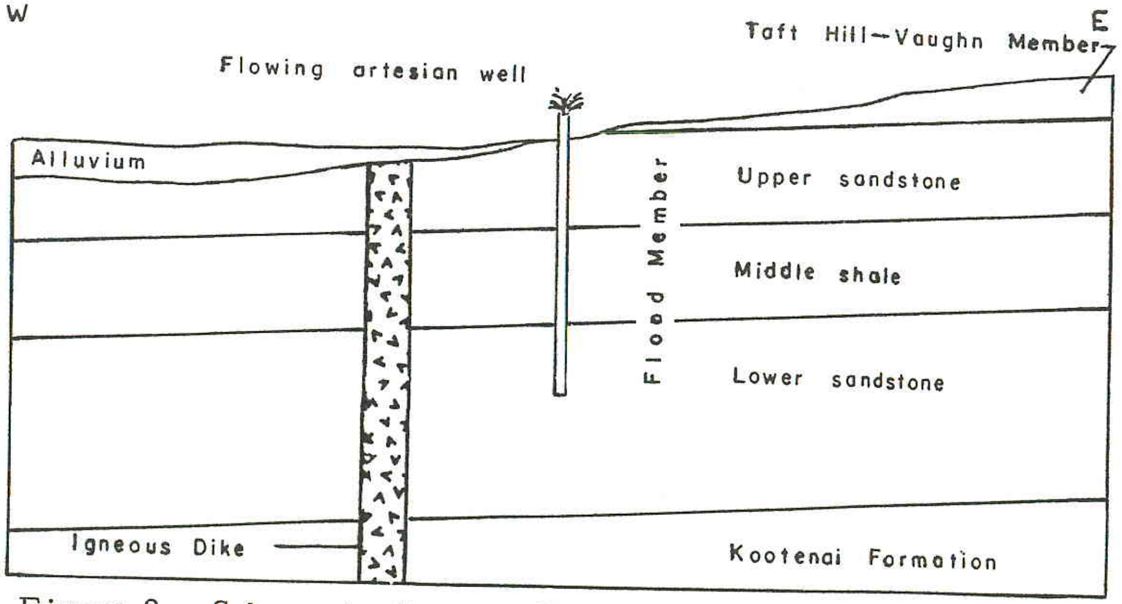

Figure 2.--Schematic diagram illustrating the structure related to the artesian wells in the central part of the area.

The potential yield of wells drilled into the Flood can only be estimated within a wide range of limits because of permeability variation. The Flood is known to yield quantities of water ranging from $3\frac{1}{2}$ to 40 gpm and no wells were reported dry, therefore the possibility of obtaining an adequate water supply from the Flood is excellent.

Deep well data west of the Missouri River are unavailable, but the possibility of obtaining water from wells drilled to the Flood seems good, because the Missouri River would provide a source of recharge.

Taft Hill-Vaughn Member

The undifferentiated Taft Hill-Vaughn Members of the Blackleaf Formation contain sandstone units capable of supplying water of fair quality to wells, as shown by Monroe well no. 115 and Coleman well no. 89. The quality of water in the Taft Hill-Vaughn is not uniform, however; some wells produce mineralized water and hydrogen sulfide. An example of the latter type comes from Weir well no. 118. Yields from the Taft Hill-Vaughn sandstone are small and limited to stock and domestic use.

The sandstone aquifers in the Taft Hill-Vaughn are generally coarse-grained and poorly cemented. This accounts for their permeability.

Ferdig-Kevin Member

The thick sequence of shale comprising the undifferentiated Ferdig-Kevin Members of the Marias River Formation form the bedrock in the northwest part of the area. The shale has only slight permeability and yields very small amounts of water of poor quality. Hydrogen sulfide and concentrations of sodium, calcium, sulfate, and iron are to be expected because of almost static circulation and the presence of iron pyrite or marcasite in the shale. Most residents of the area underlain by these units haul their domestic water; surface water impounded by dams in coulees is used as a supply for stock.

A few wells were reported to be pumping water of fair quality from the Ferdig-Kevin shale. The Cummings well no. 43 is an example. Such wells may have encountered joint systems, fractures, or relatively permeable sandstone lenses.

The Ferdig and Kevin Members are poor economic risks when drilling for potable water supplies, even though aquifers may be encountered within 50 feet of the surface. Deiro well no. 135 produces water so foul that stock animals will not drink it.

Telegraph Creek Formation

The Telegraph Creek Formation consists of thin-bedded alternating shale and sandstone. It is present only in the southwest part of the area and has scant potential as an aquifer. No wells are known to be producing from this formation, but several springs rise from it, hence it is reasonable to assume that the Telegraph Creek will yield small quantities of water to wells.

Barrett spring no. 6 (Appendix 2) and Cascade municipal spring no. 21b (Table 5) indicate that good water can be obtained from the Telegraph Creek.

Virgelle Formation

According to S. L. Groff (1964, personal communication), the Virgelle Formation is noted as a reliable aquifer west of the Sweetgrass Arch, although in restricted localities variation of cementing material and iron content impair the quality of the water. In the map area the Virgelle is present only in the southwest corner where it provides good water to springs. Barrett well no. 8 and Anderson well no. 46, which are used for stock water, have been drilled to the Virgelle and are estimated to yield 10 gpm of good water.

The Virgelle is composed of coarse subangular quartz grains and altered feldspar that forms a clayey matrix. This sandstone readily disaggregates when saturated with water. The lack of a cement and loose packing of the quartz grains account for the relative great porosity and permeability of the formation.

Alluvium

Material mapped as alluvium consists of gravel, sand, silt, and clay deposited in the channels and on the flood plains of the streams. Ground water in the alluvium of the Missouri River stands at relatively shallow depths, generally in the range of 10 to 20 feet, but some wells in the Smith River alluvium approach 150 feet in depth. These wells, however, may have been drilled completely through the alluvium and may be producing from the Kootenai Formation.

The water table is known to fluctuate, generally corresponding with but lagging behind the rise and fall of the surface streams. In irrigated areas the water table is usually high during the irrigation period. During the dry year of 1963 many ranchers and farmers deepened their wells as much as 12 feet to maintain a water supply.

