Cenozoic geology of the Madison bluffs area Gallatin County, Montana
by Gary Bradley Schneider

A thesis submitted to the Graduate Faculty in partial fulfillment of the requirements of the degree of
MASTER OF SCIENCE in Earth Sciences
Montana State University
© Copyright by Gary Bradley Schneider (1970)

Abstract:
The Miocene-Pliocene Madison Valley Formation east of the Madison River contains three unconformable cyclic units each composed of a basal fluviatile sequence of cross-bedded, andesite conglomerate, coarse sandstone, and tuffaceous siltstone grading upward into sediments that vary laterally from lacustrine beach sands to laminated clays containing fish remains and ostracods. Tuffaceous claystones and siltstones containing carbonaceous dendrites and other plant debris are typically associated with these lake beds. The lake beds are in turn cut by the basal fluviatile sequence of the overlying unit. This basic pattern is seen in all three units, but there is considerable variation from unit to unit. Although the entire section is rich in ash beds 1/2 - 2 feet thick, and in tuffaceous siltstone, the majority of the fresh glass is concentrated in the lake beds of the middle unit. One sequence of ash beds near the top of this unit, has a maximum thickness of 15 feet and is used as the marker bed on which partial measured sections are huhg.

Preliminary paleocuprent data indicate that the primary drainage was generally N. 40°E. Cyclic nature of the sediments is attributed to the recurrent uplift of the Bridget Range to the east, interrupting the through-flowing drainage in the ancestral Three Forks basin.

Block faulting along the bluffs parallel to the Madison River and the distribution of Quaternary (?) gravels to the west and within the area indicate shift of the drainage from northeastward to its present northward position in post-middle Pliocene time.

CENOZOIC GEOLOGY OF THE MADISON BLUFFS AREA

GALLATIN COUNTY, MONTANA

by

GARY BRADLEY SCHNEIDER

A thesis submitted to the Graduate Faculty in partial fulfillment of the requirements of the degree

of

MASTER OF SCIENCE

in

Earth Sciences

Approved:

Milton J. Edie
Head, Major Department

William J. McMannis
Chairman, Examining Committee

R. Goering
Graduate Dean

MONTANA STATE UNIVERSITY
Bozeman, Montana

June, 1970

STATEMENT OF PERMISSION TO COPY

In presenting this thesis in partial fulfillment of the requirements for an advanced degree at Montana State University, I agree that the Library shall make it freely available for inspection. I further agree that permission for extensive copying of this thesis for scholarly purposes may be granted by my major professor, or, in his absence, by the Director of Libraries. It is understood that any copying or publication of this thesis for financial gain shall not be allowed without my written permission.

Signature Gary Bradley Schneider

Date May 22, 1970

TABLE OF CONTENTS

	PAGE
Introduction	1
Previous investigations	2
Geography	4
Location	4
Topography	4
Climate	6
Land economics	6
Stratigraphy	8
Precambrian	8
Paleozoic	8
Cenozoic	9
Tertiary - Madison Valley Formation	16
Lower unit	16
Middle unit	18
Upper unit	26
Quaternary	33
Older rounded gravel	33
Alluvium	35
Loess	35

PAGE

Structural Geology..... 36

Geologic History..... 39

Suggestions for Future Research..... 43

References Cited..... 44

Appendix..... 50

LIST OF FIGURES

FIGURE		PAGE
1.	Index Map	5
2.	Generalized Restored Section	15
3.	Generalized Unit	19
4.	Correlation of Measured Sections	24
5.	Comparison of Size Distributions	28

LIST OF PLATES

In Pocket

PLATE

I. Geologic Map

II. Preliminary Paleocurrent Map

III. Generalized Structure Map, Southcentral Montana

LIST OF TABLES

TABLE		PAGE
I.	Composite Generalized Stratigraphic Section Tertiary and Quaternary Sediments Madison Bluffs Area, Gallatin County, Montana.....	12
II.	Mechanical Analysis	
	(1) Mid-Pliocene (?) Gravel.....	29
III.	Mechanical Analysis	
	(2) Pleistocene Gravel (Qor).....	30

ABSTRACT

The Miocene-Pliocene Madison Valley Formation east of the Madison River contains three unconformable cyclic units each composed of a basal fluviatile sequence of cross-bedded, andesite conglomerate, coarse sandstone, and tuffaceous siltstone grading upward into sediments that vary laterally from lacustrine beach sands to laminated clays containing fish remains and ostracods. Tuffaceous claystones and siltstones containing carbonaceous dendrites and other plant debris are typically associated with these lake beds. The lake beds are in turn cut by the basal fluviatile sequence of the overlying unit. This basic pattern is seen in all three units, but there is considerable variation from unit to unit. Although the entire section is rich in ash beds ½ - 2 feet thick, and in tuffaceous siltstone, the majority of the fresh glass is concentrated in the lake beds of the middle unit. One sequence of ash beds near the top of this unit has a maximum thickness of 15 feet and is used as the marker bed on which partial measured sections are hung.

Preliminary paleocurrent data indicate that the primary drainage was generally N. 40°E. Cyclic nature of the sediments is attributed to the recurrent uplift of the Bridger Range to the east, interrupting the through-flowing drainage in the ancestral Three Forks basin.

Block faulting along the bluffs parallel to the Madison River and the distribution of Quaternary (?) gravels to the west and within the area indicate shift of the drainage from northeastward to its present northward position in post-middle Pliocene time.

CENOZOIC GEOLOGY OF THE MADISON BLUFFS AREA GALLATIN COUNTY, MONTANA

INTRODUCTION

This paper is the result of geologic mapping in the bluffs area on the east side of the lower Madison River. It was undertaken as a thesis project in partial fulfillment of the requirements of the Master of Science in Earth Science with a major in geology at Montana State University. Field work was done during the spring and summer of 1969.

The principal objective of the study was to map in detail the Cenozoic sediments of the area, specifically working toward an understanding of the depositional history. An attempt has been made to find the stratigraphic position of fossil localities and formational units that have been previously described in the literature, but never accurately located geographically or stratigraphically.

The area mapped has been the subject of part of previous geologic investigations which were specialized in their objectives. It has not, however, been given the detailed coverage necessary to elucidate many of the relationships having definite bearing on the Cenozoic history. Choice of the area for study was determined by an interest in the paleontological work which has been done in the area and a desire to at least attempt to put that work in the proper stratigraphic setting. However, paleontological work is not the central theme here, and little effort was devoted to that end.

Previous Investigations

The earliest geological investigations in the region were made by Hayden (1861, 1884). The first extensive geological mapping was done by Peale (1893, 1896). His paper on the Three Forks quadrangle is of a reconnaissance nature, but serves as a good review of the general geology.

Douglass (1899, 1903, 1909) described vertebrate remains in the Tertiary strata of southwestern Montana, many of which were collected in the map area or adjacent to it. Later significant paleontological work was done by Wood (1933, 1938), Wood, and others (1941), Schultz and Falkenbach (1940, 1941, 1949), and Dorr (1956).

A regional study of the groundwater resources of the Gallatin Valley by Hackett, and others (1960) includes a general stratigraphic description and geological history of the area. Robinson (1963) published on the Three Forks quadrangle which adjoins part of the area on the west. Additional studies of the region and contiguous areas include Fix (1940), Klemme (1949), Tanner (1949), Pardee (1950), Alden (1953), McMannis (1955), Verrall (1955), Hall (1960), Robinson (1961), Mifflin (1963), Glancey (1964), Weber (1965), and Kuenzi (1966).

McMannis (1963) made a regional study of the distribution of the Precambrian Belt Supergroup. Detailed studies of the Precambrian metamorphic rocks in the areas nearby have been made by Tansley, Shafer, and Hart (1933), Clabaugh (1952), Reid (1957, 1963), and Kozak (1961).

Additional study of the metamorphic rocks, especially the tectonic features, may prove very useful in unraveling structural history of the basin.

GEOGRAPHY

Location

The map area (see Index Map, p. 5), occupying approximately 125 square miles, lies on the divide between the Madison and West Gallatin Rivers, just south and east of the headwaters of the Missouri River at Three Forks, Montana. This part of the Three Forks basin physiographic subdivision lies between the 111° 20' and 111° 30' meridians and the 45° 35' and 45° 50' parallels. The west boundary of the study area is the flood plain of the Madison River. The northern boundary is the Gallatin River. Manhattan, a small town, is situated just east of the northeast corner of the area, and Anceney, a grain terminal, is located just north of the southeast corner of the area. The southern boundary of the area is the Madison - Gallatin county line.

Topography

Elevation of the area varies from 4,100 feet on the flood plains of the rivers, to 5,200 feet on the divide between the Madison and West Gallatin rivers in the south central part of the area. The land surface rises abruptly from the Madison Valley on the west to the broad gently east- and north-sloping Madison Plateau which grades gently to the West Gallatin River on the east and the Gallatin River on the north. The plateau is deeply dissected on the bluff side. Away

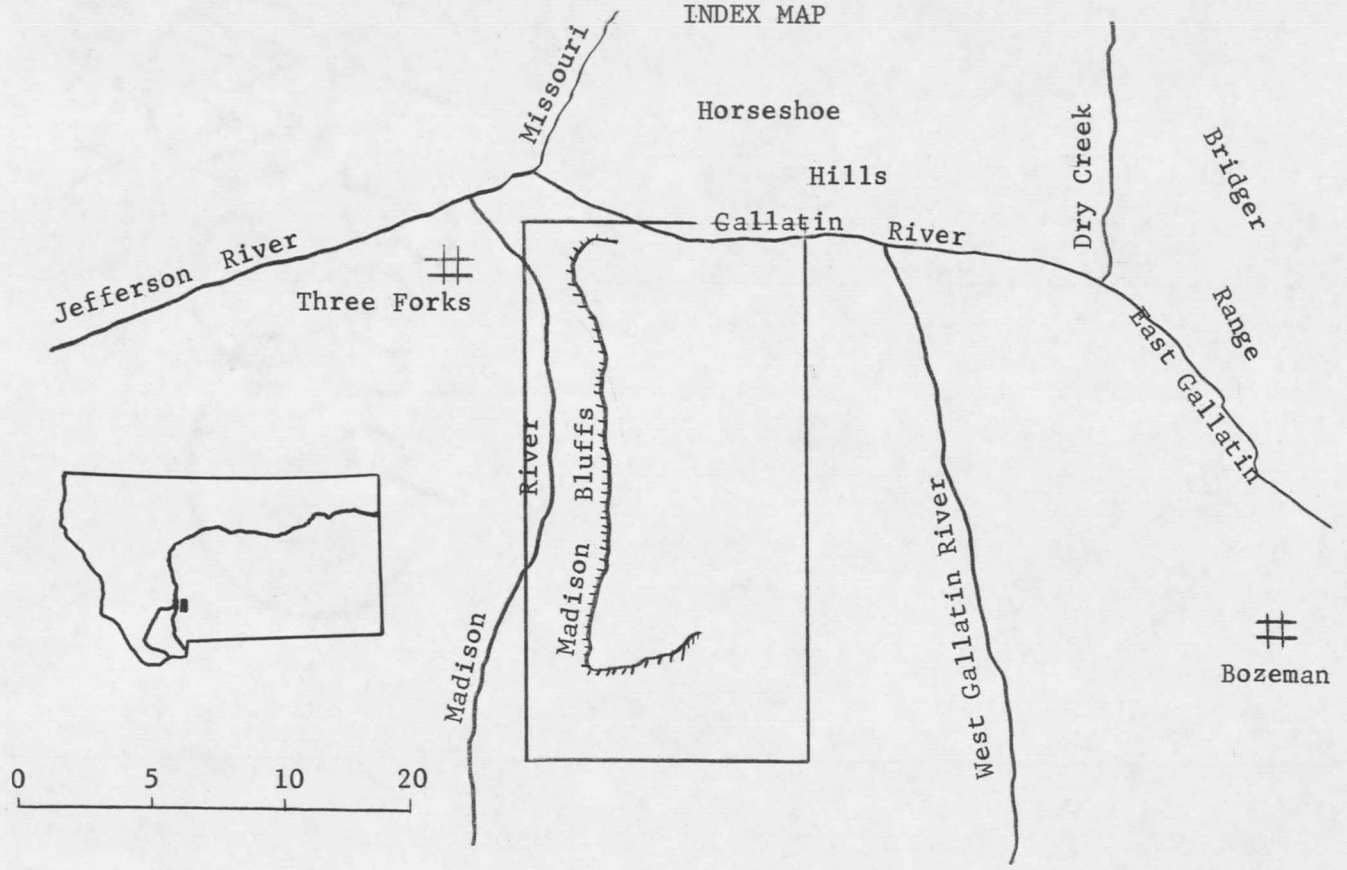


Figure 1. Index map showing location of the Madison Bluffs Area southeast of Three Forks, Montana.

from the river a series of steep-sided ravines separate flat to steeply sloping benches.

