Quaternary geology of the east portion of West Fork Basin, Gallatin County, Montana
by Thelma Helaine Walsh

A thesis submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE in Earth Sciences (Geology)
Montana State University

Abstract:
The purpose of this study was to map the geology of a portion of West Fork basin and adjacent drainages to the north and south. Description and depositional history of Cenozoic deposits were emphasized. Attention was given to the relationships between these deposits and the construction accompanying the large recreational complex being developed in the area.

Exposures in the map area consist primarily of Precambrian gneiss and schist, Paleozoic limestones, Mesozoic sandstones and shales, and Cenozoic high level river gravels, rhyolitic welded tuff, Wisconsin till, and outwash gravels. Andesitic intrusions are common throughout the Cretaceous section.

River gravels located near the mouth of Michener Creek approximately 450 feet above the present day West Gallatin River rest unconformably on Cretaceous sandstones and shales and are considered to be remnant of a former "West Fork". A faint imbricate structure indicates transport direction to the east. These gravels are overlain by a rhyolitic, ash-flow, welded tuff. This tuff is the cap rock for many of the earthflows within the map area.

The Cretaceous sandstones, shales, and claystones overlying the Kootenai Formation are weak, nonresistant units susceptible to various types of mass-gravity movements. Earthflow is the primary type of mass-gravity phenomena. The earthflows are commonly over one-half mile wide and one mile long. They display slump movement at the slide head and hummocky topography in the middle and toe portions. The earthflows are relatively stable under present climatic conditions. However, fresh piles of rock debris are evidence of recent movement in the source areas.

South Fork drainage is the source area for the West Fork plain outwash gravels. The heads of South Fork and its tributaries, Muddy and First, Second, and Third Yellow Mule, creeks, were,probably extensively glaciated during the Bull Lake glacial stade. North Fork Bull Lake moraines rest on the floor of West Fork basin near the junction of North and Middle Forks.

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Date June 1, 1971

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TABLE OF CONTENTS

LIST OF PLATES AND FIGURES

ABSTRACT

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INTRODUCTION

Location, Size, and Access

The lower West Fork basin study area covers twenty-four square miles, west of the West Gallatin River and south of the Spanish Peaks, on the east flank of the Madison Range, Gallatin County, Montana, (Figure 1). It is forty-three miles south of Bozeman, and approximately forty-nine miles north of West Yellowstone along U. S. route 191, which connects these two towns. The highway follows the valley of the West Gallatin River which forms the east margin of the study area. Forest Service and county gravel roads provide limited access.

Topographic - Geographic Setting

The area studied includes a northwest-trending structural and topographic basin and a portion of the adjacent highlands to the north. The most prominent topographic feature is a great hogback of limestone, locally known as Dudley Ridge, with a maximum elevation of 9,410 feet. To the south of Dudley Ridge is an arcuate plain which grades from an elevation of 6,500 feet at its upper western end to 5,980 feet at its lower end. The most imposing landmark as viewed from West Fork basin is Lone Mountain, a pyramidal peak approximately five miles west of the study area. It rises to an elevation of 11,166 feet and retains partial snow cover through much of the year. The southern half of the study area slopes gently northeast from Buck Creek Ridge, a prominent topographic and structural landmark which approximately parallels Dudley Ridge some ten miles to the south.

Total relief within the immediate area is slightly greater than 3,400 feet. Part of the area north of West Fork is characterized by moderate to steep mountain slopes with partial forest cover. The area south of West Fork is somewhat dissected with moderate relief and dense forest cover.

Major Drainages

The major drainage of the map area is West Fork, an eastward flowing tributary of West Gallatin River, (Figure 2). West Fork has three main tributaries, South Fork, Middle Fork and North Fork. These streams head west of the map area near the Madison-Gallatin drainage divide. The largest of these tributaries is South Fork which itself is fed by four major northward flowing drainages, Muddy Creek, and First, Second, and Third Yellow Mule creeks. All of these head south and west of the map area on the north side of Buck Creek Ridge. Beaver Creek heads farther east along Buck Creek Ridge and flows into West Gallatin River. Part of the area between Beaver Creek and South Fork is drained by Michener Creek, a short eastward flowing tributary to West Gallatin River.