The alluvial deposits range from silt and clay to sand and gravel, and the interlayered materials vary both laterally and vertically. Moderate yields of water are available from sand and gravel, whereas clay and silt yield small to insignificant amounts. If ancient stream channel gravels or sand bars (which have a greater porosity and permeability) are tapped by wells, large yields may be developed.

Sandpoint wells consist of a pipe driven into the ground and perforated at the base. Wells of this type, such as Dormer well no. 54 or Armstrong well no. 14 (Appendix 1), obtain small but dependable supplies of good water from alluvium. The sandpoint wells, most of which are 10 to 30 feet deep, probably obtain their water by slow percolation through the surrounding sandy clay. The rate of water movement is sufficient to sustain only minor yields.

The town of Cascade has drilled three wells in the alluvium, two of which are approximately 75 feet from the Missouri River. All three of the wells produce good water similar to that of Cascade municipal well no. 57 (Table 5), but the recharge rate of the wells is so slow that they are not adequate as a municipal supply. To augment the supply of Cascade municipal well no. 55, perforated sections of pipe approximately 30 feet long were extended horizontally from the central well shaft to increase the drainage area. This method of increasing the yield has been successful and could be applied to other wells where a larger yield is desired.

SPRINGS

Springs are a natural discharge of water that occurs where the water table intersects the land surface on a slope in a low area. Artesian water can emerge as a flowing spring along a fault or fissure, but there are no springs of the latter type in the mapped area. The rate of ground-water discharge is greatly affected by annual variations in precipitation and irrigation.

Springs are abundant and constitute an important source of domestic and stock water. They may be found issuing from fractured igneous rock, unconsolidated alluvium, dune sand, or sedimentary rock.

Springs situated around the base of Square Butte and Cascade Butte probably derive their flow from snow melt and rain water percolating downward through fractures in the sills.

Negro Creek Springs

Five springs at the base of Cascade Butte in Negro Creek canyon constitute, as a group, the largest natural discharge of water in the project area. The springs emerge along the trace of the Negro Creek Fault and are fed by aquifers intersected by the fault. The water is discharged from fractured igneous rock and an outcrop of Telegraph Creek sandstone too small to map.

These springs were developed for part of the Cascade municipal water supply by constructing concrete collection boxes. The collected water is piped to a central reservoir where it is chemically treated. These springs emit a large volume of water in the spring and early summer, but by late summer or early fall they are nearly dry. This fluctuation renders them inadequate as a municipal water supply.

Williams Spring

The largest perennial spring found along the Missouri River is the Williams spring no. 7 (Appendix 2). This spring yields good water at a rate of 100 gpm and has been developed for domestic and stock supply. The water issues from an alluvial sand lens underlain by a 3-inch layer of impermeable clay. This spring is reported to have a nearly constant volume, and its source of supply is thought to be some one of the nearby mountain streams, which are influent in their lower courses.

Along the edge of the Missouri River valley numerous springs were observed. Discharge rates range from about 1 to 100 gpm. Many of the springs are intermittent, and very few of them have been developed.

Springs in Dune Sand

A few springs were found in the dune sand, as seeps in blowout depressions. They are developed to yield about 1 gpm by driving a perforated pipe into the sand, but their small yield renders them inadequate as a reliable water supply. The source of this water, used only for livestock, is rain water that percolates down through the sand.

Springs in Cretaceous Sedimentary Rocks

Springs in Cretaceous sedimentary rocks are by far the most numerous and important source of naturally discharged water. These springs have been extensively developed for domestic, irrigation, and stock use.

Only one spring, Habel spring no. 17, was found in the Kevin Member of the Marias River Formation and this spring has a surficial expression as a seep. Because of the poor quality of the water, the low yield, and the intermittent discharge, this spring has not been developed.

Most springs issue from the sandstone and siltstone in the Blackleaf Formation. Combined, these springs provide a valuable source of water for the ranchers between the Smith and Missouri Rivers.

Springs in the Bootlegger are numerous, but water is poor and the discharge is small, and therefore none of them have been developed. Generally the springs were noted to be slowly oozing out of bentonitic shale, and most were characterized by a white efflorescence of salts.

The Coleman spring no. 27 issues from fractured sandstone of the Bootlegger and yields about 5 gpm. Water from this spring was reported to be of fair quality, and no deposits were noted.

An unusual geomorphic feature along Geyser Creek is a result of hydrogeologic conditions in the bentonitic shale of the Bootlegger. Here springs that rise through bentonitic shale have opened holes and made bogs that range from 5 to 10 feet in depth. C. Coleman (1964, personal communication) reported that at times in the past water was expelled upward with such force as to have the appearance of a small geyser (mud volcano), thus giving the creek its name. As a result of upward expulsion of mud and water, small cones of mud 2 to 4 feet high were built up. This phenomenon has not been observed along the creek valley for several years.

The fractured sandstone units of the Vaughn contain numerous springs that have been developed mainly for stock water but also for domestic supply (Gollaher spring no. 11). Yields from these springs range from 2 to 10 gpm, and the water is of fair quality. Numerous intermittent springs yielding less than $\frac{1}{2}$ gpm emerge from the bentonitic shale, especially after rains and during the spring months. The springs are believed to be supplied by rain water that has accumulated in the shale, which then slowly release the water to the sandstone, where it accumulates and then trickles along fractures until it reaches the surface.

Bogs as much as 15 feet deep accompanied by geysers (mud volcanos) like those along Geyser Creek were reported by B. Kennenburger (1964, personal communication) in the Vaughn Member along Little Muddy Creek, but these geysers are not currently active either.

Springs issuing from the upper unit of the Flood abound in the area and have been extensively utilized for domestic, stock, and irrigation water. The springs were observed to discharge from fractures in the rock. Yields range from 1 to 10 gpm, and the quality of the water is excellent. These are the most consistent springs, indicating that the sandstone of the Flood contains large reserve quantities of water.

In the area of study the Kootenai Formation gives rise to only one developed spring, Brattain spring no. 15. The water from this spring is good and it flows at a rate of 8 gpm from fractured friable sandstone. Numerous undeveloped springs issue from an upper sandstone bed of the Kootenai in Spanish Coulee.

Table 5.--Chemical analyses of well and spring water, in parts per million (ppm). (Well numbers refer to Appendix 1.)