Climate

The average annual precipitation in the area according to calculations made in 1952 (Hackett, and others, 1960, p. 18) ranges between 11.5 and 15.5 inches. At Bozeman, 15 miles to the east, nearly two-thirds of the precipitation falls during the period from April to September. The precipitation in May and June amounts to about one-third of the annual total. A second maximum, much less than that in the spring, generally occurs in September. The precipitation from year to year, however, is characterized by many departures from the average.

Daily and seasonal fluctuations in temperature vary widely. Hackett, and others (1960) report that the average annual temperature at Bozeman is 42°F. and the extreme temperature ranges from above 110°F. to below -50°F. Snow cover in the area during the winter rarely exceeds two feet for any length of time. The best means of transportation for geologic field work is by four-wheel-drive vehicle in the summer months.

Land Economics

Most of the map area at present is in agricultural use, either as crop land or as pasture. Areas of low relief and good soil are used in the dryland production of wheat. Areas of steep or broken terrain are used for the grazing of cattle or sheep. Irrigated lands on the flood

plains of the rivers are used for the production of hay. Except for fishing accesses on the Madison River and the Madison Valley Buffalo Jump Archaeological Site all of the lands are privately owned.

At present there is little economic development of mineral deposits within the area. Gallatin County as well as some of the land owners operate gravel pits in the northwest part of the area. Little other development has taken place.

STRATIGRAPHY

Precambrian

Potassium feldspar-rich gneiss and hornblende gneiss are exposed in the southeastern corner of the area and in scattered outcrops along the southern border. Exposures of gneiss in the southwestern part of the area have a minimum surface relief of 610 feet, and are unconformably overlain by Tertiary and Quaternary sediments.

In the northern part of the area Precambrian strata of the Belt Supergroup (Verrall, 1955) crop out. These strata consist of arkosic sandstones and conglomerates, and intercalated dolomitic limestones and argillite. Presumably they unconformably overlie gneiss. They are in turn unconformably overlain by Tertiary and Quaternary sediments.

Paleozoic

Along the northern border of the area the Cambrian Flathead Sandstone, Wolsey Shale, Meagher Limestone, Pilgrim Limestone, and Snowy Range Formation, the Devonian Jefferson Dolomite, the Devonian-Mississippian Three Forks and Sappington formations, and the Mississippian Madison Group are exposed in Logan Canyon. Description of the lithologies of these formations are given by McMannis (1955), Verrall (1955), and Robinson (1963).

Cenozoic

Cenozoic sedimentary rocks, divided into eight map units, dominate the area. The units, all of nonmarine origin, have a maximum aggregate exposed thickness of 1500 feet, but total exposed thickness is probably nowhere greater than 1000 feet. The Cenozoic column here is composed of late Miocene to middle Pliocene (?) rocks, but the high part of the Madison Plateau is covered by a veneer of unconsolidated Quaternary alluvium, and much of the area is covered by loess and soil.

The Cenozoic of the area has been variously investigated since the publication of the Three Forks folio (Peale, 1896). Paleontological collections have been made and described by Douglass (1899, 1903, 1909), Matthew (1903), and Dorr (1956). Extensive collections have also been made by members of the Carnegie Museum of Pittsburgh, the Frick Laboratory, Princeton University, the University of Michigan, the University of Chicago, and other organizations, but little publication has yet resulted (Robinson, 1963).

Systematic study of the Cenozoic stratigraphy in this part of Montana has been undertaken only within the last two decades (Verrall, 1955; Dorr, 1956; Robinson, 1963; and Kuenzi, 1966). Much more work is needed in order to make firm correlations of the Cenozoic deposits in the area, and to obtain a comprehensive picture of the regional Cenozoic history.

The Three Forks basin is formed in soft Tertiary rocks that were laid down in a basin of dimensions similar to those of the modern one. The Madison Bluffs area, in the west-central part of the basin was also in the west-central part of the Tertiary basin as shown by Peale (1893, Pl. I). Rocks of known or inferred Tertiary age are exposed over approximately one-half of the surface and are thinly mantled by unconsolidated Quaternary deposits over an additional one-quarter of the surface.

Principal rock types are siltstone, sandstone, conglomerate, and claystone in subequal amounts, and minor amounts of limestone and travertine. About one-half of the Tertiary deposits were derived from erosion of the pre-Tertiary rocks, and one-half from pyroclastic debris. Few beds are free of volcanic ash, and many strata are made up wholly of such material, much of which is fresh glass (Robinson, 1963).

The Tertiary rocks, of late Miocene to middle Pliocene (?) age (Wood, 1941; Dorr, 1956; Robinson, 1963), may be divided naturally into three units, designated here lower, middle, and upper (see Composite General Section, p.12), each of which reflects a definite cycle of sedimentation. No attempt has been made to assign formal formational names to the units, however, detailed work in the adjoining areas may make this feasible in the future. (see Figure 2.).

Generally, the units consist of basal sandstone - conglomerate channels that represent an episode of through-running drainage in the basin. These channels are unconformable on the underlying strata and

grade upward into sands and silts which are laterally variable, and represent the onshore-nearshore facies of a lake sequence. Typical variation in the onshore-nearshore phase ranges from eolian sands to ripple-marked siltstones to carbonaceous claystone that resembles a paleosol, all laterally separated by a few miles, but at the same stratigraphic horizon. The onshore-nearshore sequence is interbedded with and overlain by laminated clays and very fine silts that contain fish remains and ostracods. These lake deposits are of finite geographical extent within the area and can be traced and delineated in the field (see Figure 3.).

The laminated clays are not all in the same stratigraphic position in all of the units or within one unit. In some instances the lake sediments are of sufficient thickness and lateral distribution to indicate a persistant lake of considerable size - with a maximum measurable dimension at one place of 7 miles (see Geologic Map).

The lake beds are overlain by sandstone and siltstone which have the same general characteristics as the underlying shoreline phase. This probably represents a lateral shift in the position of the lake or a decrease in the size of the lake, the magnitude of which can not be determined from the present outcrops.

The entire unit is unconformably overlain by the channels of the next higher unit which reflects the renewal of through-flowing drainage and the beginning of the next depositional cycle.

TABLE I

COMPOSITE GENERALIZED STRATIGRAPHIC SECTION
TERTIARY AND QUATERNARY SEDIMENTS
MADISON BLUFFS AREA, GALLATIN COUNTY, MONTANA

Quaternary

7. Loess and soil; medium gray loess and soil present over much of the area and best developed on the Madison Plateau section of the map. Obscures the bedrock geology over much of the area..... 10'

6. Gravel; clasts ranging from 6" down to sand size. Cobbles and pebbles are predominantly Belt quartzite, with a few igneous clasts, and lesser amounts of gneiss and Paleozoic sandstone. Spills down slopes and makes the thickness difficult to estimate..... 25'

(?) Pliocene

5. Claystone and sandstone interbedded; yellow to white. Sandstone is channel-form within claystone, and also at some horizons has an onshore-nearshore aspect. Some lake sediments were found within this sequence..... 190'

UPPER UNIT

4. Conglomerate and sandstone; large scale, widespread channel deposits that form prominent cliffs in the central part of the Bluffs exposure. Contains proboscidian material referred to Serridentinus progressus. Sequence varies greatly in thickness. Maximum.... 50'

Miocene

MIDDLE UNIT

3. Sandstone; yellow to gray-white. Sandstone composed of quartz sand with clay matrix, and interbedded with numerous beds of fresh glassy ash. Sequence contains well developed lake beds exposed along the central and northern parts of the Bluffs. Equivalent to Anceney Beds of Dorr (1956). Maximum..... 250'

2. Conglomerate and sandstone; large-scale and widespread channel deposits distinguishable in the lower part of the Bluffs and forming a prominent vertical cliff in the north..... 60'

LOWER UNIT

1. Claystone interbedded with sandstone and conglomerate in minor channels, and gray siltstone; unit more variable lithologically both vertically and laterally than those above. Contains Leuciscus turneri beds of Wood (1940) in about the middle of the exposed section. Thickness variable, base covered by recent alluvium.....125'

Total Thickness 710'

General transport direction (see Preliminary Paleocurrent Map, Plate II) indicated by numerous measurements of the cross-bedding and imbrication of the coarser parts of the channels of all three units indicates a drainage pattern with a general trend of N. 40° E. The composition of the sediments and the direction of transport indicate that the material was probably transported from the mountains to the west or southwest of the area.

GENERALIZED RESTORED SECTION

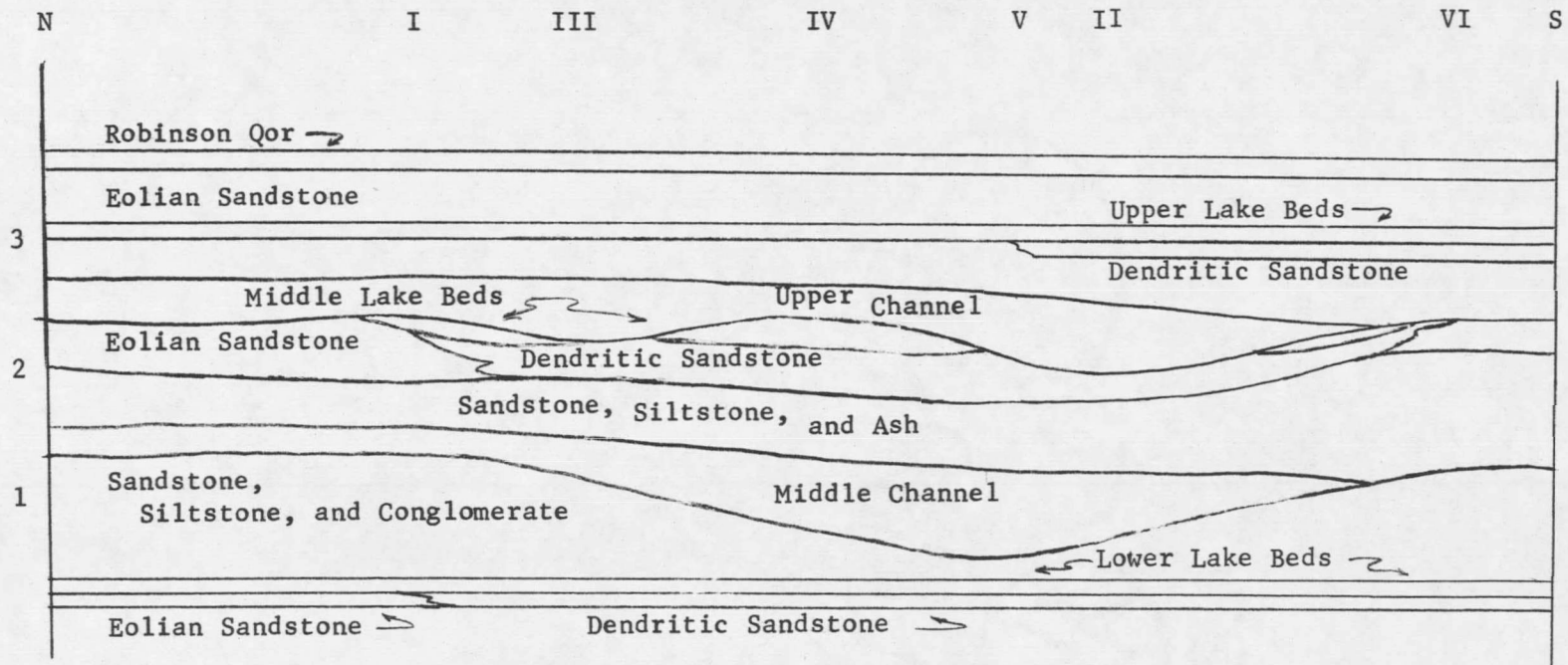


Figure 2. Generalized Restored Section showing the relationship of the beds in the Lower (1), Middle (2), and Upper (3) Units as exposed in the Madison Bluffs. Roman numerals indicate approximate location of measured sections.