Nomenclature of West Fork Tributaries

The naming of West Fork and its source streams has inconsistencies which lead to considerable confusion when the several streams are discussed unless the peculiarities are known. Therefore, it is necessary to explain the relationships of streams in the basin to each other.

The name West Fork is appended to a medium-sized tributary to the West Gallatin River, (Figure 2). From the mouth of West Fork upstream to the confluence of its first real tributary, South Fork, is a distance of one mile. At this point the confusion is generated because South Fork is obviously not a tributary but the main stream, and the northerly fork should be designated North Fork and not West Fork as it is. To add to the confusion, this "main stream" continues another two and one-half miles westerly to the mouth of a still smaller tributary from the north, called North Fork. The south branch is called the Middle Fork (of the West Fork of the West Gallatin River).

The reader as well as the field investigator must recognize that, despite the names, the "South Fork" is the major drainage of West Fork basin - in terms of length, area drained, and volume of water and sediment load. Evidence supporting this observation has been gathered by Botz and Van Voast (written communication, 1971) by measuring the stream flow of South, Middle, and North Forks. Measurements taken on August 2, 1970 show the volume of North and Middle Forks combined as 47.12 cubic feet per second and the volume of South Fork as 52.84 cfs. The results of measurements taken on February 25, 1971, are similar, the volume of North and Middle Forks 7.85 cfs and that of South Fork 11.86 cfs. Other stream flow data obtained through the autumn of 1970 and early winter of 1971 also indicates that South Fork is the major drainage of the area.

Vegetation and Vegetational Distribution

The vegetation of West Fork Basin includes a discontinuous forest cover, scattered groves of trees, and relatively untimbered rangeland. References used in identification of the taxa are Booth (1950) and Booth and Wright (1959). The major tree taxa of the upland forests are *Picea engelmannii* (Engelmann spruce), *Pseudotsuga menziesii* (Douglas "fir"), *Abies lasiocarpa* (Sub-alpine fir), and *Pinus contorta* (Lodgepole pine). Major trees of the riparian communities are *Populus tremuloides* (Quaking aspen), *Salix* (Willow) spp., and *Populus trichocarpa* (Western cottonwood). Grove trees include *Pinus flexilis* (Limber pine), *Pinus albicaulis* (Whitebark pine), *Juniperus scopulorum* (Rocky Mountain juniper), and *Populus tremuloides* (Quaking aspen). One of the major components of the understory in the groves is Juniperus communis (Common juniper).

The untimbered rangeland is characterized by a mosaic of shrub dominated areas interspersed with grass and forb covered tracts. The dominant shrubs are Artemisia tridentata (Big sagebrush) and Potentilla fruticosa (Shrubby cinquefoil). Conspicuous grasses include Festuca idahoensis (Idaho fescue), Poa (Bluegrass) spp., and Agropyron (Wheatgrass) spp.

The most abundant tree of the upland forest is Pinus contorta, which in number exceeds Picea and Pseudotsuga. Pinus contorta is considered a seral species to Picea and Pseudotsuga, replacing those taxa following a fire or other disturbance. In the area of study Pinus contorta is so widespread and the effects of disturbance so repetitive that it has achieved a long-term relatively self-perpetuating status.

In this area, where both Pinus albicaulis and Pinus flexilis are present, they do not generally occur together. Timberline in the area averages about 9,600 feet, but will vary as much as 200 feet higher or lower depending upon aspect and microclimatic factors. Pinus albicaulis is a true sub-alpine tree, often in great mature stands from about 8,400 to 9,400 feet elevation, with a nearly exclusive ground cover of Vaccinium scoparium (Low red huckleberry). By contrast Pinus flexilis in this area is a low- to middle-elevation tree, common from 6,500 to 7,500 feet, and very uncommon above 8,000 feet. It seldom comprises the main taxon of a large stand.

Several geologic units habitually are barren of trees but support a cover of Festuca Idahoensis, Poa spp., and Agropyron spp. with an overstory of Artemisia tridentata and Potentilla fruticosa. Very few trees grow upon the outwash gravel terraces or upon the siliceous shale (porcellanite) units of the Albino Formation and the un-named similar layers in the Upper Cretaceous sequence.

Purpose and Scope

This report presents the results of a study of the surficial geology of the eastern portion of West Fork basin and the directly adjacent drainages both to the north and south. The general distribution of stratigraphic units and structure were mapped only where they helped in understanding the geomorphic features of the region.