Well number	126	57	5	125	21b*	48	59
Iron (Fe)	0.3	0.0	0.34	0.0	0.1	0.7	0.1
Calcium (Ca)	553	53	39	4	53	60	100
Magnesium (Mg)	215	11	4	2	3	50	90
Sodium and potassium calc. (Na+K)	1,850	23	21	303	32	300	140
Carbonate radical (CO_3)	0	0	0	0	0	0	0
Bicarbonate radical (HCO_3)	480	198	162	543	204	503	485
Sulfate radical (SO_4)	4,790	47	25	200	35	555	462
Chloride (Cl)	630	13	0	16	6	10	23
Fluorine (F)	2.4	1	0.2	1.1	0.6	0.8	0.6
Nitrates (NO_3)	1.8	0	2.3	0	1.8	1	4.5
Total hardness (as Ca CO_3)	2,264	179	112	20	143	454	617
Total dissolved solids	8,546	254	175	772	236	1,195	1,078

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*Spring number, Appendix 2.

(Analyses by Montana State Board of Health.)

QUALITY OF WATER

The quality of water is indicated by chemical analyses that determine the amount and kinds of dissolved solids. The dissolved solids contained in water from seven selected wells in the map area are shown in Table 5. These analyses were made by the Montana State Board of Health. Although the dissolved solids range from 175 to 8,546 parts per million (ppm), six of the wells yield good water and contain less than 1,195 ppm of dissolved solids.

Most of the ground water in the area is satisfactory for domestic and stock use, but many wells yield water that is hard. Many ranchers use water softeners on their domestic supplies.

The Wadsworth well (sample 126) yields the poorest water found in the map area. The sulfate content of this water is approximately 100 times greater than that of the water sampled from other wells. This well is drilled in an area of unconsolidated material derived from the bentonitic shale of the Taft Hill-Vaughn and Bootlegger Members and it probably draws its water from an aquifer that is being recharged by seepage through this unconsolidated material. T. Wadsworth (1964, personal communication) reported that this water is toxic to plants and stock; animals will not drink it.

Chemical analyses of Cascade municipal well (sample 57) and Lien well (sample 5) are similar. This similarity is to be expected, as both wells were drilled in alluvium adjacent to the Missouri River, which undoubtedly is the source of recharge. The sulfate content of the municipal well is only 47 ppm, which is far below the maximum sulfate content of 250 ppm recommended for municipal water supply by the U. S. Public Health Service (1962).

Water from Ulm Bar well (sample 125) contains an unexpected amount of dissolved solids for a well situated close to the Missouri River. Inasmuch as this well is located in the vicinity of the Wadsworth well, it may be drawing part of its water from a source similar to that of the Wadsworth well and only part from the Missouri River.

The water from Cascade municipal spring (sample 21b) contains only 236 ppm of dissolved solids. This is because the spring is recharged from rain water and snow melt. Comparison of samples 57 and 21b indicate only slight differences in quality between the spring and river water.

Water from the Wolfe artesian well (sample 48) contains a total of 1,195 ppm of dissolved solids. A comparatively large sulfate content of 555 ppm indicates that this water has probably percolated through shale of the Ferdig-Kevin Member. The aquifer may be a shaly sandstone unit.

Sample 59, obtained from the Ferguson artesian well, is characteristic of water obtained from the Flood Member.

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APPENDIX 1

WATER WELLS

Well	Location				Depth	Static level	Date			Amt
no.	¼ sec.	Twp.	Rge.	Owner	(feet)	(from surface)	measured	Aquifer	Use[1]	gpm
1	NE 13,	16 N.,	1 E.	K. Mortag	36.90	.50	7/16/64	Kootenai Fm.	S	Sm
2	NW 15,	16 N.,	1 E.	C. Duerr	21.50	4.05	7/16/64	Bird Creek al.	D	Sm
3	SW 25,	17 N.,	2 W.	W. Hawn	15 R[3]	10 R	7/ 9/64	Missouri River al.	D	Sm
4	SE 35,	17 N.,	2 W.	P. Siebold	116.35	19.94	7/ 9/64	Missouri River al.	D	Sm
5	SE 35,	17 N.,	2 W.	O. Lien	20.19	13.24	7/ 9/64	Missouri River al.	D	10
6	NE 5,	17 N.,	1 W.	W. Ellis	47.20	6.10	9/16/64	Antelope Creek al.	D, S	Sm
7	SE 8,	17 N.,	1 W.	B. Barrett	26 R	8 R	7/ 2/64	Missouri River al.	S	Sm
8	SE 8,	17 N.,	1 W.	B. Barrett	123 R	23 R	7/ 2/64	Virgelle Fm.	S	10
9	NW 13,	17 N.,	1 W.	R. Williams	-----	8.20	7/ 2/64	Missouri River al.	S	Sm
10	NE 13,	17 N.,	1 W.	C. Obrecht	24	4.50	7/ 2/64	Missouri River al.	S	Sm
11	SE 19,	17 N.,	1 W.	R. Tintinger	-----	-----	7/ 9/64	Missouri River al.	D	Sm
12	NW 27,	17 N.,	1 W.	F. Vanatta	-----	7.45	9/ 2/64	Missouri River al.	None	--
13	SW 29,	17 N.,	1 W.	G. Hammer	10.80	5.56	7/ 2/64	Missouri River al.	D	Sm
14	SW 5,	17 N.,	1 E.	D. Armstrong	12 R	10 R	7/ 4/64	Missouri River al.	S	Sm
15	NE 6,	17 N.,	1 E.	D. Armstrong	18 R	16 R	7/ 4/64	Missouri River al.	D, S	Sm
16	NE 6,	17 N.,	1 E.	D. Armstrong	180 R	7 R	7/ 4/64	Missouri River al.	S, Ir	Sm
17	SW 8,	17 N.,	1 E.	G. Wolfe	108 R	30 R	7/ 2/64	Kevin Mm.	S	30
18	SE 9,	17 N.,	1 E.	M. Gollaher	24.80	11.20	7/15/64	Willow Creek al.	S	Sm
19	SE 9,	17 N.,	1 E.	M. Gollaher	55.70	15.57	7/15/64	Willow Creek al.	D, Ir	Sm
20	SE 29,	17 N.,	1 E.	T. Grimes	12.30	8.07	7/16/64	Willow Creek al.	None	--

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[1] D, Domestic; S, Stock; Ir, Irrigation.
[2] Sm, Small.
[3] R, Reported.