TERTIARY - MADISON VALLEY FORMATION

Miocene

LOWER UNIT

The lowest part of the Tertiary section on the east side of the Madison River is exposed in the W ½ sec. 27, T. 1 N., R. 2 E. west of the road. The rocks consist of coarse, poorly size-sorted sandstone composed of quartz and gneiss fragments. Large festoon cross-beds indicate a transport direction toward the northeast.

The sandstone at this outcrop is like the Oligocene Dunbar Creek which crops out in the W ½ sec. 29, T. 1 N., R. 2 E. west of the river. The base of the section east of the river may be Dunbar Creek.

The strata immediately above the sandstone (Measured Section II) correlate with that part of the lower unit exposed in the NE ¼ sec. 4, T. 1 N., R. 2 E. as a vertical cliff at the base of the Bluffs about a mile northeast of the Christiansen Ranch buildings (see Geological Map). The Leuciscus turneri lake beds of Wood (1941) are exposed near the base of the Bluffs in the Christiansen Ranch section (Measured Section I) and are also present in Measured Section II. They can be seen at road level in the cut east of the road in NW ¼ sec. 3, T. 1 S., R. 2 E. These beds, mapped as a single unit (T1), are presumably Hemmingfordian, Barstovian, or both in age (Wood, 1941). Of the three cyclic units, the lower unit least well exhibits the generalized sedimentational pattern.

The rocks of the lower unit are light- to medium-gray, tuffaceous sandstone, siltstone, and claystone intertongued with channel-form conglomerate. The sandstone is composed of angular, medium- to coarse-grained quartz and sub-rounded, medium- to fine-grained fragments of andesite and dacite in a gray to buff clay matrix. The conglomerate is composed of sub-angular to sub-rounded andesite and dacite similar to that of the area to the west (Robinson, 1963), and lesser amounts of Precambrian gneiss, and pebbles and cobbles of sub-angular to sub-rounded Mississippian limestone. A few clayballs with maximum diameters of six inches are also present. Cross-bedding and imbrication in the conglomerates indicate a general transport direction toward the N. 40° E. (see Preliminary Paleocurrent Map).

The only exposures of the lower unit are in the lower part of the Bluffs along the river. Overlying this sequence and deeply cut into it is the basal channel-form conglomerate and sandstone of the middle unit.

MIDDLE UNIT

The middle unit is well exposed over much of the area (see Geological Map), and has been chosen as the model for the sedimentational cycles seen in this part of the Tertiary sequence (see Figure 3.).

The base of the middle unit, unconformable on the underlying strata, is best seen in the Bluffs in the E ½ sec. 4., T. 1 N., R. 2 E. The unconformity can be traced in the exposures of the Bluffs for more than three miles. The basal part of the unit consists of channel-form conglomerate and sandstone composed of pebbles and cobbles of angular to sub-rounded andesite and dacite, Mississippian limestone, and minor amounts of Paleozoic sandstone and Precambrian gneiss (see Measured Sections III, IV, and V). The conglomeratic lenses generally become finer up-section and intertongue with cross-bedded quartz sandstone with clay matrix and tuffaceous floodplain deposits. The base of the middle unit is exposed only in the northern part of the Bluffs along the river.

The top part of the sand and conglomerate sequence contains hot springs deposits that can be traced along the Bluffs for more than nine miles. The hot springs deposits seem to have invaded a particularly porous sequence of sandstone and conglomerate and are localized or concentrated at a particular stratigraphic horizon. The cementing effects of the travertine produces a strong bed which forms a prominent ledge in the

GENERALIZED UNIT

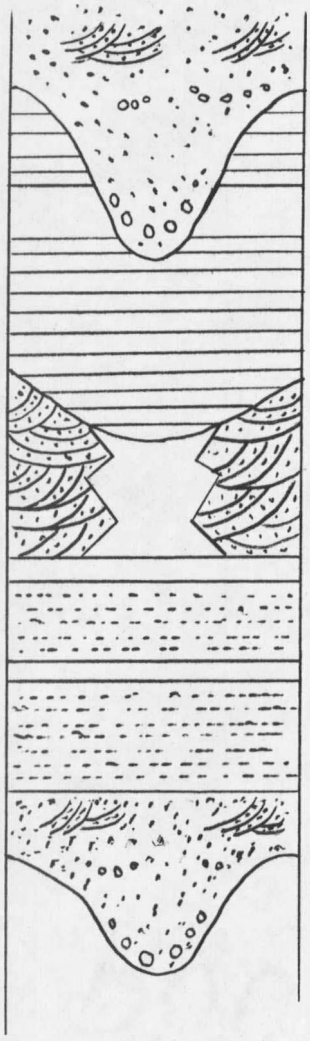


Figure 3. Generalized columnar section showing the relationship of the sediments within the stratigraphic unit. Based on the outcrops of the middle unit of late Miocene age.

lower part of the Bluffs in the northern part of the area. In the E ½ sec. 4, T. 1 N., R. 2 E. the travertine also takes the form of pipes or tubes up to six feet in diameter. This type of occurrence can be seen in the Bluffs at about the same stratigraphic level four or five miles to the south. Thin beds and uneven lenses of limestone can be traced to these pipes. Although the tubes and some of the limestone lenses have an agal structure, it is believed that they are all of hot springs origin primarily because they are not immediately associated with lake sediments. Away from the Bluffs no exposures of limestone or indications of hot springs activity have been found.

The channel-form conglomerate and sandstone grade upward into plane-bedded sandstone composed of angular, medium- to fine-grained quartz with biotite, and a buff clay matrix. Sandstones up to five feet thick are interbedded with fresh, glassy ash layers up to six inches thick. Ash beds are numerous and there may be more than 21 in just over 100 feet of section (Measured Section III).

Exposures of the plane-bedded sandstone form the middle part of the sequence in the northern half of the Bluffs. From north to south along the Bluffs progressively higher parts of the section are exposed. In the southeastern part of the area the plane-bedded sandstone forms low rolling fields. In this area the sandstone was delineated mainly on the color differences between it and the overlying tuffaceous sandstone of the upper unit, and on the topographic expression.

Associated with the plane-bedded sandstone in the western part of the area are large quantities of buff-gray to white opalized wood. The wood is particularly abundant in the E ½ sec. 11, T. 1 N., R. 2 E. on the slopes just east of the road. Although no wood was found in situ, it is likely that the wood is from the plane-bedded sandstone. The size of the wood fragments (some more than one foot in length) is too great to be associated with the conglomerates up-section. Although small one to two inch fragments of the wood can be found in the conglomerate, no larger reworked fragments have been found. It appears that the wood is from the sandstone and the fragments in the conglomerate above are reworked from it.

The plane-bedded sand and ash sequence is overlain by a laterally variable sequence of eolian sandstone and dendritic claystone. The contact between the plane-bedded sandstone and the overlying sediment is gradational. Angular, medium- to fine-grained quartz sand with biotite and a clay matrix is intertongued with lenses of sub-rounded, well size-sorted, cross-bedded, eolian sandstone with calcareous cement. The lenses are not everywhere present in the sequence. Good exposures of the eolian sand are located in the W ½ sec. 3., T. 1 N., R. 2 E. about two-thirds of the way up the Bluff.

The eolian sandstone grades laterally into dendritic claystone with beds from two to twenty four inches thick. The dendrites are carbonaceous, and individual dendrites are about 1/8 inch thick and are not

more than two inches long. Some poorly preserved fish (?) material (vertebrae) were found associated with the dendrites in the extreme NW ¼ sec. 10. T. 1 N., R. 2 E. northwest of the road.

Although the contact between the basal channel-form conglomerate and the plane-bedded sandstone is easily distinguishable in the Bluff-side of the area, it is rather difficult to pick the position of this contact on the gentle slopes to the east. The conglomeratic and sandstone sequences were, therefore, mapped together as a single unit (Tllb). The travertine mapped as unit Tlla is roughly co-incident with the conglomerate on the west side of the area.

Above the dendritic claystone and above and lateral to the eolian sandstone is a thick sequence of laminated claystone containing ostracods. These lake beds of the middle unit are well exposed in the western part of the area and can be seen all along the Bluffs (Tllc on the Geologic Map). The thickest exposure of lake beds is in the northern part of the Bluffs. Here the laminated claystone reaches a thickness of more than twenty feet (Measured Section III). Thinning of the lake beds to the south can be attributed at least in part to removal during the deposition of the overlying channel deposits of the upper unit.

Above the lake beds, and included with them for mapping purposes, are 25 to 50 feet of ash and sandstone of the same general type as that below. The thickness of the section depends on the depth to which the streams eroded during the deposition of the basal part of the upper unit.

Although the individual beds of ash are only 6" to 10" thick, the entire aggregate of beds is about 15' thick and is persistent throughout the area. The ash is exposed in the northern part of the Bluffs as noted in Measured Section III. It can be traced along the Bluffs in the various measured sections to the south, and is well exposed in Measured Section VI where it forms a conspicuous marker bed in the middle of the section.

At all exposures some of the individual 6" to 10" beds of this ash exhibit very marked convolute bedding and slump structures. In some places, particularly the SW ¼ sec. 3, T. 1 N., R. 2 E., and in the center of sec. 3, T. 1 S., R. 2 E., the slump structures and convolute bedding can be seen even in the underlying laminated lake sediments.