An effort has been made to determine the Quaternary history of the area through analysis of Tertiary-Quaternary deposits and present-day landforms. The major geologic features used in reconstructing the history were:

1) The minor amounts of glacial and relatively large amounts of glacio-fluvatile deposits within West Fork basin and the adjacent drainage to the north;

2) The elaborate system of river terraces as they have developed in West Fork basin and along Beaver Creek and the West

Gallatin River;

3) The very large and almost ubiquitous mass-gravity deposits;

4) The upper reaches of the valleys which head high on the north side of Buck Creek Ridge, that were probably extensively glaciated during the Pleistocene;

5) The Quaternary or late Tertiary welded tuff that is considered to be part of the Crown Butte ash flow tuff sequence described by Hall (1961);

6) The Tertiary river gravel preserved beneath the welded tuffs in the Michener Creek area, within three-quarters of a mile of the present West Gallatin River, but 400 feet higher.

An attempt has been made to describe the components of the forest communities, their features, and their usual geographic position in West Fork basin. The type of vegetation has been correlated with the underlying bedrock, insofar as possible.

Previous Work

Early exploration of the Upper Gallatin region was summarized in detail by Hall (1961). Between 1883 and 1889, A. C. Peale of the U. S. Geological Survey mapped the general geology of the Three Forks quadrangle. This was the first important study made of the geology of the Gallatin drainage (Peale, 1896).

Two recent works relied upon by the author are the open file report "Geology of Part of the Virginia City and Eldridge Quadrangles, Montana" (Swanson, 1950) and the unpublished work of W. B. Hall (1961) detailing the general geology and the stratigraphy of the Upper Gallatin Valley directly south of West Fork basin.

Other general geologic literature utilized includes "Geology of the Garnet Mountain Quadrangle, Gallatin County, Montana" (McMannis and Chadwick, 1964), "Environmental Geology of part of the West Fork Basin, Gallatin County, Montana" (Kehew, 1970), "Geology of the Lone Mountain Area, southwestern Montana" (Bolm, 1969), and the unpublished thesis material of C. Montagne (1971).

Method of Study

Approximately seven weeks were spent in the field during August and September of 1970, plus several weekends during the fall of the same year.

The geology was mapped on vertical airphotos (U. S. Forest Service contract E10, 1962) at a nominal scale 1:15,840, and a computed valley floor scale of 1:18,100. Original map compilation was upon preliminary 1:24,000 scale topographic map sheets, produced for the U. S. Geological Survey during preparation of the Sphinx Mountain and Spanish Peaks 15-minute topographic quadrangle maps. It became apparent after careful comparison of the 1:15,840 scale airphotos with the 1:24,000 scale preliminary topographic map sheets that the maps were so inaccurate in so many details which were visible on the airphotos, that the possibility of precise transfer of geologic data to the base maps was very limited. This situation was further demonstrated when the attempt was made to project the airphoto images by Salzman projector onto the topographic base. Both the survey network and the topographic contours are in error in numerous places, and there is no way of checking for the magnitude or direction of error in most instances. For this reason it was necessary to transfer all geologic information from airphotos to the topographic base by inspection.

A paleomagnetic study of the welded tuffs in the area was attempted. However, due to the highly fractured nature of the exposures and the amount of time that would be necessary, this aspect of the study was not continued. It is possible that with sufficient time and adequate equipment such a study of the Quaternary (Tertiary) volcanics (Crown Butte ash flow sequence) throughout the Gallatin drainage would be of considerable interest and would facilitate an understanding of the history of vulcanism in this region.

STRATIGRAPHY

The study area includes a portion of an asymmetrical synclinal basin trending N 60 W. The syncline is characterized by gentle dips (6-10° N) on the southwest flank and steep, in places overturned, dips on the northeast flank. Hall (1961) refers to this synclinal basin as the Lower Basin syncline. This usage is continued by the writer in this report.

Lower Basin syncline contains more than 4,000 feet of sedimentary strata ranging in age from Cambrian to Cretaceous. All units except the Upper Jurassic Morrison Formation and some of the Cretaceous are considered marine in origin. Unconformities record the many depositional breaks. As previously mapped (Swanson, 1950), units from all Paleozoic and Mesozoic geologic periods except the Silurian are present. However, McMannis and Chadwick (1964) believe that the section mapped as Ordovician by Swanson (1950) is actually part of the Cambrian. The writer has concurred with the latter concept for the purposes of this paper.