21	SE 30, 17 N., 1 E.	F. Vanatta	40.70	5.41	7/31/64	Ferdig Mm.	S	Sm
22	NW 33, 17 N., 1 E.	Browning Ranch	48.30	9.80	7/16/64	Willow Creek al.	D	Sm
23	SE 1, 17 N., 2 E.	W. Meer	-----	18 R	7/17/64	Smith River al.	D, S	Sm
24	NW 4, 17 N., 2 E.	G. Murphy	20.70	3.40	7/14/64	Flood Mm.	S, Ir	Sm
25	NE 5, 17 N., 2 E.	A. Simpson	20 R	Flows	7/15/64	Flood Mm.	S	Sm
26	NE 6, 17 N., 2 E.	W. Peck	17.50	8.27	7/14/64	Flood Mm.	S	Sm
27	SE 9, 17 N., 2 E.	A. Simpson	56 R	2 R	7/15/64	Flood Mm.	D, S	Sm
28	NE 10, 17 N., 2 E.	W. Brattain	125 R	100 R	7/15/64	Kootenai Fm.	D, S	Sm
29	SE 18, 17 N., 2 E.	G. Anderson	139.40	18.27	7/15/64	Flood Mm.	S	3.5
30	SE 18, 17 N., 2 E.	G. Anderson	14 R	5 R	7/15/64	Alluvium	D	4.0
31	SE 18, 17 N., 2 E.	G. Anderson	61 R	15 R	7/15/64	Alluvium	D	5
32	SE 24, 17 N., 2 E.	J. Carlile	11 R	6 R	7/17/64	Smith River al.	S	Sm
33	SE 24, 17 N., 2 E.	J. Carlile	43 R	8 R	7/17/64	Smith River al.	D	Sm
34	NE 34, 17 N., 2 E.	C. Ogden	14.42	12.90	7/21/64	Flood Mm.	S	Sm
35	NE 34, 17 N., 2 E.	C. Ogden	22.56	13.15	7/21/64	Flood Mm.	D, S	Sm
36	NW 8, 17 N., 3 E.	G. Marko	41 R	7.60	7/17/64	Smith River al.	D, S	Sm
37	SW 1, 18 N., 1 W.	B. Habel	15.80	1.10	7/13/64	Kevin Mm.	S	Sm
38	SW 7, 18 N., 1 W.	Walker Co.	501 R	43.90	7/24/64	Kevin Mm.	S	3
39	SE 7, 18 N., 1 W.	Walker Co.	39.80	7.89	7/24/64	Rocky Gap Cr. al.	S	Sm
40	NW 11, 18 N., 1 W.	J. Humphrey	10.27	1.20	7/24/64	Kevin Mm.	S	Sm
41	NW 11, 18 N., 1 W.	J. Humphrey	29.47	Dry	7/24/64	Kevin Mm.	None	--
42	SW 13, 18 N., 1 W.	J. Cummings	104 R	65 R	7/13/64	Ferdig Mm.	D	5
43	SW 13, 18 N., 1 W.	J. Cummings	130 R	80 R	7/13/64	Ferdig Mm.	S	Sm
44	NW 15, 18 N., 1 W.	Unknown	18.35	3.69	7/24/64	Kevin Mm.	S	Sm
45	SW 18, 18 N., 1 W.	Walker Co.	38 R	15.58	7/24/64	Kevin Mm.	S	Sm
46	NW 21, 18 N., 1 W.	L. Anderson	126.45	24.18	7/22/64	Virgelle Fm.	S	10
47	SE 23, 18 N., 1 W.	G. Wolfe	50.66	13.59	7/10/64	Missouri River al.	S	Sm
48	SW 24, 18 N., 1 W.	G. Wolfe	-----	Flows	7/ 8/64	Missouri River al.	S	2
49	NW 26, 18 N., 1 W.	Cascade Cemetery	36.90	Dry	7/23/64	Alluvium-colluvium	D	--
50	NE 31, 18 N., 1 W.	L. Anderson	23	6.78	7/ 9/64	Knapp Creek al.	S	Sm

51	NE 31, 18 N., 1 W.	L. Anderson	18.20	6.92	7/ 9/64	Knapp Creek al.	D	Sm
52	NE 32, 18 N., 1 W.	B. Barrett	9.80	3.92	7/ 9/64	Knapp Creek al.	S	Sm
53	SW 35, 18 N., 1 W.	K. Gilbert	58.70	23.97	7/ 9/64	Missouri River al.	S	Sm
54	SE 35, 18 N., 1 W.	J. Dormer	17 R	12 R	7/ 4/64	Missouri River al.	D, S	Sm
55	SE 35, 18 N., 1 W.	City of Cascade	23.31	7.59	7/ 1/64	Missouri River al.	D	Sm
56	NW 35, 18 N., 1 W.	Cascade School Dist.	77 R	Flows	7/ 1/64	Missouri River al.	Ir	30
57	NE 35, 18 N., 1 W.	City of Cascade	31.90	33.91	7/ 1/64	Missouri River al.	D	Sm
58	SW 1, 18 N., 1 E.	Cascade School Dist.	65 R	Flows	7/ 7/64	Flood Mm.	D, S	30
59	NE 1, 18 N., 1 E.	A. Ferguson	20 R	Flows	7/16/64	Flood Mm.	D, S	40
60	NW 5, 18 N., 1 E.	B. Kennenburger	61	12.44	7/28/64	Vaughn Mm.	S	Sm
61	SW 10, 18 N., 1 E.	D. Standley	13 R	9 R	7/ 7/64	Missouri River al.	S	17
62	SW 10, 18 N., 1 E.	D. Standley	20 R	16 R	7/ 7/64	Missouri River al.	D, S	Sm
63	SE 11, 18 N., 1 E.	R. Standley	95 R	Flows	7/ 7/64	Flood Mm.	D, S	4
64	NE 13, 18 N., 1 E.	D. Johnson	26.55	15.79	8/ 1/64	Vaughn Mm.	S	Sm
65	NE 13, 18 N., 1 E.	V. Parson	50 R	15 R	7/14/64	Vaughn Mm.	S	7
66	NW 19, 18 N., 1 E.	W. Beecher	20 R	16 R	7/ 7/64	Missouri River al.	D, Ir	Sm
67	NW 19, 18 N., 1 E.	W. Beecher	20 R	16 R	7/ 7/64	Missouri River al.	D, S	Sm
68	SE 20, 18 N., 1 E.	D. Jones	18 R	10 R	7/ 4/64	Missouri River al.	D, S	Sm
69	NE 23, 18 N., 1 E.	L. Klock	40.30	21.55	8/ 1/64	Vaughn Mm.	None	--
70	SE 24, 18 N., 1 E.	C. Coleman	30 R	8 R	7/21/64	Vaughn Mm.	Ir	6
71	NW 24, 18 N., 1 E.	L. Klock	50 R	11	8/ 1/64	Vaughn Mm.	S	Sm
72	NE 24, 18 N., 1 E.	D. Johnson	85 R	Flows	8/ 1/64	Flood Mm.	S	5
73	SE 26, 18 N., 1 E.	J. Flanagan	64.41	20.01	7/30/64	Vaughn Mm.	D	Sm
74	SW 27, 18 N., 1 E.	H. Bent	89 R	Flows	7/13/64	Flood Mm.	S	20
75	SW 27, 18 N., 1 E.	D. Jones	69 R	Flows	7/ 4/64	Flood Mm.	S	15
76	SE 29, 18 N., 1 E.	H. Bent	27 R	23 R	7/13/64	Missouri River al.	D	Sm
77	SE 29, 18 N., 1 E.	H. Bent	30 R	18 R	7/13/64	Missouri River al.	D	Sm
78	SE 29, 18 N., 1 E.	H. Bent	29 R	20 R	7/13/64	Missouri River al.	S	Sm
79	SW 1, 18 N., 2 E.	D. Roehm	155 R	125 R	7/17/64	Smith River al.	D, S	20
80	SW 1, 18 N., 2 E.	D. Roehm	205 R	190 R	7/17/64	Smith River al.	S	Sm