Because of the unusual thickness and conspicuous nature of this ash bed sequence it is particularly useful as a stratigraphic marker horizon, and has been used as the key horizon on which the measured partial sections are hung (see Figure 4.). Investigation to the southeast in sec. 13. T. 2 S., R. 3 E., in the area from which the Anceney fauna was collected (Dorr, 1956), indicates that the fauna is stratigraphically just below the level of this key ash sequence. At that location the ash has about 75 feet of gray-buff plane-bedded sandstone above it, which is then, in turn, cut by the channel-form conglomerate of the basal part of the upper unit. There is also a change in color to the light pinkish-yellow characteristic of the upper unit. The position of the ash and the channel-form conglomerate indicate that the upper part of the

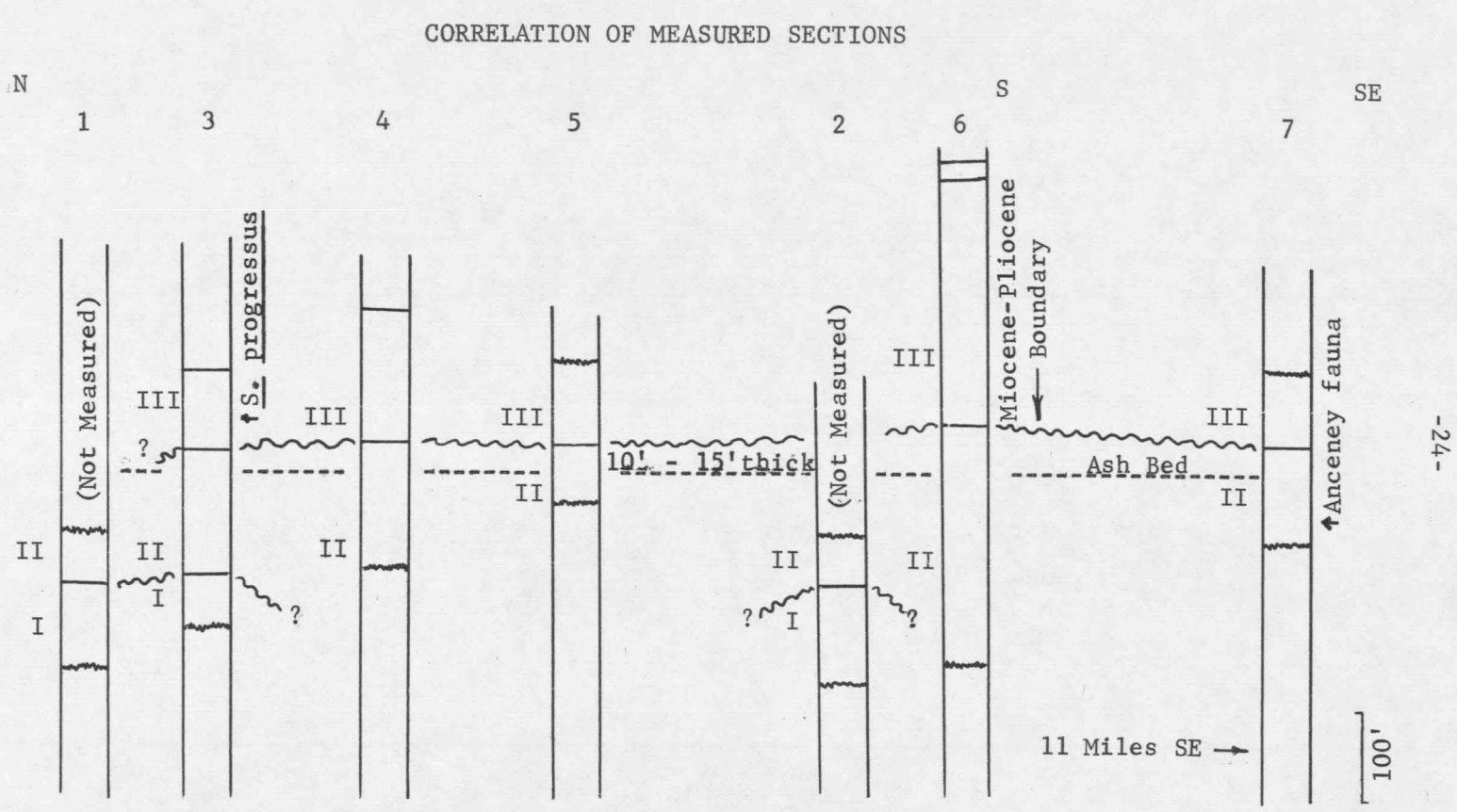


Figure 4. Correlation of the measured sections on the 10' - 15' thick ash bed that occurs near the top of the Middle Unit. Position of the Anceney fauna inferred from field data collected in the NW¼ sec. 13, T. 2 S., R. 3 E.

plane-bedded sandstone (T11b) is equivalent in age to the Anceney fauna which Dorr (1956) called latest Miocene. Therefore, the plane-bedded part of the middle unit very likely is Late Miocene in age.

Pliocene (?)

UPPER UNIT

The middle unit is unconformably overlain by a thick sequence of channel-form deposits (Tlla on the Geologic Map) which crop out over the entire area except in the southwest quarter. In this part of the area the lower and middle units were either never present, or they were completely removed before the deposition of the upper part of the upper unit. Locally the sediments of the upper unit are gray and buff, but the predominant color of the upper unit is light-pink to light pinkish-yellow.

The channel-form conglomerate and sandstone of the basal part of the upper unit is well exposed in the upper part of the northern half of the Bluffs where it forms a vertical cliff at the summit (see Geological Map). To the southeast the conglomerate and sandstone cap a prominent ridge that trends from just north of Montana Highway 289 northeast four miles to Camp Creek. In both of these areas the unconformity with the underlying strata is visible. The conglomerate has been beveled on the flood plain of Camp Creek and no longer forms a prominent scarp. This part of the section is, however, more resistant than the sandstone and siltstone above (Tllb) and below (Tlb), and the contact between them here and to the north was drawn on a minor break in slope and on the distribution of the gravel on the slope. To the northwest the surface is covered with conglomerate and sandstone from these beveled beds and the

approximate position of the contact with the overlying sandstone and siltstone (T111b) was drawn on the basis of the distribution of clasts.

The conglomerate of this part of the middle unit is composed of sub-angular to sub-rounded clasts which range from coarse pebble gravel (3.5 cm) to sand and silt size (see Figure 5.). About 41% by weight of the material from a sample collected in the NE ¼ sec. 10, T. 1 N., R. 2 E. southeast of the road is composed of extrusive igneous rock including andesite, dacite, and minor amounts of scoria (see Table II). Most of this material is between one and three centimeters in maximum diameter. An additional 31% of the clasts is composed of quartzite, predominantly Belt, but including some Paleozoic. Most of this material is also between one and three centimeters in maximum diameter. The remaining 28% of the clasts are composed of Paleozoic sandstones, Precambrian gneiss, and granitic material which span the complete range of size distribution.

The preponderance of extrusive igneous rock clasts in this gravel compared with the paucity of this material in the Pleistocene older rounded gravel (Qor) above, the difference in size distribution in two gravels, and the greater amount of quartzite in the Qor were used to distinguish these gravels in mapping the northern half of the area (see Table III).

The channel-form conglomerate of the upper unit generally contains a tuffaceous matrix and calcareous cement. The matrix contains

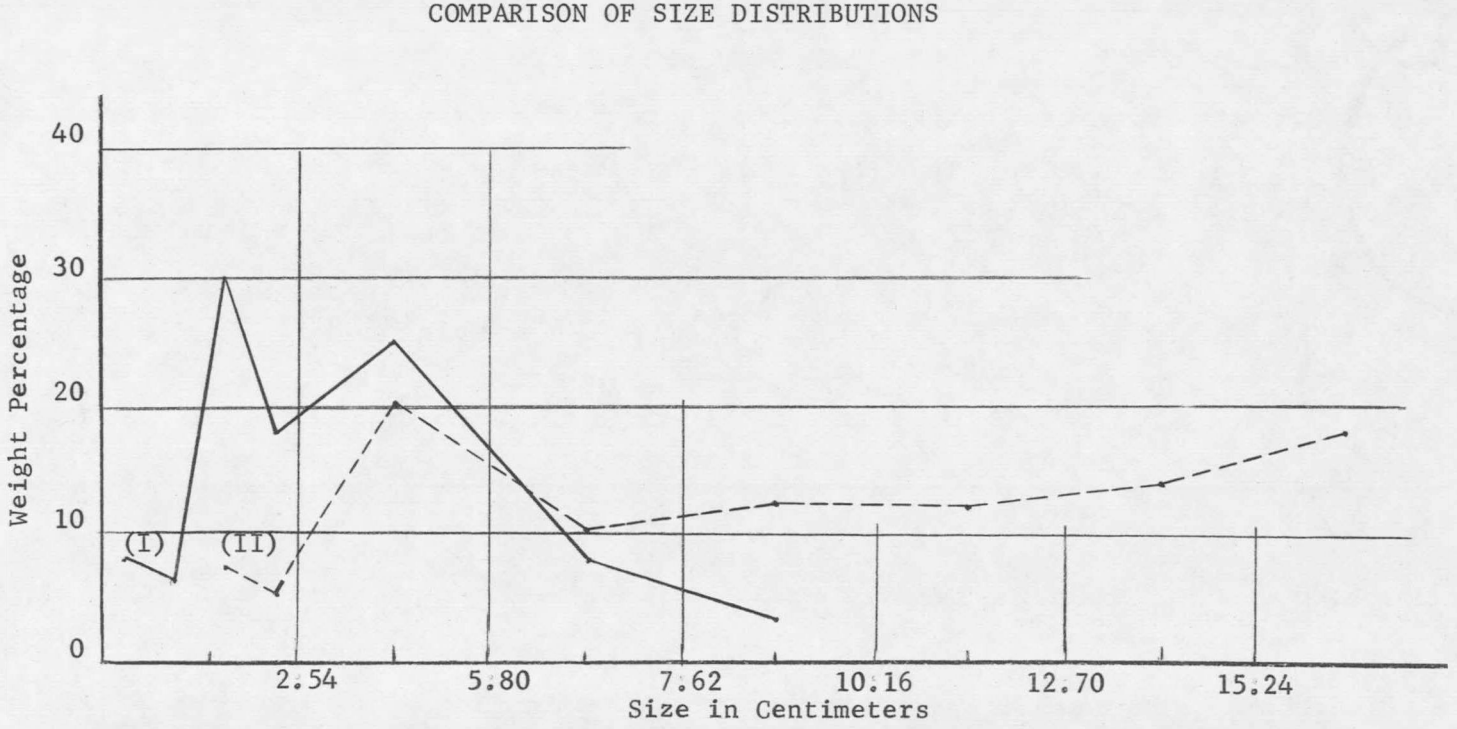


Figure 5. Comparison of size distribution in the Mid-Pliocene (?) (I) and Pleistocene (II) gravels from the Madison Bluffs Area, Gallatin County, Montana

TABLE II

MECHANICAL ANALYSIS

(I) Mid-Pliocene (?) Gravel
Total amount 29664 cm^3

Size (cm)[1]	<0.63[2]	>0.63[2]	<1.90[2]	<2.54	>2.54	>5.80	>7.62	Total	Wt.%
Weight (gm)	2035.0	1468.0	7413.0	4483.0	5986.2	2110.8	902.1	24398.1	
Composition[3]									
Sedimentary	124.0	215.0	592.0	420.2	465.1	493.8	347.5	2657.6	10.80
Quartzite	408.0	523.0	3260.0	1723.2	1417.3	269.3	83.4	7684.2	31.49
Gneiss	1093.0	226.0	286.0	304.1	489.3	157.9	-----	2556.3	10.47
Plutonic	63.0	203.0	426.0	218.9	373.1	-----	-----	1284.0	5.26
Extrusive	347.0	301.0	2849.0	1816.6	3241.4	1189.8	471.2	10216.0	41.87
									99.89
WEIGHT PERCENT	8.34	6.01	30.38	18.37	24.53	8.65	3.69		99.97

1 All matrix and material less than 0.63cm removed
2 Calculated from examination of 1/10th of the total
3 Composition - Sedimentary includes primarily Paleozoic and Tertiary sandstones
Quartzite - predominantly Belt Quartzite
Gneiss - metamorphics exhibiting good foliation
Plutonics - igneous rocks, mainly granitic in composition and texture
Extrusive - fine grained igneous rocks, mainly andesitic and dacitic in composition with some scoria

TABLE III

MECHANICAL ANALYSIS

(II) Pleistocene Gravel (Qor)
Total amount 29664 cm^3

Size (cm)[1]	<1.90[2]	<2.54	>2.54	>5.80	>7.62	>10.16	>12.70	>15.24	Total	Wt.%
Weight (gm)	3185.9	2443.2	9172.3	4439.8	5663.8	5308.2	6089.4	7962.5	44265.1	
Composition[3]										
Sedimentary	617.4	506.8	856.1	495.9	1055.3	------	833.7	1030.2	5395.4	12.18
Quartzite	2075.5	1631.6	7856.2	3823.3	4100.2	5308.2	5255.7	6932.3	36983.0	83.54
Gneiss	141.7	86.2	------	63.2	------	------	------	------	291.1	0.65
Plutonic	165.1	92.1	75.6	------	------	------	------	------	332.8	0.75
Extrusive	186.2	126.5	384.4	57.4	508.3	------	------	------	1262.8	2.85
										99.97
WEIGHT PERCENT	7.19	5.51	20.72	10.03	12.79	11.99	13.75	17.98		99.96

1 All matrix and material less than 0.63cm removed
2 Calculated from examination of 1/10th of the total
3 Composition - Sedimentary includes primarily Paleozoic and Tertiary sandstones
Quartzite - predominantly Belt Quartzite
Gneiss - metamorphics exhibiting good foliation
Plutonics - igneous rocks, mainly granitic in composition and texture
Extrusive - fine grained igneous rocks, mainly andesitic and dacitic in composition with some scoria

fresh glass shards and medium- to coarse-grained, angular quartz. The conglomerate and sandstone generally become finer-grained upward and grade into and intertongue with typical sandy and silty floodplain deposits (see Measured Section VI).