Late Tertiary or early Pleistocene river gravels and welded tuffs rest unconformably on Cretaceous sandstones and shales at elevations 450 feet to 950 feet above the present day West Gallatin River. These units form the cap rocks of many of the earthflows within the map area.

Precambrian rocks are exposed north of the Spanish Peaks fault.

These are probably metasediments, pre-Belt in age (McMannis and Chadwick, 1964).

The description of the strata through the Mesozoic is a composite from previous works, particularly Hall (1961), McMannis and Chadwick (1964), and Becraft and others (1966). Descriptions of Tertiary gravels, Quaternary (Tertiary) welded tuffs, and igneous intrusions are based on field investigation and thin section studies by the writer.

Precambrian

Precambrian gneisses and schists compose nearly all the area north of Spanish Peaks fault to the Squaw Creek fault, (Figure 3). The dominant rock types of the Precambrian within the map area are granitic gneisses and schists, with amphibolite and quartzite lenses and veins. Becraft and others (1966) describe the granitic gneisses as consisting principally of quartz, plagioclase, potassium feldspar, biotite, hornblende, and muscovite. The common types of schist are amphibole-biotite-quartz, muscovite-biotite-quartz, garnet-biotite-quartz, amphibole-feldspar, and muscovite-biotite-feldspar.

Paleozoic

Cambrian

Within the study area the Cambrian can be divided into three main units, the Meagher Limestone, Park Shale, and Pilgrim Limestone.

Both the Flathead Sandstone and the Wolsey Shale are absent due to faulting.

The Meagher Limestone of Middle Cambrian age is the lowermost stratigraphic unit within the map area. It is 449 feet thick as measured by McMannis and Chadwick (1964) at Garnet Mountain some twenty miles north of the study area. This unit is adjacent to the Spanish Peaks fault near the mouth of Dudley Creek. The Meagher forms a great limestone cliff above Dudley Creek on the south valley wall. It is a dense, grey, yellow-mottled, thin-bedded to massive limestone. The mottles are fine-grained silty limestone found in a dense finely crystalline, relatively pure limestone. Glauconite is common in the upper beds.

The Park Formation rests conformably on the Meagher Limestone. This unit appears as a grey-green, fissile, micaceous shale. Interbeds of calcareous siltstone and limestone are present. The Park is nonresistant and has few good exposures, but its thickness has been measured in the study area as 175 feet by McMannis and Chadwick (1964).

The Pilgrim is some 170 feet thick (McMannis and Chadwick, 1964) and similar to the Meacher except for dolomitization. It is a greyish-brown to brown dolomite; fine to medium saccharoidal, dense, massively bedded, and ledge-forming. Various beds in the Pilgrim are glauconitic, oolitic, and fossiliferous. The Pilgrim is irregularly mottled and has many shale partings. According to McMannis and Chadwick (1964) the Pilgrim in the area of Dudley Creek is thinner than in areas to the north and northeast. This is attributed to erosion of the Pilgrim and younger Cambrian beds prior to deposition of overlying Devonian strata.

Devonian

Ordovician and Silurian strata are missing in this area. The Ordovician as mapped by Swanson (1950) is here considered to be part of the Pilgrim Limestone.

The Jefferson Formation lies disconformably on the Pilgrim. This unit is some 400 feet thick (McMannis and Chadwick, 1964) and comprised of medium-bedded to massive, grey and brown dolomite. Some dolomitic limestone, limestone, and shaly limestone are present. A few beds have a strong petroliferous odor. Both Amphipora and Stromatopora are common.

The Three Forks Formation conformably overlies the Jefferson. The unit consists of massive dolomite, thin-bedded dolomite with shale partings, grey-brown and yellow-brown calcareous siltstone, mudstone, and sandy limestone. A calcareous, fine-grained sandstone is present at the contact with the Mississippian Lodgepole Limestone. These upper siltstone and sandstone units have been called the Sappington Member. They have been included in the Devonian strata for mapping purposes. However, the faunal boundary separating the Devonian and Mississippian strata is probably midway in the Sappington (Gutschick and others, 1962; Sandberg, 1965). As mapped at Dudley Creek by McMannis and Chadwick (1964) the Three Forks Formation is approximately 135 feet thick.