81	SW	2, 18 N., 2 E.	S. Eller	55 R	47 R	7/15/64	Flood Mm.	S	4
82	SW	6, 18 N., 2 E.	Fraunhofer Bros.	64 R	21	7/16/64	Vaughn Mm.	D, S	Sm
83	SE	10, 18 N., 2 E.	S. Eller	39 R	36 R	7/15/64	Flood Mm.	D, S	Sm
84	NE	10, 18 N., 2 E.	E. Olson	60 R	50 R	7/14/64	Flood Mm.	D, S	Sm
85	SE	14, 18 N., 2 E.	R. Gruel	60 R	52 R	7/21/64	Smith River al.	S	Sm
86	SE	17, 18 N., 2 E.	E. Freiboth	20 R	10 R	7/17/64	Vaughn Mm.	S	Sm
87	SE	17, 18 N., 2 E.	E. Freiboth	20 R	10 R	7/17/64	Vaughn Mm.	D	Sm
88	NE	18, 18 N., 2 E.	D. Johnson	50 R	6 R	8/ 1/64	Vaughn Mm.	D	Sm
89	SE	19, 18 N., 2 E.	C. Coleman	110 R	50 R	7/21/64	Vaughn Mm.	D	Sm
90	SW	20, 18 N., 2 E.	Fraunhofer Bros.	76 R	30 R	7/13/64	Vaughn Mm.	D	Sm
91	SW	20, 18 N., 2 E.	Fraunhofer Bros.	105 R	30 R	7/13/64	Vaughn Mm.	D	3.5
92	SW	20, 18 N., 2 E.	Fraunhofer Bros.	30 R	20 R	7/13/64	Alluvium	S	Sm
93	SW	20, 18 N., 2 E.	Fraunhofer Bros.	16.20	1.85	7/13/64	Alluvium	S	Sm
94	NE	21, 18 N., 2 E.	E. Olson	55 R	18 R	7/14/64	Flood Mm.	D, S	Sm
95	NW	22, 18 N., 2 E.	E. Olson	70 R	63 R	7/14/64	Flood Mm.	S	10
96	NW	24, 18 N., 2 E.	R. Gruel	15 R	10 R	7/21/64	Smith River al.	D, S	Sm
97	NE	27, 18 N., 2 E.	R. Gruel	60 R	50 R	7/21/64	Flood Mm.	S	Sm
98	SW	29, 18 N., 2 E.	E. Edmonson	47.81	25.80	7/14/64	Vaughn Mm.	S	Sm
99	NE	29, 18 N., 2 E.	R. Johnson	25.20	12.83	7/14/64	Alluvium	D	Sm
100	NE	29, 18 N., 2 E.	R. Johnson	24	3.25	7/14/64	Alluvium	S, Ir	Sm
101	SE	32, 18 N., 2 E.	S. Carlson	60 R	-----	7/14/64	Flood Mm.	S, Ir	Sm
102	SE	32, 18 N., 2 E.	S. Carlson	150	37.50	7/14/64	Flood Mm.	D, S	20
103	SW	33, 18 N., 2 E.	H. Wren	11.80	6.30	7/14/64	Flood Mm.	D	Sm
104	SW	33, 18 N., 2 E.	H. Wren	10.70	1.50	7/14/64	Flood Mm.	D, S	Sm
105	SE	36, 18 N., 2 E.	F. Murphy	26.30	2.05	7/17/64	Smith River al.	D	Sm
106	NW	36, 18 N., 2 E.	A. Young	72 R	40 R	7/21/64	Smith River al.	D, S	Sm
107	NW	1, 19 N., 1 W.	W. Beecher	49.09	15.40	7/ 7/64	Ferdig Mm.	S	9
108	NE	2, 19 N., 1 W.	W. Beecher	50.13	5.70	7/ 7/64	Ferdig Mm.	S	4
109	NE	22, 19 N., 1 W.	C. Melinger	19.35	10.38	7/28/64	Kevin Mm.	S	Sm
110	NE	1, 19 N., 1 E.	M. Gould	200 R	10 R	7/20/64	Missouri River al.	S	7