A complete lower jaw of a young mastodon and a partial jaw of an adult were found by Montana highway construction people in a sandy lens of this part of the section in the NW ¼ sec. 5, T. 1 N., R. 3 E. The jaws are very similar to Serridentinus progressus and are probably Middle Pliocene in age (McMannis, personal communication, 1970). On the basis of this evidence, the basal part of the upper unit is tentatively assigned a Middle Pliocene age.

The channel-form sequence of the upper unit is overlain by a variable sequence of plane-bedded sandstone, siltstone, eolian sandstone, dendritic claystone, and lake beds (Tlllb on the Geologic Map). While the section contains all of the elements of the middle unit, conditions during this phase of deposition seem to be more chaotic than they were during the Late Miocene. The plane-bedded sandstone is interbedded with numerous one to two foot thick lake bed sequences of small lateral extent. The lake beds generally overlie dendritic claystone, but they are not all associated with eolian sandstone.

On the west side of the area the entire section is cut by small lenses of conglomerate and cross-bedded sandstone. The variability in the section can be seen in exposures on the Bluffs from sec. 3, T. 1 S.,

R. 2 E. on to the south.

To the east and southeast the upper part of the upper unit contains fewer conglomeratic lenses and less coarse sandstone. In this part of the area, especially in the southeast where the upper part of the upper unit lies directly on the plane-bedded sands of the middle unit, the difference in color, yellow below (Tllb) and light pinkish-yellow above (Tlllb), was used to differentiate the units in mapping.

QUATERNARY

Pleistocene

OLDER ROUNDED GRAVEL

Above 4500 feet the Madison Plateau and the Bluffs in the central and southern part of the area are covered by a conspicuous rounded, percussion-marked cobble gravel (Qor on the Geologic Map) which overlies the upper unit of the Tertiary. The gravel spills down the slopes making accurate estimates of the thickness difficult. In the N ½ sec. 3, T. 1 S., R. 2 E. an estimated 25 feet of gravel overlies the upper part of the upper unit. Away from the Bluffs the gravel is obscured by loess and soil, but it can be seen in patches in the wheat fields on the Madison Plateau, and to the east on the slopes of the coulees that separate the benches on the dissected part of the plateau.

A sample of the gravel, collected in the center of sec. 14, T. 1 S., R. 2 E., is composed of more than 83% by weight of Belt quartzite clasts most of which are greater than one centimeter in maximum diameter and the majority of which are greater than four centimeters in maximum diameter (see Table III). Other constitutents include 12% Paleozoic and Tertiary sandstone, and minor amounts of extrusive igneous rock, granite, and Precambrian gneiss, none of which is greater than three centimeters in maximum diamter. The large Belt clasts in the gravel make it easily distinguishable from the Pliocene (?) gravels, even where the rounded

clasts have spilled down the slopes and mixed with the gravel below (see Figure 5.).

Present outcrops of the Belt quartzites of the type contained in the older rounded gravel lie far to the northwest in the region around Missoula, Montana, and far to the south and west in the mountains near the Montana-Idaho border (McMannis, personal communication, 1970). Distribution of the gravel, limited to south of the Jefferson River (Robinson, 1963) on both sides of the Madison River, and the preliminary paleocurrent data indicating a transport direction of N. 40° E., at least for the previous depositional cycles, suggests that the quartzite cobbles of the older rounded gravel had their source to the southwest.

Between the present outcrops of the Belt quartzites to the southwest and the Madison Bluffs lies an area partially covered by lower Tertiary conglomerates (e. g., Beaverhead Formation) which contain large rounded clasts of Belt quartzites. Robinson (1963) states that the clasts of the older rounded gravel are well-rounded even at the margins of the basin, indicating considerable transport by the time they reached that point. Perhaps the quartzite cobbles of the older rounded gravel have as their immediate source the reworked lower Tertiary conglomerates such as the Beaverhead Formation which is 9700 $\pm$ feet thick in sections measured in Beaverhead County to the southwest (Lowell and Klepper, 1953).

Recent

ALLUVIUM

The flood plains of the Madison, West Gallatin, and Gallatin Rivers are covered with thick alluvial deposits, all of which were mapped as a single unit (Qra). The gravel of the West Gallatin and Gallatin Rivers can easily be distinguished in the field from that of the Madison River by the presence of large quantities of medium-brown, silicified wood which is abundant in the former and lacking in the latter. Other constituents of the gravels reflect a source within the valley and in the mountains to the south.

LOESS

The area is covered by a gray-brown silt which has some of the characteristics of loess. The silt was probably derived locally by the action of the wind blowing over the bare exposures of relatively soft Tertiary rock, perhaps during the Altamont interglacial stade. Although the material obscures the bedrock geology over large parts of the area it was not mapped.

STRUCTURAL GEOLOGY

The Three Forks basin is situated where the intricately deformed sedimentary and volcanic rocks of the Disturbed Belt along the Rocky Mountain front are faulted against the Precambrian rocks that make up the core of the Tobacco Root, Madison, Gallatin, and Beartooth Ranges (Robinson, 1961). The eastern boundary of the basin is linear along the frontal Bridger Range and Gallatin Range faults, and all other boundaries are sinuous and show little sign of structural control (see Generalized Structure Map, Pl. III).

East - West Trends

Although the general structure of the Tertiary sediments has been described by various workers as a relatively flat-lying sequence of sedimentary rocks with a regional dip of 2^{o} to 3^{o} to the east, closer inspection of the rocks in the field reveals major divergences from that trend. A number of broad open synclines and anticlines are evident in the area. Examination of the outcrops on the Madison Bluffs indicates that the strata are gently folded in a series of numerous broad open folds that are as much as two miles wide, but in which dips vary only 2^{o} to 3^{o} from the horizontal. The main trend of these folds seems to be east-west. Because of the low dips, the open nature of the folds, and the difficulty in determining their trends away from the Bluffs most of them were not put on the map.

In the Bluffs in the E ½ sec. 11, T. 1 N., R. 2 E. sediments of the lower unit dip gently below the surface of the Madison River flood plain in a syncline with an east-northeast trending axis. Sediments of the middle and upper units, though folded, appear to be less so than those of the unit below. A normal fault with a trend approximately parallel to that of the axis of the syncline and downthrown on the north side about two feet, can be seen in the outcrops of the Bluffs.

Just north of the Buffalo Jump, in the N ½ sec. 34, T. 1 N., R. 2 E., along the road a block of travertine-armored sandstone and siltstone of the lower unit more than a quarter mile long dips due south at 35°. This marks the location of the extension of the Willow Creek fault across the area. Subsurface data from the gravity and magnetic anomalies (Davis, and others, 1965) also indicate that the fault extends all the way across the area, though surface expression is not obvious except in the Bluffs.

North - South Trends

Along the west boundary of T. 1 S., R. 3 E. the dip of the strata is 2° to 3° to the west and a broad open syncline more than a mile wide is evident in the exposures of the sandstone of the upper part of the middle unit and the conglomerate of the lower part of the upper unit. In some of the broad open folds the channel-form conglomerate of the fluviatile deposits appear to have entrenched the under-

lying sediments more deeply in the trough of the synclines than at other structural locations.

Trending in a north-south line parallel to the Bluffs, and extending at least three miles north of the Buffalo Jump, is a normal fault downthrown as much as 200 feet on the west side. Although hard to see because it is in the plane-bedded sands of the middle unit, careful examination of the stratigraphic section indicates that a fault is present. At various locations along the fault where the conglomerate of the upper unit had deeply cut into the sands of the middle unit, small blocks of the conglomerate too small to map are preserved on the downthrown side of the fault. At one place the conspicuous ash marker-bed of the upper part of the middle unit is also repeated. The presence of the conglomerate of the upper unit on the downthrown side of the fault indicates that the faulting parallel to the Madison River occurred in post-middle Pliocene (?) time.

From the Generalized Structure Map (Plate III) it is evident that these faults and folds are associated with the regional pattern of structural weakness that was operative in the Precambrian and again very active in Laramide time. Evidence from within the area, as well as from the surrounding area, indicates that some of the faults have been active until the Pleistocene, and indeed, some of them have been active even in Recent time.

GEOLOGIC HISTORY

Early Cenozoic history of the Three Forks basin is described in these words by Hackett (1960):

> "After the deposition of Cretaceous sediments, tectonic activity related to the Laramide orogeny began. There seem to have been several phases of folding and faulting in the area, which culminated in late Paleocene time with major mountain building. Then followed a long period of erosion, during which sediments derived from surrounding mountain ranges and from contemporary vulcanism began to accumulate in basins which were probably formed by tectonic movements. Deposition continued into Oligocene time, and a few thousand feet of Tertiary sediments accumulated in the gradually sinking basins. At that time the area must have been characterized by gently sloping lowlands separated by moderately low mountains. From middle Oligocene to late Miocene time, in the vicinity of the Gallatin Valley at least, the drainage was exterior and erosion prevailed over deposition."

Rocks of the lowest part of the section on the east side of the Madison River indicate that the late Miocene landscape was characterized by through-running major streams with a transport direction toward the northeast. At intervals, this through-running drainage was interrupted by uplift along the frontal faults of the Bridger Range to the east (McMannis, 1955) which effectively blocked the drainage of the streams causing small lakes to form. As the basin continued to impound, the lakes increased in size until their level reached that of the threshold of the basin.

Overflow and downcutting at the northeast margin of the basin allowed the release of the impounded water and renewal of the through-

flowing drainage. Passes in the northern part of the Bridger Range may coincide with the position of these late Tertiary outlets. Three episodes of major ponding and re-establishment of the through-flowing drainage are recorded in the Miocene-Pliocene rocks of the Madison Bluffs. Variations in the distribution of the minor lake sediments within the sequence suggests that the tectonic patterns were not clear-cut events, but rather may have been gradual, at times punctuated by sharp movements.

The tectonic activity concomitant with the deposition of the middle unit of late Miocene age was accompanied by major volcanic events evidenced by numerous ash falls. Volcanism culminated near the end of the Miocene with the accumulation of a very thick sequence of ash beds indicating either a major episode of activity, or lesser activity in an area very near by. This volcanic activity was followed by downcutting which again opened the drainage of the basin and allowed the re-establishment of through-running streams in Pliocene time. The Pliocene (?) sediments also reflect a third episode of ponding and re-establishment of through-running streams.

The major structural movements along the Bridger Range were accompanied by down-dropping of the east side of the basin. The Tertiary sediments dip gently to the east and progressively higher and younger rocks off-lap on the east side of the basin (Robinson, 1963), indicating that it was being tilted toward the east throughout

Tertiary time. This tilting was also accompanied by minor folding of the rocks.

In post-middle Pliocene (?) time the surface of the basin was effectively beveled (McMannis, 1955) and the plain served as a surface of accumulation for the deposits of Pleistocene older rounded gravel. Distribution of the gravel over the area on both sides of the Madison River indicates that at that time the Madison River had not as yet effectively entrenched itself in its present valley. Five flights of terraces west of the river (Robinson, 1963) also indicate that the Madison River was an active agent of lateral planation in reaching its present position in the valley.