Mississippian

The Mississippian strata within the study area are the Lodgepole and Mission Canyon limestones of the Madison Group. The Lodgepole has been considered by Weller and others (1948) as Kinderhookian and early Osagian. The Mission Canyon is Osagian. These carbonates rest disconformably on the Sappington Member of the Three Forks Formation. They are of marine origin and in places it is not easy to distinquish between the two.

The Lodgepole is a grey-brown, thin- to medium-bedded, finely crystalline limestone with interbeds of argillaceous limestone or calcarious siltstone. In places the Lodgepole is oolitic, fossiliferous, and chert bearing. The argillaceous interbeds are yellow-grey to yellow-brown, fine-grained and commonly fossiliferous. Thickness of the Lodgepole is approximately 575 feet (McMannis and Chadwick, 1964).

The Mission Canyon along with the Lodgepole forms the crest of the prominent hogback within the map area, Dudley Ridge. This unit measures about 650 feet in thickness (McMannis and Chadwick, 1964) and consists of grey to brown, medium-bedded to massive, fine to coarsely crystalline dolomite, dolomitic limestone, and limestone.

The Mission Canyon Limestone weathers to rubbly outcrops with obscure bedding planes. Some solution breccias are present in the upper beds.

Pennsylvanian

The Amsden Formation is Early Pennsylvanian age and is extremely variable in thickness, ranging from zero to greater than 200 feet. Within the map area this unit is difficult to distinquish from the underlying Mission Canyon. However, the characteristic reddish outcrops, although quite thin in the study area, are easily seen just to the east, directly across the West Gallatin River. The Amsden consists of yellow-grey, thin- to thick-bedded, medium- to coarse-grained dolarenite; pale-grey to white, dense, thin- to medium-bedded dolomite; grey-brown, fine-grained, medium-bedded to massive, fossiliferous limestone; purplish-red, dense, dolomitic mudstone; and argillaceous dolomite. There is some green and red flaky dolomitic shale.

The Quadrant Formation consists of all the sandstones, limestones, and gradations between sandstone and limestone overlying the Amsden and underlying the Permian Phosphoria. This formation measures 205 feet in thickness (McMannis and Chadwick, 1964). The Quadrant includes white to cream colored, medium- to thick-bedded, cross-bedded, fine to medium-grained quartz sandstone. In the lower portion of the formation are medium-bedded light colored crystalline limestones and calcarenites. These grade upward to sandy limestones, limy sandstones, and other quartzites.

Permian

The Phosphoria Formation rests disconformably on the upper Quadrant Formation and consists of 119 feet (McMannis and Chadwick, 1964) of grey to yellow-brown nodular chert, grey-brown, medium-grained, thick-bedded quartzite and yellow-brown silicified siltstone interbedded with chert. The quartzite beds contain numerous tubular burrows. The phosphate content of this formation in the Upper Gallatin region is of no economic significance. The Phosphoria is disconformably overlain by the Dinwoody Formation of Triassic age.

Mesozoic

The Triassic formations and the Jurassic Ellis Group of the Mesozoic strata are of marine origin whereas the latest Jurassic Morrison Formation is non-marine. Some 9,000 feet of Cretaceous strata (not all present within the map area) is composed of fine normal and volcanic clastics. The Mesozoic rock types are dominantly mudstone, shale, and tuffaceous sandstone, in contrast to the Paleozoic marine carbonate sequence.

Triassic

Two hundred sixty-five feet of the Triassic Dinwoody Formation is exposed in the map area but is absent in the Squaw Creek area to the north, (McMannis and Chadwick, 1964). In the West Fork area the exposures are poor. Most of the formation is covered; boundaries are determined by float. The Dinwoody rests conformably on the underlying Phosphoria (Kummel, 1954), and consists of dark to light brown, thick-bedded, sandy limestone and calcareous siltstone. Linguloid brachiopods are present locally.

Jurassic

The Ellis Group is of marine origin and includes the Sawtooth, Rierdon, and Swift formations. The Ellis Group is 570 feet in the map area (McMannis and Chadwick, 1964). The basal unit is the Sawtooth of Middle Jurassic age which rests disconformably on the Dinwoody. This lowermost unit includes argillaceous limestones and calcareous shales. The upper beds include yellow-brown, calcareous sandstone, sandy limestone, and silty shale. Fossils are abundant, especially in the upper half of the formation.