111	SW 3, 19 N., 1 E.	R. Donnelly	41.36	25.60	7/28/64	Vaughn Mm.	D, S,	8
112	SE 7, 19 N., 1 E.	V. Monroe	103	15.47	7/24/64	Vaughn Mm.	S	Sm
113	SE 15, 19 N., 1 E.	A. Dugas	10 R	5.80	7/27/64	Vaughn Mm.	S	Sm
114	NE 17, 19 N., 1 E.	V. Monroe	65.20	37	7/27/64	Vaughn Mm.	S	Sm
115	NW 21, 19 N., 1 E.	V. Monroe	33.70	15.30	7/27/64	Vaughn Mm.	S	Sm
116	SE 22, 18 N., 1 E.	F. Steffani	125 R	-----	7/ 5/64	Taft Hill Mm.	D, S	Sm
117	NW 23, 19 N., 1 E.	J. Nicholls	125 R	20 R	7/ 5/64	Taft Hill Mm.	D, S	Sm
118	SE 27, 19 N., 1 E.	W. Weir	55 R	5 R	7/ 7/64	Vaughn Mm.	D, S	Sm
119	SE 27, 19 N., 1 E.	W. Weir	14 R	8	7/ 7/64	Missouri River al.	S	Sm
120	NW 33, 19 N., 1 E.	E. Rossmiller	29 R	15 R	7/ 5/64	Little Muddy Cr. al.	S	Sm
121	NW 33, 19 N., 1 E.	E. Rossmiller	19 R	15 R	7/ 5/64	Little Muddy Cr. al.	D, S	5
122	NW 35, 19 N., 1 E.	W. Weir	11.71	3.03	7/ 7/64	Missouri River al.	None	--
123	NW 36, 19 N., 1 E.	E. Freiboth	20 R	-----	7/17/64	Missouri River al.	S	Sm
124	NW 36, 19 N., 1 E.	E. Freiboth	195 R	8 R	7/17/64	Missouri River al.	D, S	70
125	NE 5, 19 N., 2 E.	Ulm Bar	-----	-----	7/ 8/64	Missouri River al.	D	Sm
126	NE 6, 19 N., 2 E.	T. Wadsworth	44 R	15 R	7/20/64	Alluvium	S	Sm
127	SW 7, 19 N., 2 E.	D. Ulsh	20 R	17 R	7/27/64	Missouri River al.	D, S	Sm
128	SE 21, 19 N., 2 E.	A. Ferguson	15.70	9.40	7/16/64	Flood Mm.	S	5
129	SW 23, 19 N., 2 E.	D. Marxer	144 R	40 R	7/17/64	Smith River al.	D, S	Sm
130	SW 26, 19 N., 2 E.	Truly School Dist.	147 R	85 R	7/17/64	Smith River al.	D	46
131	NW 26, 19 N., 2 E.	D. Marxer	150 R	25 R	7/17/64	Smith River al.	D, S	Sm
132	NE 27, 19 N., 2 E.	Unknown	63.90	50	8/24/64	Flood Mm.	S	Sm
133	SW 30, 19 N., 2 E.	A. Ventz	-----	40 R	9/ 1/64	Missouri River al.	D, S	Sm
134	SE 35, 19 N., 2 E.	H. Hastings	21.10	14.70	7/17/64	Smith River al.	D	Sm
135	NE 27, 20 N., 1 W.	G. Deiro	14.20	10.10	7/28/64	Kevin Mm.	S	Sm
136	NW 34, 20 N., 1 W.	G. Hamlet	52.30	2.15	7/28/64	Kevin Mm.	S	Sm
137	SW 35, 20 N., 1 W.	W. Beecher	100 R	30 R	7/ 7/64	Ferdig Mm.	S	6
138	NE 34, 20 N., 1 E.	R. Standley	79.50	17.82	7/28/64	Taft Hill Mm.	None	--

APPENDIX 2

SPRINGS

Spring	Location				Est. flow	Temp.		
no.	¼ sec.	Twp.	Rge.	Owner	(gpm)	°F	Use*/	Aquifer
1	SW 11,	16 N.,	1 E.	H. Baseda	1.0	55	D, S	Flood Mm.
2	SW 13,	16 N.,	1 E.	B. Mortag	2	49	D, S	Vaughn Mm.
3	NW 15,	16 N.,	1 E.	C. Duerr	2	45	D	Bird Creek al.
4	SW 8,	16 N.,	2 E.	J. Zorze	3	--	D, S	Alluvium-colluvium
5	NW 6,	17 N.,	1 W.	B. Brown	15	45	D, S	Virgelle Fm.
6	SE 8,	17 N.,	1 W.	B. Barrett	10	50	D, S, Ir	Telegraph Creek Fm.
7	SE 14,	17 N.,	1 W.	R. Williams	100	55	D, S, Ir	Missouri River al.
8	SE 19,	17 N.,	1 W.	G. Cristman	10	50	D, Ir	Glacial lake deposits
9	NE 25,	17 N.,	1 W.	A. Loring	1.5	48	S	Alluvium
10	NW 26,	17 N.,	1 W.	F. Vanatta	---	--	D, S, Ir	Alluvium
11	NE 2,	17 N.,	1 E.	M. Gollaher	10	48	S	Vaughn Mm.
12	SW 28,	17 N.,	1 E.	Salo Ranch	5	49	D, S	Alluvium
13	SW 29,	17 N.,	1 E.	T. Grimes	3	45	D, S	Alluvium
14	SE 9,	17 N.,	2 E.	A. Simpson	10	48	S	Flood Mm.
15	NE 10,	17 N.,	2 E.	W. Brattain	8	46	D	Kootenai Fm.
16	SE 15,	17 N.,	2 E.	A. Mesaros	---	--	D, S, Ir	Flood Mm.
17	NW 12,	18 N.,	1 W.	B. Habel	---	--	S	Kevin Mm.
18	NW 13,	18 N.,	1 W.	J. Cummings	1/3	52	S	Terrace gravel
19	SE 16,	18 N.,	1 W.	L. Anderson	5	49	S	Knapp Creek al.
20	NE 27,	18 N.,	1 W.	Unknown	4	48	S	Telegraph Creek Fm.
21a	SW 27,	18 N.,	1 W.	City of Cascade	---	48	D	Cascade Butte
21b	SW 27,	18 N.,	1 W.	City of Cascade	---	49	D	Telegraph Creek Fm.
21c	SW 27,	18 N.,	1 W.	City of Cascade	---	48	D	Cascade Butte
21d	SW 27,	18 N.,	1 W.	City of Cascade	---	50	S	Cascade Butte
21e	SW 27,	18 N.,	1 W.	City of Cascade	---	47	D	Cascade Butte