Down-faulting of the older rounded gravel on the north side of the Elk Creek fault, just south of the map area (see Generalized Structure Map, Pl. III), may be associated with the faulting that parallels the present Madison Valley and, in effect, may have provided structural control for the entrenchment of the Madison River in its present valley. It would appear, however, that the Madison River was actively downcutting and laterally planating the Pliocene (?) erosion surface before it was, in effect, caught in its present valley by the faulting. Further proof to support this contention must await additional field investigation both locally and on a regional basis.

The final episode in the history of the area is the northward tilting of the basin (Robinson, 1963) and capture of the drainage by

the Missouri River. This capture established the major drainage pattern as it is today. Concomitant with the capture was the glaciation of the Pleistocene, climatic conditions of which were the probable cause of the loess-like silt which is the youngest sediment deposited in the area aside from Recent alluvium.

While the major events of the post-middle Miocene geology have been worked out, details of the events in the area must await further investigation, some suggestions for which are given in the following section.

SUGGESTIONS FOR FURTHER RESEARCH

1. Sedimentary petrology of the fine-grained rocks
2. Heavy mineral analysis of the sandstone
3. Petrology of the andesites and dacites in the gravels
4. Non-opaque heavy mineral analysis
5. Carbonate petrology of the travertine and limestone
6. Analysis of the ash
7. Detailed paleocurrent study
8. Stratigraphic vertebrate paleontology
9. Diatom and ostracod analysis
10. Paleobotanical study of the wood and pollen analysis
11. Study of the source and distribution of the loess
12. Study of the regional distribution of the Qor
13. Geomorphic analysis
14. Structural studies of the metamorphic rocks
15. X-ray analysis of clays

REFERENCES CITED

Alden, W. C., 1953, Physiography and glacial geology of western Montana and adjacent areas: U. S. Geol. Survey Prof. Paper 231, 200 p.

*Calvert, W. R., 1912, The Livingston and Trail Creek coal fields, Park, Gallatin, and Sweetgrass Counties, Montana: U. S. Geol. Survey Bull. 471, Pl. 29.

Clabaugh, S. E., 1952, Corundum deposits of Montana: U. S. Geol. Survey Bull. 983, p. 58-77.

*Davis, W. E., Kinoshito, W. T., and Robinson, G. D., 1965, Bouguer gravity, aeromagnetic, and generalized geologic map of the eastern part of the Three Forks basin, Broadwater, Madison, and Gallatin Counties, Montana: U. S. Geol. Survey Geophysical Investigations Map GP-497, 1965

Dorr, J. A., Jr., 1956, Anceney local mammal fauna, latest Miocene, Madison Valley Formation: Journal of Paleontology, v. 3, p. 62-74.

Douglass, Earl, 1899, Neocene lake beds of western Montana and description of some new vertebrates from the Loup Fork: Master's thesis, June 1899, Montana State University, Missoula, Montana.

_____, 1903, New vertebrates from the Montana Tertiary: Pittsburgh, Pa., Carnegie Mus. Annals 2, p. 145-199.

_____, 1909, Description of a new species of Procamelus from the Upper Miocene of Montana, with notes upon Procamelus madisonius Douglass: Pittsburgh, Pa., Carnegie Mus. Annals 5, p. 159-165.

*Egbert, R. L., 1960, Geologic Map of the Madison Valley - Hebgen Lake southwestern Montana's in Billings Geol. Soc. Guidebook - 11th Annual Field Conference, 1960.

*Fix, P. F., 1940, Structure of Gallatin Valley, Montana: Unpublished Ph.D. dissertation, University of Colorado, Boulder, Colorado, 68 p.

* - denotes references used solely for compilation of Structure Map.

*Fraser, George D., Waldrop, Henry, and Hayden, Harold, 1969, Geology of the Gardiner area, Park County, Montana: U. S. Geol. Survey Bull. 1277, 118 p.

Glancy, Patrick A., 1964, Cenozoic Geology of the Southeast Part of the Gallatin Valley, Montana: Unpublished Master's thesis, Montana State University, Bozeman, Montana, 66 p.

Hackett, O. M., 1960, Geology and ground-water resources of the Gallatin Valley, Gallatin County, Montana: U. S. Geol. Survey Water-Supply Paper 1482, 282 p.

Hall, W. B., 1961, Geology of the Upper Gallatin Valley Area, Southwestern Montana: Unpublished Ph.D. dissertation, University of Wyoming, Laramie, Wyoming, 239 p.

Hayden, F. M., 1861, Sketch of the geology of the country about the headwaters of the Missouri and Yellowstone rivers: Am. Jour. Sci. Ser. 2, v. 31, p. 229-245.

_____, 1884, Report of Dr. F. V. Hayden to Director of the U. S. Geological Survey: U. S. Geological Survey - 6th Ann. Rept. 1884-1885, p. 48-53.

Klemme, H. D., 1949, Geology of Sixteenmile Creek area, Montana: Princeton University, Princeton, New Jersey, Ph.D. thesis (available on microfilm).

Kozak, S. J., 1961, Structural geology of the Cherry Creek basin area, Madison County, Montana: Unpublished Ph.D. thesis, University of Iowa, Iowa City, Iowa.

Kuenzi, W. D., 1966, Tertiary Stratigraphy in the Jefferson River Basin, Montana: Unpublished Ph.D. thesis, University of Montana, Missoula, Montana, 293 p.

Lowell, Wayne R. and Klepper, Montis R., 1953, Beaverhead Formation, a Laramide Deposit in Beaverhead County, Montana: U. S. Geol. Soc. America Bull., v. 64, p. 235-244.

*Mann, John A., 1960, Geology of part of the Gravelly Range area, Montana: in Billings Geol. Soc. Guidebook - 11th Annual Field Conference, 1960, p. 114-127.

Matthew, W. D., 1903, The fauna of the Titanotherium beds at Pipestone Springs, Montana: Am. Mus. Nat. Hist. Bull. 19, p. 197-226.

McMannis, W. J., 1955, Geology of the Bridger Range, Montana: Geol. Soc. America Bull., v. 66, p. 1385-1430.

_____, 1963, LaHood Formation -- a coarse facies of the Belt Series in southwestern Montana: Geol. Soc. America Bull., v. 74 p. 407-436.

_____, 1965, Resume of the depositional and structural history of western Montana: Am. Assoc. Petroleum Geologists Bull., v. 49, no. 11, p. 1801-1823.

_____, Unpublished work on the western Beartooth Mountains, Montana.

*_____, and Chadwick, R. A., 1964, Geology of the Garnet Mountain quadrangle, Gallatin County, Montana: Mont. Bur. of Mines Bull. 43, 47 p.

Mifflin, Martin D., June 1963, Geology of a Part of the Southern Margin of the Gallatin Valley, Southwest Montana: Master's thesis, Montana State University, Bozeman, Montana, 111 p.

*Montagne, J., and others, 1960, Preliminary Geomorphic Map of the Madison Valley, Montana: in Billings Geol. Soc. Guidebook - 11th Annual Field Conference, 1960.

Pardee, J. T., 1950, Late Cenozoic block faulting in western Montana: Geol. Soc. America Bull., v. 61, p. 359-406.

Peale, A. C., 1893, The Paleozoic section in the vicinity of Three Forks, Montana: U. S. Geol. Survey Bull. 110, p. 9-56.

_____, 1896, Description of the Three Forks quadrangle, Montana: U. S. Geol. Survey Geol. Atlas, Folio 24.

Reid, R. R., 1957, Bedrock geology of the north end of the Tobacco Root Mountains, Madison County, Montana: Mont. Bur. Mines & Geology, Mem. 36, 27 p.

_____, 1963, Metamorphic rocks of the Northern Tobacco Root Mountains, Madison County, Montana: Geol. Soc. America Bull., v. 74, p. 293-306.

*Roberts, A. E., 1964a, Geology of the Brisbin quadrangle, Montana: U. S. Geol. Survey, Geol. Quadrangle Map, GQ-256.

*_____, 1964b, Geology of the Chimney Rock quadrangle, Montana: U. S. Geol. Survey, Geol. Quadrangle Map, GQ-257.

*_____, 1964c, Geology of the Hoppers quadrangle, Montana: U. S. Geol. Survey, Geol. Quandrangle Map, GQ-258.

*_____, 1964d, Geology of the Livingston quadrangle, Montana: U. S. Geol. Survey, Geol. Quadrangle Map, GQ-259.

*_____, 1964e, Geologic Map of the Maxey Ridge quadrangle, Montana: U. S. Geol. Survey, Misc. Geol. Investigations Map, I-396.

*_____, 1964f, Geologic Map of the Fort Ellis quadrangle, Montana: U. S. Geol. Survey, Misc. Geol. Investigations Map, I-397.

*_____, 1964g, Geologic Map of the Mystic Lake quadrangle, Montana: U. S. Geol. Survey, Misc. Geol. Investigations Map, I-398.

*_____, 1964h, Geologic Map of the Bozeman Pass quadrangle, Montana: U. S. Geol. Survey, Misc. Geol. Investigations Map, I-399.

Robinson, G. D., 1961a, Middle Tertiary Unconformity in southwestern Montana: in U. S. Geol. Survey Prof. Paper 400-B, p. B-227-B-228.

_____, 1961b, Origin and Development of the Three Forks Basin, Montana: Geol. Soc. America Bull., v. 72, p. 1003-1014.

_____, 1963, Geology of the Three Forks quadrangle, Montana: U. S. Geol. Survey Prof. Paper 370, 143 p.

Schultz, C. B. and C. H. Falkenbach, 1940, Merycochoerinae, a new subfamily of oreodonts: Am. Mus. Nat. Hist. Bull., v. 77, p. 213-306.

_____, 1941, Ticholeptinae, a new subfamily of oreodonts: Am. Mus. Nat. Hist. Bull., v. 93, p. 1-105.

Schultz, C. B. and C. H. Falkenbach, 1949, Promerycochoerinae, a new subfamily of oreodonts: Am. Mus. Nat. Hist. Bull., v. 93, p. 69-198.

Skeels, D. C., 1939, Structural geology of the Trail Creek-Canyon Mountain area, Montana: Jour. Geol., v. 47, p. 816-840.

Tanner, J. J., 1949, Geology of the Castle Mountain area, Montana: Princeton University, Princeton, New Jersey, Ph.D. thesis (available on microfilm).

Tansley, Wilfred, P. A. Shafer, and L. H. Hart, 1933, A geological reconnaissance of the Tobacco Root Mountains, Madison County, Montana: Mont. Bur. of Mines and Geology Mem. 9, 36 p.

Verrall, Peter, 1955, Geology of the Horseshoe Hills area, Montana: Princeton University, Princeton, New Jersey, Ph.D. thesis (available on microfilm).

Weber, W. Mark, 1965, General geology and geomorphology of the Middle Creek area, Gallatin County, Montana: Montana State University, Bozeman, Montana, Unpublished Master's thesis, 86 p.

Wood, H. E., II, 1933, A fossil Rhinoceros (Diceratherium armatum) from Gallatin County, Montana: U. S. Nat. Mus. Proc., v. 82, p. 1-4.

_____, 1938, Continental Cenozoic at Three Forks, Montana: Abst. Geol. Soc. America Proc. 1937, p. 291-292.

_____, and others, 1941, Nomenclature and correlation of the North American continental Tertiary: Geol. Soc. America Bull., v. 52, p. 1-58.

APPENDIX

APPENDIX A

Partial Stratigraphic Section I

Measured in the bluff in the NE. 1/4, sec. 4., T. 1 N., R. 2 E., east and about 1/4 mile north of the Christiansen Ranch buildings. This is the lowest part of the section exposed on the east side of the Madison River.

MIDDLE UNIT

13. Sandstone, yellow; angular quartz grains, biotite, with clay matrix. Contact gradational and intertongues with beds below. This is the basal part of the "Anceney beds" of Dorr. Upper part of section not measured.