The Rierdon Formation is Middle to Late Jurrassic in age and rests conformably on the Sawtooth. In the map area the Rierdon is a dominantly mudstone, shale, and tuffaceous sandstone, in contrast to the Paleozoic marine carbonate sequence.

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The Rierdon Formation is Middle to Late Jurrassic in age and rests conformably on the Sawtooth. In the map area the Rierdon is a ledge forming oolitic limestone. The limestone is impure, argillaceous and silty.

The Swift Formation consists of glauconitic sandstones and shales. This unit is of Late Jurassic age and rests disconformably on the Rierdon. The sandstones are yellow-brown to greenish-grey, calcareous, thin- to meidum-bedded, cross-bedded, ripplemarked, fine- to medium-grained. Sporadic conglomeratic zones contain pebbles consisting mainly of chert. Fossils are common.

The Morrison Formation overlies the Ellis Group and is an uppermost Jurassic non-marine unit. The formation is 335 feet thick (McMannis and Chadwick, 1964) and consists of terrestial claystones and sandstones that conformably rest on the marine Swift. Imlay (1952) considers the Morrison to be Kimmeridgian (middle Upper Jurassic). The claystones are non-calcareous, green, grey, olive, or red. These are interbedded with laterally discontinuous sandstones. The lower Morrison is dominated by reds, yellows, and greens, while the upper beds are dull colored.

Cretaceous

The Cretaceous sequence consists of more than 9,000 feet of predominantly non-marine strata. The Kootenai and Thermopolis formations constitute the Lower Cretaceous. The Upper Cretaceous is a sequence of shales, claystones, and some sandstones that have not been studied in detail.

The Lower Cretaceous Kootenai Formation consists of fresh water conglomerate, claystone, limestone, and sandstone. The lowest of the units is a basal conglomeratic sandstone. The sandstone is fine to coarse-grained, thick and cross-bedded. The pebbles are of chert, quartzite, and limestone. Within the study area, coarse irregular blocks of Kootenai sandstone conglomerate form large talus slopes which in places cover the prominent source ledge.

The middle unit of the Kootenai is composed of yellow-brown to maroon mudstone and shale, limy siltstone, and fresh water limestone. The limestones occur in two zones approximately 50 and 100 feet above the basal sandstone and contain numerous steinkerns and shells of gastropods. Sandstone comprising the upper unit of the Kootenai is a well-sorted quartz arenite. This unit weathers to a dark red-brown and commonly forms a prominent ledge or bench at the top of the Kootenai slope. The Kootenai Formation as measured by McMannis and Chadwick (1964) is 412 feet thick. This formation is considered Aptian in age (Cobban and Reeside, 1952).

The Thermopolis Formation conformably overlies the Kootenai Formation in West Fork basin and areas adjacent to the south. Bolm (1969) measured 195 feet of Thermopolis in West Fork basin. In places to the south of West Fork basin the formation is more than 350 feet thick (Hall, 1961). The Thermopolis Formation consists of an un-named basal shale member overlain by the Muddy Sandstone Member. The shale member is medium to dark grey, very fissile, carbonaceous shale and intercalated irregularly bedded siltstone. This member is considered to be the brackish water equivalent of the marine Thermopolis shale of Wyoming. Overlying the basal shale member are 80 feet (Bolm, 1969) of greyish-green to buff colored sandstone called the Muddy Sandstone Member. Lithologically this sandstone is cross-bedded, medium-bedded, fine- to medium grained, poorly sorted, and has discontinuous lenses of olive to greenish-grey claystone and shale. The Muddy weathers to a dirty yellow color. Excellent exposures of the Thermopolis Formation and other Creteceous units are found along South Fork east of Ousel Falls.

The Albino Shale rests with apparent conformity atop the Muddy Sandstone Member of the Thermopolis Formation. Bolm (1969) has measured 160 feet of Albino. This unit is non-resistant and poorly exposed. The Albino consists of claystone, bentonite, shale, siliceous ash, and tuff. Siliceous shales, ash, and tuff are white to pink or bright red. These beds predominate in the Upper Albino and are fossiliferous (ferns, leaves, and wood).