22	SW 29, 18 N., 1 W.	R. Taylor	10	48	D, S	Virgelle Fm.
23	SE 10, 18 N., 1 E.	L. Nicholls	3.5	--	D, S	Vaughn Mm.
24	SW 11, 18 N., 1 E.	L. Standley	5	--	S, Ir	Missouri River al.
25	NW 15, 18 N., 1 E.	D. Standley	.5	53	S	Dune sand
26	SE 22, 18 N., 1 E.	D. Jones	2	--	S	Dune sand
27	SW 19, 18 N., 2 E.	C. Coleman	5	49	D, S, Ir	Bootlegger Mm.
28	SE 29, 18 N., 2 E.	R. Johnson	10	48	S	Vaughn Mm.
29	NE 31, 18 N., 2 E.	Fraunhofer Bros.	---	--	S	Vaughn Mm.
30	NW 33, 18 N., 2 E.	R. Johnson	---	--	S	Alluvium
31	SW 3, 19 N., 1 E.	R. Donnelly	8	47	D, S	Vaughn Mm.
32	NW 5, 19 N., 1 E.	M. Gould	10	--	S	Bootlegger Mm.
33	NE 34, 19 N., 1 E.	W. Weir	1	--	S	Vaughn Mm.
34	NW 25, 19 N., 2 E.	J. Lord	---	--	S	Flood Mm.
35	NE 33, 19 N., 2 E.	G. Ferguson	3	49	D, S	Flood Mm.

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*/D, Domestic; S, Stock; Ir, Irrigation.

APPENDIX 3

DEEP WELLS

1. COUCH DRILLING COMPANY[*]
   Location: $SE\frac{1}{4}$ $NE\frac{1}{4}$ sec. 29, T. 16 N., R. 3 E.
   Purpose for drilling: Oil and gas exploration
   Completed: 1955
   Total depth: 2, 875 feet
   Status: Abandoned
   Formation tops: Started in Charles Formation(?);
   Madison 755; Lodgepole 1, 580; Three Forks 2, 235; Jefferson 2, 345.

2. RIVERDALE OIL COMPANY
   Location: $SW\frac{1}{4}$ $NW\frac{1}{4}$ sec. 8, T. 17 N., R. 2 E.
   Purpose for drilling: Oil and gas exploration
   Completed: 1956
   Total depth: 3, 803 feet
   Status: Abandoned
   Formation tops: Started in Vaughn Member of Colorado Group;
   Madison 1, 010.

3. RIVERDALE OIL COMPANY
   Location: $NW\frac{1}{4}$ $SW\frac{1}{4}$ sec. 10, T. 17 N., R. 2 E.
   Purpose for drilling: Oil and gas exploration
   Completed: 1955
   Total depth: 200 feet
   Status: Abandoned
   Formation tops: Started in Flood Member of Colorado Group;
   Kootenai 155.

4. ANACONDA COMPANY[*]
   Location: $SW\frac{1}{4}$ $NE\frac{1}{4}$ sec. 17, T. 18 N., R. 2 W.
   Purpose for drilling: Oil and gas exploration
   Completed: 1959
   Total depth: 4, 380 feet
   Status: Abandoned
   Formation tops: Started in Two Medicine Formation; Virgelle 914;
   Telegraph Creek 1, 055; Colorado Group 1, 375; Kootenai 3, 012;
   Morrison 3, 351; Madison 3, 618.

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[*] Not in map area.

5. STRUNK NO. 1 and 2
   Location: E$\frac{1}{2}$ NW$\frac{1}{4}$ sec. 10, T. 18 N., R. 2 E.
   Purpose for drilling: Oil and gas exploration
   Completed: 1926
   Total depth: 3,700 feet
   Status: Abandoned
   Formation tops: Started in Flood Member of Colorado Group; Kootenai 750.

6. MR. ART E. DAININGER
   Location: SE$\frac{1}{4}$ SW$\frac{1}{4}$ sec. 24, T. 20 N., R. 1 E.
   Purpose for drilling: Oil and gas exploration
   Completed: 1953
   Total depth: 794 feet
   Status: Plugged and abandoned
   Formation tops: Started in Taft Hill Member of Colorado Group; Kootenai 235; Morrison 642; Swift 675; Madison 776.

APPENDIX 4 -- MEASURED SECTIONS

KOOTENAI FORMATION

Location: Along road cut in sec. 36, T. 18 N., R. 2 E., Cascade County, Montana.

Unit number		Thickness (feet)
	Covered	
8	Sandstone, red, weathers dark red brown; medium indurated, slightly calcareous, quartz, plagioclase, chert, fine-grained, massive, cross-bedded, sparse chert pebbles $\frac{1}{2}$ inch diameter; upper 5 feet contains several hackly 4-inch to 1-foot siltstone beds that pinch out.	51
7	Interbedded sandstone and siltstone, red, weathers dark red brown: sandstone poorly indurated, calcareous, quartz, plagioclase, biotite, chert, medium-grained, thin-bedded, cross-bedded, porous, pock marked; siltstone poorly indurated, some siltstone variegated yellow and red, beds 1 to 2 feet thick pinch out laterally.	42
6	Limestone, reddish gray, weathers yellowish red; dense, fractured, weathers into nodules, bed 2 to 4 feet thick, very distinctive.	4
5	Shale, variegated purple, red, and green, weathers same; medium indurated: upper 2 feet carbonaceous siltstone, black, weathers gray; grades laterally into a yellowish-purple quartz and chert sandstone.	6
4	Interbedded sandstone and shale, gray, weathers grayish pink: sandstone well indurated, siliceous, quartz, chert, very fine grained, lenticular; shale medium-indurated, thin-bedded.	21
	Covered	10
3	Sandstone, light gray, weathers tan brown; well indurated, siliceous, quartz, plagioclase, chert, medium-grained, massive, contains angular clastic gray limestone pebbles $\frac{1}{4}$ inch to 2 inches in diameter.	4

2	Siltstone, variegated purple, gray, and red, weathers same; well indurated, hackly.	45
1	Sandstone, light gray, weathers dark gray; medium indurated, slightly calcareous, quartz, plagioclase, biotite, chert, coarse- to fine-grained, cross-bedded, scattered chert pebbles $\frac{1}{4}$ inch to 2 inches in diameter, local graded bedding, pock marked, ledge former; light-gray shale lenses, 1.5 to 2 feet long, 2 to 8 inches thick; upper 3 feet of unit is medium-grained greenish-gray quartz sandstone.	45
	Total thickness measured	228

FLOOD MEMBER

Upper unit

Location: At head of creek in SE$\frac{1}{4}$ sec. 1, T. 18 N., R. 2 E., Cascade County, Montana.