12. Channel deposits of great lateral extent; composed of sub-angular to sub-rounded clasts of andesite, quartzite, and some minor amounts of Paleozoic limestone. The top of the bed forms a prominent ledge cemented with calcite and containing travertine tubes up to 6' in diameter. Thickness variable, maximum..... 60'

Unconformity

LOWER UNIT

11. Sandstone, gray; medium-grained, andesitic, with a clay matrix. Contains some small lenses of clay and small conglomerate-filled channels..... 25'

10. Claystone, very light-gray; laminated. Upper part cut by white, medium-grained, angular quartz sandstone with a clay matrix. Claystone contains poorly preserved fish remains, Leuciscus turneri beds of Wood (1941)..... 2'

9. Sandstone, light-rust, calcareous; and travertine..... 1'

8. Claystone, gray; tuffaceous. Contains medium-grained, angular quartz sand..... 2'

Partial Stratigraphic Section I (continued)

7.	Bentonite, light-gray to gray-green	1'
6.	Claystone, gray; tuffaceous. Contains channels 1' - 2' thick with pebbles and cobbles of andesite, quartzite, and limestone	16'
5.	Travertine, forms a limy ledge	1'
4.	Claystone, gray-buff; contains a few sandy lenses, some slightly cross-bedded. One conspicuous green to white bentonite bed 3" thick about 7' from base	10'
3.	Sandstone, gray; andesitic, medium-grained, with clay matrix, interbedded with 1/2" - 1" local beds and lenses of buff clay. Sandstone coarser at base. Some small conglomerate-filled channels containing pebbles and cobbles of andesite, quartzite, and some minor amounts of Paleozoic limestone	6'
2.	Sandstone and claystone intertongued, gray. Sandstone is cross-bedded and channel-form, containing pebbles of andesite, quartzite, chert, and limestone in a calcareous clay matrix	6'
1.	Claystone, gray; tuffaceous. Contains minor medium-grained, angular quartz sand	10'
	Total	140'

Base covered with Madison River alluvium

All levels of this section contain tubes and lenses of TRAVERTINE

Partial Stratigraphic Section II

Numbers 4 - 9 measured in the SW 1/4 sec. 34, T. 1 N., R. 2 E., about 1/4 mile south of the Buffalo Jump, adjacent to the road. Numbers 1 - 3 measured in the SE 1/4 sec. 28, T. 1 N., R. 2 E., about 1/4 mile north of the Buffalo Jump on the west side of the road.

MIDDLE UNIT

9. Sandstone, yellow; angular quartz grains, biotite, with clay matrix. Contact gradational with beds below. Basal part of the "Anceney Beds". Upper part of the section not measured.

LOWER UNIT

8. Claystone, buff-white, weathers light rusty-red; tuffaceous. Becomes increasingly calcareous up section, top is a limestone ledge which can be traced to hotspring vents to the north..... 16'

7. Claystone, buff-white; tuffaceous, thinly bedded. Contains two 6" ash beds about 7' from the base, and small lenses of limestone..... 14'

6. Covered..... 25'

5. Sandstone, yellow to buff; angular quartz, biotite, with a clay matrix. Partially covered..... 6'

4. Siltstone, white; calcareous, laminated, flaggy. Contains abundant carbonaceous matter. Probably equivalent to the Leuciscus turneri beds exposed at about the same horizon to the north..... 2'

3. Claystone, gray; tuffaceous. Mostly covered..... 12'

Partial Stratigraphic Section II (continued)

2. Sandstone, gray, weathers brown; cross-bedded. Sand is poorly size-sorted, angular to sub-rounded quartz, feldspar, quartzite and andesite. Quartz is much more angular than the rock fragments. Some pebbles of andesite and quartzite, small amount of clay matrix. May correlate with Dunbar Creek section to west across the river..... 50'

1. Covered, Recent Madison River alluvium.

Total 125'

Partial Stratigraphic Section III

Section measured in the Bluff in the SE 1/4 sec. 4, T. 1 N., R. 2 E., due east of the Christiansen Ranch.

23. Loess and soil, medium gray..... 7'

UPPER UNIT

22. Sandstone, gray; cross-bedded, medium to coarse grained, conglomeratic in places..... 12'

21. Sandstone, siltstone, and conglomerate interbedded, gray; cross-bedded and channel-form. Sub-angular to sub-round quartz sand and silt, pebbles of quartzite, and andesite. Poorly developed sand crystals 6' from the base. Upper part is the horizon from which Serridentinus progressus was collected..... 68'

Unconformity

MIDDLE UNIT

20. Siltstone, light gray to gray-green; laminated, beds about 2' thick..... 16'

19. Sandstone, white; tuffaceous, medium to coarse, angular quartz in a clay - ash matrix..... 29'

18. Siltstone, yellow-white; laminated, beds up to 1' thick..... 5'

17. Siltstone, yellow-white; tuffaceous, laminated, convoluted bedding and slump structures..... 10'

16. Claystone, yellow-white; tuffaceous, lumpy, no apparent bedding. Partially covered..... 6'

15. Sandstone, gray-buff; tuffaceous, angular quartz grains and sub-angular to sub-rounded rock fragments, biotite, clay matrix. Mostly covered..... 23'

Partial Stratigraphic Section III (continued)

14. Sandstone, light gray-buff; tuffaceous. Contains carbonaceous material, dendrites, and possible fish material. Joints and fractures managanese stained. Bedding poorly developed, splits into uneven flags..... 2'

13. Sandstone, gray-buff; tuffaceous, iron-stained, with angular quartz grains, sub-angular to sub-rounded rock fragments, biotite, in a clay matrix. Thinly bedded, flaggy. Mostly covered..... 35'

12. Siltstone, light-buff; tuffaceous, quartz and biotite. Forms covered slopes..... 20'

LOWER UNIT

11. Sandstone gray; coarse angular quartz, black chert, and andesite fragments. Highly calcareous in places and contains much travertine. Travertine forms a ledge that can be traced 2 - 3 miles to the north and picked up farther to the south..... 2'

10. Siltstone, gray to gray-brown; fine-grained, angular quartz in a clay matrix. Contains some conglomerate lenses..... 8'

9. Sandstone and coarse to fine conglomerate; contains angular quartz grains, and angular to sub-rounded andesite, quartzite and Paleozoic limestone fragments in channels. Iron-stained in places..... 3'

8. Conglomerate, medium-tan; interbedded with coarse quartz sand. Conglomerate contains clasts up to 6" in diameter..... 3'

7. Sandstone and conglomerate interbedded, gray; pebbles of andesite and quartzite, a few gneiss pebbles and clay balls in an angular to sub-angular quartz silt and clay matrix..... 4'

6. Sandstone, clay, and siltstone interbedded, medium gray-brown. Clay exhibits contorted bedding, and slump structures. Silt and clay are laminated in places. Sand is medium to fine quartz in a calcareous clay matrix..... 11'

Partial Stratigraphic Section III (continued)

5.	Sandstone, light-gray to white; contains lenses and stringers of clay pellets up to 3" in diameter. Sand is angular to sub-rounded quartz grains in a calcareous clay matrix.....	13'
4.	Covered.....	15'
3.	Sandstone and conglomerate, white to gray; sand is sub-angular quartz and black chert. Conglomerate contains pebbles of andesite, quartzite, and some gneiss. This part of section also contains prominent travertine tubes.....	2'
2.	Siltstone, gray to gray-brown; fine-grained, angular quartz in a clay matrix, contains a few lenses of conglomerate composed of clasts of andesite, quartzite, and gneiss to 4" in diameter.....	2'
1.	Madison River alluvium.	
	Total	296'

Partial Stratigraphic Section IV

Section measured in the Bluffs in the SE. ¼ sec. 10, T. 1 N., R. 2 E., east of the road.

UPPER UNIT

13. Sandstone and conglomerate, gray; tuffaceous, calcareous matrix. Caprock of the Bluffs in the central part. Channel-form and cross-bedded..... 60'

12. Claystone, white to pink; tuffaceous. Bioturbite..... 25'

11. Sandstone and conglomerate interbedded, gray; angular quartz grains, and angular to sub-rounded andesite fragments poorly size-sorted. Pebbles of andesite, quartzite, and gneiss, and Paleozoic limestone. Irregular lenses and beds of sand-crystals which have maximum dimensions of ¼"..... 70'

Unconformity

MIDDLE UNIT

10. Sandstone, yellow; angular to sub-rounded, medium-grained quartz sand, biotite, clay matrix. Partially covered..... 18'

9. Claystone, siltstone, and sandstone interbedded, yellow. Claystone laminated and contains clastic dikes of sand up to 3" wide. Sandstone is coarse, angular quartz with clay matrix. Partially covered..... 25'

8. Sandstone, white; angular to sub-angular, coarse quartz sand containing poorly preserved ostracods. Forms a ledge..... 1'

7. Claystone, white; tuffaceous. Mostly covered..... 17'

6. Ash, gray; fresh. In places resistant enough to form a ledge.. 2'

5. Sandstone, siltstone, and ash interbedded, yellow to white; quartz sandstone interbedded with tuffaceous claystone and thin beds of fresh, glassy ash. Siltstone cut in places by clastic dikes..... 11'

4. Covered..... 7'

Partial Stratigraphic Section IV (continued)

3.	Claystone, yellow; tuffaceous. Mostly covered.....	2'
2.	Sandstone, yellow; angular to sub-angular, medium-grained quartz, biotite, in a clay matrix.....	26'
1.	Covered, gentle slope to road level.....	9'
	Total	263'

Partial Stratigraphic Section V

Section measured in the Bluffs in the SE. ¼ sec. 15, and the S.E. ¼ sec. 14, T. 1 N., R. 2 E., east of the road.

UPPER UNIT

6. Conglomerate and sandstone, gray; contains pebbles and cobbles of andesite, quartzite, and lesser amounts of gneiss, and Paleozoic limestone. Sandstone consists of angular to sub-rounded coarse-to medium-grained quartz in a calcareous, clay matrix containing some glass shards. Forms caprock of the Bluffs. Maximum thickness..... 50'

5. Claystone, gray to pink; tuffaceous..... 40'

Unconformity

MIDDLE UNIT

4. Sandstone, siltstone, claystone interbedded, yellow to white; contains beds to 6" of fresh, gray ash. Partially covered..... 30'

3. Ash, white to gray; forms a resistant ledge. Partially covered..... 1'

2. Sandstone and siltstone interbedded, yellow to white; medium-grained, angular quartz, biotite, minor amounts of rounded rock fragments in a clay matrix. Cross-bedded in places. Base covered..... 25'

1. Covered, Madison River alluvium.

Total 146'

Partial Stratigraphic Section VI

Section measured in the Bluffs in the NE. ¼ sec. 3, and the S.W. ¼ sec. 2, T. 1 N., R. 2 E., about ¼ mile south of the Jorgenson Ranch house, east of the road.