Conformably overlying the Albino Shale is more than 1,400 feet (Bolm, 1969), of undifferentiated sandstone and shale of Late Cretaceous age. A conglomerate in the lower unit of Late Cretaceous age is composed of sandstone and chert pebbles in a sandy matrix.

The pebbles are resistant to weathering but are stained red by iron oxide. The sandstone consists of fine- to medium, subangular grains of quartz and chert. Biotite is present in some sandstone units, and there is some interstitial fine silt and clay. The beds of Late Cretaceous age are probably equivalent to the upper part of the Colorado Group.

Tertiary

No sedimentary rocks of Tertiary age are present in the study area, with the possible exception of a river gravel some 400 feet above the present day West Gallatin River near the north of Michener Creek. To the south of West Fork basin Tertiary materials are present. They are of terriginous and volcanic clastic sedimentary rocks. Gravels, similar topographically to these, occur in numerous places throughout the Upper Gallatin Valley preserved beneath volcanic rocks. The volcanics flowed into the lower portions of the stream channels, represented by these gravels. The thickness of the gravel in the study area was determined on the basis of float to be between 80 and 100 feet. These gravels, called the Michener Creek gravels, consist of moderately coarse, well-rounded clasts of gneisses and schists, several varieties of igneous rocks, and sandstones. Andesite clasts constitute approximately one half of the gravel material. Basaltic material comprises only a minor portion of the gravels. Where exposed, this high level river gravel displays an imbricate structure indicating transport direction to the east.

IGNEOUS AND VOLCANIC ROCKS

Andesitic dikes and sills occur throughout the West Fork basin area. Some of these intrusions are part of a laccolithic complex located some five miles west of the study area. The andesites associated with this intrusive body, centered around Lone Mountain, are acidic in composition. Other more basic andesites occur along the same northwest trend as do the major structural features of the area, (Figure 3).

Late Cenozoic and early Pleistocene welded tuff caps the Tertiary river gravel near the mouth of Michener Creek. These tuffs are equivalent to the Crown Butte ash flow sequence of the Upper Gallatin Valley mapped by Hall (1961).

Lone Mountain Laccolith

A large multiple-horizon laccolithic complex (Hall, 1961) is located five miles west of the study area. This complex centers around Lone Mountain but includes Fan, Cedar, and Pioneer mountains. Andesite is the dominant rock type. Igneous rocks from the intrusive complex have been transported into the study area; they constitute the majority of clasts in the glacial outwash of West Fork basin and the high-level Tertiary river gravels near the mouth of Michener Creek. Sills and dikes project from the center of the intrusive complex into the surrounding country rock. The variety of rock types could indicate that each of the peaks was an intrusive center.

In hand specimen the rocks appear to be porphyritic andesite, grey to tan in color with phenocrysts of plagioclase and hornblende. Megascopically, the variation in andesites appears to be due to the difference in size and number of phenocrysts.

Thin sections were made of two varieties of andesite found in the West Fork outwash gravels. In addition, one sample from Lone Mountain was studied. Twinned green hornblende along with twinned and zoned plagioclase are the dominant phenocryst in each of the andesites. Minor amounts of potash feldspar were also found in each. Sparse quartz phenocrysts are present in the sample from Lone Mountain and in one specimen from the outwash gravel. Dark brown biotite is present in all three specimens, but the amount varies from one to six percent. All of the andesites have a cryptocrystalline matrix. The specimen from Lone Mountain displays flow alignment of the matrix around the phenocrysts. Secondary chlorite and clay minerals have formed by alteration and replacement of the hornblende and biotite. Magnetite and hematite are also present as alteration material. All three of the samples are considered to be acidic andesites. However, a chemical analysis of two of the samples might reveal sufficient normative quartz to permit classification as dacite.

Age of the Lone Mountain laccolith has not been determined; no detailed analysis of the complex has been worked out. Swanson (1950) suggests that intrusion of the andesite porphyry occurred at approximately the time the Spanish Peaks fault and associated structures were developing. Hall (1961) postulates the intrusives to be post-Paleocene and pre-Eocene; dikes of similar andesite intrude the Livingston Formation considered to be Paleocene to the south of the study area. Bolm, (1969) considers the emplacement to be post-Eocene, following the formation of Lower Basin syncline. Without further study no exact age can be appended to the Lone Mountain laccolith.