Unit number		Thickness (feet)
17	Sandstone, light gray, weathers tan brown; poorly indurated, slightly calcareous, plagioclase, quartz, chert, medium-grained, distinct irregular vertical jointing and bedding plane joints, forms flagstonelike outcrop, iron stains along joints, 4- to 6-inch ferruginous concretions, worm casts.	14
16	Sandstone, light tan gray, weathers yellow gray; medium indurated, slightly calcareous, plagioclase, chert, and quartz, medium-grained, massive, distinct horizontal and vertical joints, some bedding-plane joints (scattered calcareous ferruginous concretions 1 to 4 inches in diameter) pock marked, iron stain on outcrop surface.	40
	Total thickness of upper unit	54

FLOOD MEMBER--contd.

Middle unit

Location: Along road cut in SE¼ sec. 1, T. 18 N., R. 2 E., Cascade County, Montana.

15	Shale, dark gray, weathers light gray; poorly indurated, weathered, grades upward to siliceous quartz and plagioclase sandstone, medium grained, shale is slightly calcareous and contains limonite specks 1/8 inch in diameter.	5
14	Sandstone, dark tan, weathers light tan; medium indurated, slightly calcareous, quartz, plagioclase, chert, biotite, fine-grained, slightly friable, fractured, thickness 2 to 4 feet.	4
13	Shale, dark gray, weathers same; poorly indurated, slightly calcareous, deeply weathered.	1
12	Sandstone, tan gray, weathers light gray; well indurated, siliceous, quartz, plagioclase, chert, biotite, fine grained, worm casts, iron stains.	1
11	Shale, black, weathers gray; poorly indurated, calcareous.	1.5
10	Siltstone, dark gray, weathers light gray; slightly indurated, joints normal to bedding.	1.5
9	Shale, gray tan, weathers light gray tan; poorly indurated, calcareous, worm casts, grades upward to dark-gray shale, occasional lenses of fine-grained sandstone with worm casts, grades upward to discontinuous fine-grained quartz and chert sandstone with abundant worm borings, fractured.	10
8	Siltstone, dark tan gray, weathers light tan gray; medium indurated, contains some very fine quartz grains, worm casts.	0.5
7	Siltstone, dark gray, weathers light gray; poorly indurated, bentonitic, contains gypsum crystals, hackly.	4
6	Shale, dark gray, weathers light gray; poorly indurated, in places grades vertically to siltstone.	2.5

5	Sandstone, tan, weathers same; well indurated, siliceous, quartz, plagioclase, chert, fine grained, numerous worm borings.	1
4	Siltstone, gray brown, weathers light gray; poorly indurated, slightly calcareous, contains some 1- to 2-inch claystone stringers.	2
3	Alternating siltstone and sandstone: sandstone, tan, weathers light gray; well indurated, siliceous, quartz, plagioclase, fine grained, worm borings, beds 3 inches thick: siltstone, dark gray, weathers light gray; poorly indurated, thin bedded.	3.5
2	Shale, dark gray and tan, weathers light gray; poorly indurated, calcareous.	4
	Total thickness of middle unit	41.5

Lower unit

Location: At crest of anticline in NE¼ sec. 9, T. 16 N., R. 1 E., Cascade County, Montana.

1	Sandstone, tan gray to light olive green, weathers same; poorly indurated, slightly calcareous, plagioclase, chert, quartz, biotite, augite, coarse grained, thinly cross-bedded; calcareous, ferruginous concretions, 1 to 10 feet in diameter, which may contain calcareous petrified wood; round gray slightly calcareous 1-inch concretions.	102
	Total thickness of lower unit	102±
	Total thickness of Flood Member	197.5

VAUGHN MEMBER

Location: NW¼ SE¼ sec. 35, T. 18 N., R. 1 E., Cascade County, Montana.

Unit number		Thickness (feet)
9	Argillaceous lignite, black, weathers light gray; poorly indurated, contains fossil plants and wood.	3.0

VAUGHN MEMBER--contd.

8	Bentonitic siltstone, dark gray to black, weathers light gray to tan; medium indurated, hackly, gastroliths, petrified wood, contains clinoptilolite, which imparts a pink tinge to parts of the unit.	15
7	Alternating shale and bentonitic shale, dark gray, weathers light gray; well indurated, poor popcorn weathering, clinoptilolite imparts pink coloring to outcrop; contains some resistant 2- to 3-inch nodular-weathering shale beds.	20.5
6	Alternating siltstone and bentonitic shale, light gray, weathers same; medium indurated, slightly arenaceous, sparsely scattered clinoptilolite grains, poor popcorn weathering, grades vertically to a hackly siltstone.	3
5	Bentonitic siltstone, lower 6 feet variegated gray, tan, and pink, upper 5 feet tan pink, both weather pink; medium indurated, hackly, clinoptilolite, poor popcorn weathering.	11
4	Siltstone, dark purple gray, weathers light purple gray; well indurated, hackly, tuffaceous, grades vertically to chunky, contains 6-inch bed of tuff, which is ledge former.	3
3	Siltstone, light gray, weathers olive green; well indurated, hackly, tuffaceous, contains 5-inch bed of tuff, which forms small ledge.	2
2	Silty sandstone alternating with bentonitic shale: silty sandstone, grayish white, weathers pinkish gray; medium indurated, quartz, chert, medium grain, thin bedded, fractured, produces knobby outcrop appearance: bentonitic shale, dark gray, weathers light gray; well indurated, poor popcorn weathering, clinoptilolite specks, beds 2 inches to 2 feet in thickness.	12
1	Siltstone, dark gray, weathers light gray; well indurated, slightly bentonitic, poor popcorn weathering, vertically the light-gray siltstone may alternate with light-tan-brown siltstone.	8
	Base covered by unconsolidated material.	
	Total thickness measured	77.5