HIGH TERRACE DEPOSIT

14. Loess and soil, medium-gray.

13. Conglomerate, ranges from clasts 6" downward. Cobbles and pebbles of Belt Quartzite, andesite, some gneiss, and Paleozoic limestone. Equivalent to the Qor of Robinson west of the Madison River. Conglomerate spills over Bluffs and partially covers section below. Estimated thickness..... 25'

UPPER UNIT

12. Claystone and sandstone interbedded, gray to buff; claystone silty, locally finely laminated in beds to 1' thick. Sandstone composed of medium-grained, angular quartz in a clay matrix, locally cross-bedded. Sandstone contains lenses of conglomerate with pebbles of quartzite andesite, gneiss and some Paleozoic limestone. Most covered ...130'

11. Claystone, buff; tuffaceous, silty, interbedded with 2" - 6" lenses of yellow to gray, cross-bedded sandstone composed of rounded fragments of andesite, and angular quartz with a clay matrix. Scattered outcrops, mostly covered..... 32'

10. Covered..... 20'

9. Claystone, gray; contains clay balls up to ¼" in diameter. Contains carbonaceous dendrites, may be a paleosol..... 10'

8. Conglomerate, gray; channel-form, consists of sub-rounded pebbles of andesite, quartzite, gneiss, and Paleozoic limestone, in a slightly calcareous matrix. Interbedded with buff to gray siltstone, claystone, and containing clay balls up to 6" in diameter. Forms the caprock of the lower Bluffs..... 50'

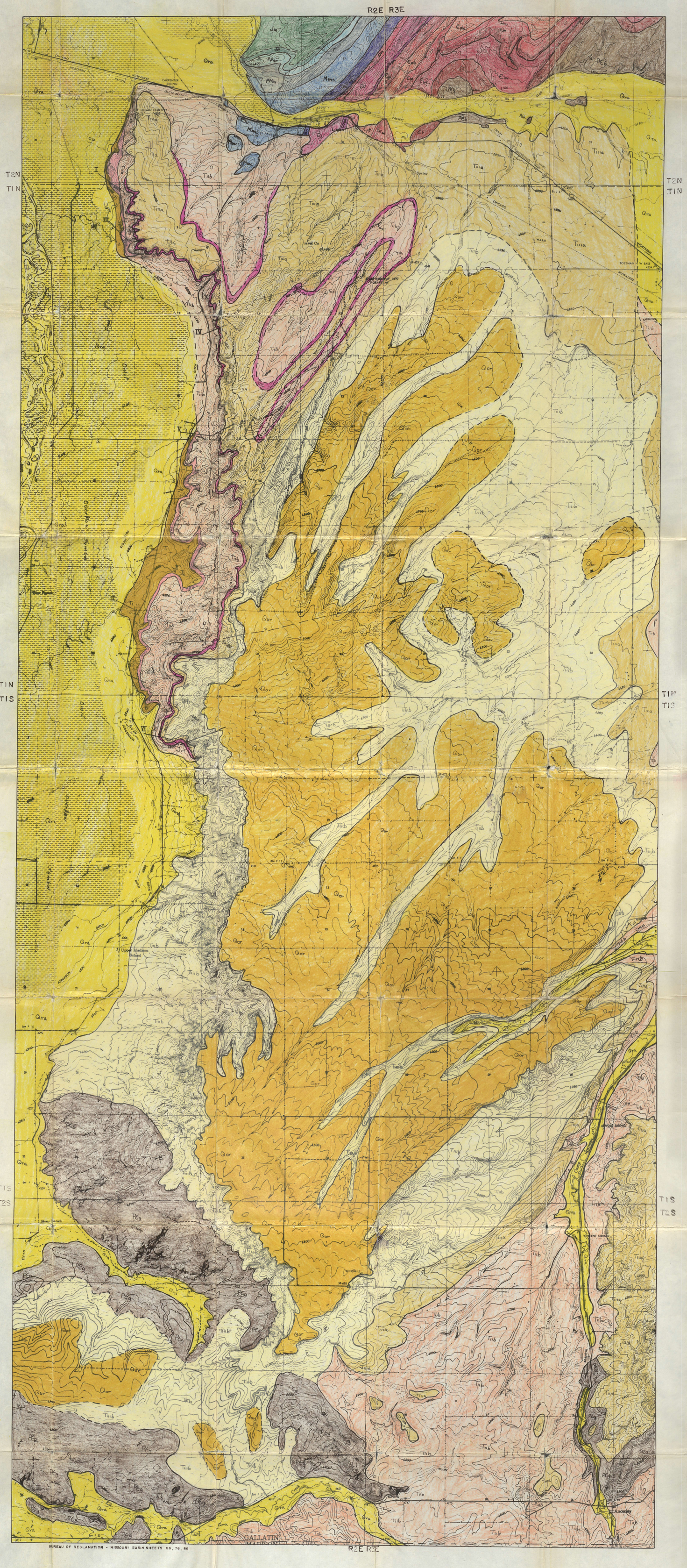
Partial Stratigraphic Section VI (continued)

MIDDLE UNIT

7.	Claystone, buff; silty and sandy in places	8'
6.	Sandstone, gray; fine, well-rounded andesite fragments, fine, angular quartz grains in a clay matrix. Convolute bedding, and slump structures. Partly covered	15'
5.	Sandstone, yellow; medium-grained, angular quartz sand in a clay matrix, contains a few bone chips on the surface of slopes	35'
4.	Ash, gray; fresh with slump structures, convolute bedding, and ripple-marks at the base	10'
3.	Claystone, yellow; laminated, contains ostracods	5'
2.	Sandstone, yellow; tuffaceous, medium-grained, angular quartz grains, biotite, with a clay matrix. Interbedded with ash	160'
1.	Covered to road level	30'
	Total	530'

MADISON BLUFFS AREA

PLATE I



LEGEND

SCALE 1/24000

5000 0 2000 4000 6000 8000 10,000 FEET

CONTOUR INTERVAL 20 FEET

CENOZOIC	QUATERNARY		RECENT ALLUVIUM — Qra
			OLDER ROUNDED GRAVEL — Qor
			UNCONFORMITY
	TERTIARY	PLIOCENE (?)	SANDSTONE, SILT- & CLAYSTONE — Tmb
		MIOCENE-PLIOCENE	CHANNEL-FORM CGL. & SANDSTONE — Tma — UNIT III
			UNCONFORMITY
			LAKE BEDS — Tmc
			TUFFACEOUS CLAYSTONE & SS., ASH — Tmb — UNIT II
			TRAVERTINE — Tma
			UNCONFORMITY
		MIOCENE	SS., CGL., & TUFFACEOUS CLAYSTONE — Ti — UNIT I
MESOZOIC	JURASSIC		MORRISON FORMATION — Jm
			ELLIS GROUP — Je
	MISS.-PENN. PERMO-PENN.		QUADRANT & PHOSPHORIA FMS. — PPqp
			AMSDEN FORMATION — PMa
	MISSISIPPIAN		MISSION CANYON LIMESTONE — Mmc
			LODGEPOLE LIMESTONE — Mml
PALEOZOIC	DEVONIAN		THREE FORKS & SAPPINGTON FMS. — Dts
			JEFFERSON DOLOMITE — Dj
	CAMB.-DEV.		SNOWY RANGE & MAYWOOD FMS. — CDsm
	CAMBRIAN		PILGRIM LIMESTONE — Cpl
			PARK SHALE — Cpk
			MEAGHER LIMESTONE — Cm
			WOLSEY SHALE — Cw
			FLATHEAD FORMATION — Cf
PRE-CAMBRIAN			BELT SUPERGROUP — PCb
			PRE-CAMBRIAN GNEISS — PCg

STRIKE AND DIP

CONTACT

CONCEALED CONTACT

MEASURED SECTION

HIGH ANGLE FAULT

CONCEALED FAULT

ANTICLINE

SYNCLINE

BUREAU OF RECLAMATION - MISSOURI BASIN SHEETS 66, 76, 86

GEOLOGY OF THE MADISON BLUFFS AREA

GALLATIN COUNTY, MONTANA

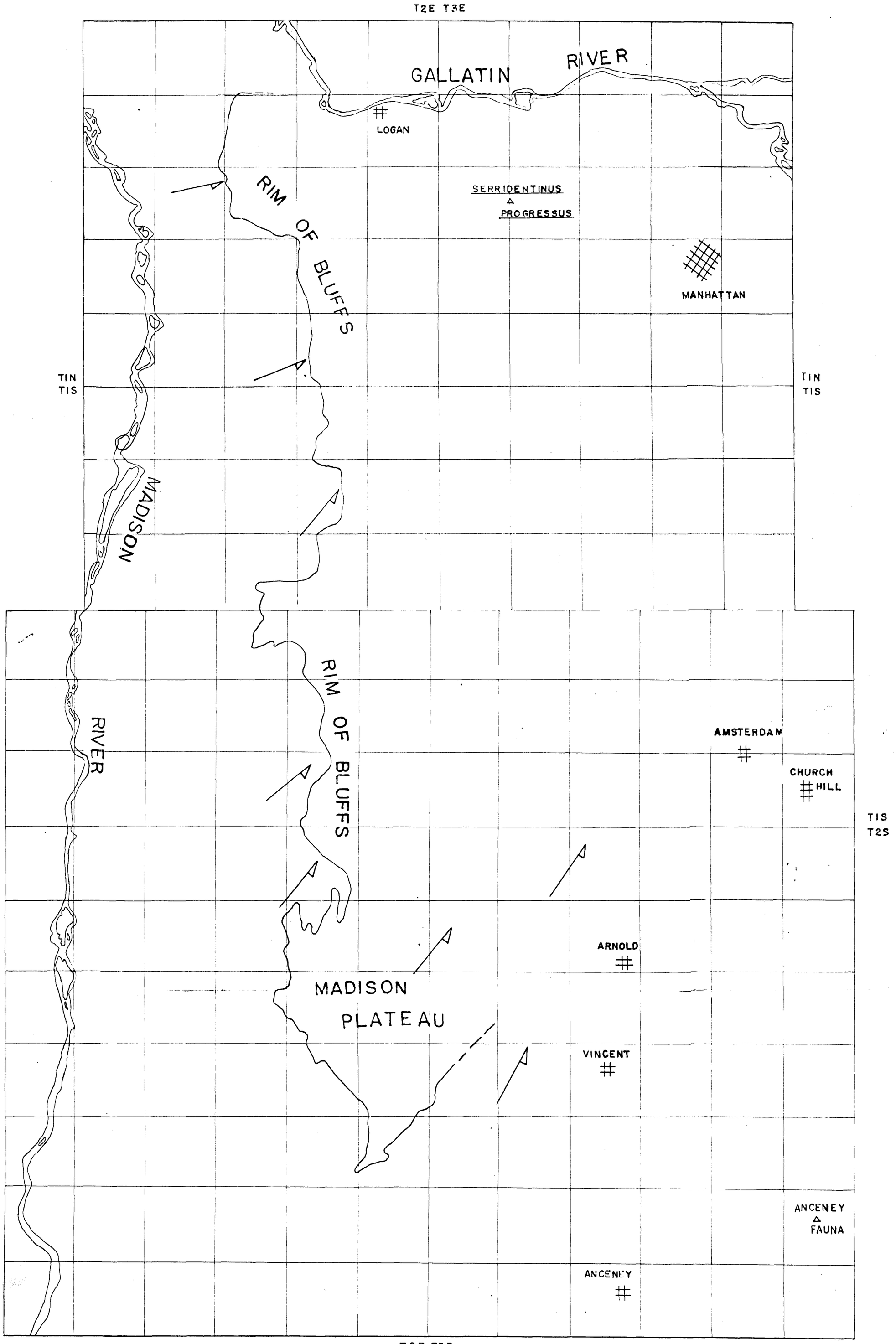
GARY B. SCHNEIDER JUNE 1970

PRESENTED TO THE FACULTY OF THE DEPARTMENT OF EARTH SCIENCES, IN PARTIAL FULFILLMENT OF REQUIREMENTS FOR THE MASTER OF SCIENCE DEGREE AT MONTANA STATE UNIVERSITY, BOZEMAN

N378
Sch57

MADISON BLUFFS

PLATE II



PRELIMINARY PALEOCURRENT MAP

MADISON BLUFFS AREA, GALLATIN COUNTY, MONTANA

GARY B. SCHNEIDER JUNE 1970

0 1 2 3

— GENERALIZED CURRENT DIRECTION

NORRIS – MADISON BLUFFS

PLATE III

GENERALIZED STRUCTURE, SOUTH-CENTRAL MONTANA

SYLVIA H. FEICHTINGER GARY B. SCHNEIDER JUNE 1970

0 5 10 15 20

NORMAL FAULT — THRUST FAULT — ANTICLINE — SYNCLINE

SCALE 1 : 250, 000

BOZEMAN, MONTANA; WYOMING

N378
Sch 57

MONTANA STATE UNIVERSITY LIBRARIES
3 1762 10015446 5