Other Intrusives

Sills ranging from five feet to over eighty feet thick occur in the Cretaceous sequence stratigraphically above the Kootenai Formation. These sills appear to trend in approximately the same direction as the major synclinal and anticlinal structures of the north end of the Upper Gallatin region, N 60 W. Compositionally these rocks are highly weathered andesites, now mostly unconsolidated, that appear dark yellow-brown at the surface. These units are best exposed along South Fork on the south margin of West Fork basin.

Thin sections show that the ferromagnesian minerals have been so altered that only pseudomorphs of the original crystals remain. The original mineral was probably hornblende; hydrous mica and clay now replace it. The plagioclase crystals are twinned and display clay alteration rims. Secondary calcite is present in one biotite-bearing intrusive. All samples contain sparse magnetite and hematite. These sills lack quartz and potash feldspar in contrast to the Lone Mountain intrusive. One sample of a highly weathered intrusive body along Middle Fork contains perlite. The glass comprises approximately ninety percent of the sample. The rock contains phenocrysts of plagioclase, quartz, and hornblende and about two percent hematite, magnetite and limenite.

Chadwick (1970) discusses the Spanish Peaks fault as a portion of the Western Absaroka belt, one of two northwest-trending belts of eruptive centers across southwestern Montana. Sills and stocks commonly intrude the eruptive centers along the northwest trends. Basaltic necks located at the head of Porcupine Creek to the southeast of the study area in secs. 29 and 32, T. 7 S., R. 5 E. are discussed by Hall (1961). If the linear trend associated with the volcanic necks is projected, the Western Absaroka belt continues northwestward to coincide with the Spanish Peaks fault. Several sills and dikes similar in composition to the andesitic Gallatin volcanics parallel this fault (Becraft and others, 1966). The fault zone and associated intrusives have been extended northwestward across the Madison Valley by Andretta and Alsup (1960) and Reid (1957). These intrusives, like those of the Lone Mountain laccolith, probably represent activity in the Late Cretaceous and early Tertiary, while flows spread over the Gallatin and possibly Madison ranges from the many eruptive centers.

Volcanics

Near the mouth of Michener Creek and westward for approximately two miles rhyolitic welded tuff crops out. These tuffs are considered by Christiansen (oral communication, 1970) to be part of the two million year old Huckleberry Ridge Member of the Yellowstone Tuff sequence. They occur in irregularly distributed patches throughout the Upper Gallatin Valley and are called the Crown Butte ash-flow sequence by Hall (1961). Within the study area the welded tuff unconformably caps the gently inclined Cretaceous rocks on the southwest flank of Lower Basin syncline. Areas occupied by volcanics are characterized by a relatively smooth flat surface. In the study area the lowest elevation of the tuff is at 6,500 feet and the highest is approximately 7,000 feet. This rise is over a distance of 1,000 feet horizontally. Therefore the average dip of the tuff is about three degrees. No decision was reached concerning the portion of the dip that is primary and the portion due to deformation. In places the tuff overlies the Tertiary river gravels previously discussed.

The contact of the welded tuffs with the Tertiary river gravels is a chill zone consisting of a slightly granular, crumbly, medium- to light grey to pink non-solidified ash layer. This zone appears as a smooth blocky surface and is everywhere less than one foot thick. Above this zone is about 150 feet of pink to grey, porphyritic, conglomeratic, vitric, rhyolitic welded tuff. The groundmass of the tuff is glass dust. The rock contains phenocrysts of sanidine, quartz, biotite, and sparse clino- and orthopyroxene. Glass shards constitute about five percent of the rock. Tuff and pumice fragments occur as inclusions.

STRUCTURAL SETTING

The regional structural relationships of the Upper Gallatin Valley have been discussed by Hall (1961). Portions of his work are useful in understanding the geomorphic history of the study area.

The Lower Basin syncline lies on the southwest side of the Spanish Peaks fault block. The Spanish Peaks fault can be traced to Ennis Lake on the west and to the head of Porcupine Creek on the east where it passes under volcanics dated as Eocene (McMannis and Chadwick, 1964), (Figure 3). Swanson (1950) considered the Spanish Peaks fault to be the northwest extension of the Gardiner thrust fault mapped by Wilson (1934). Chadwick (1970) considers the Spanish Peaks fault to be in line with the Western Absaroka belt of eruptives extending across southwestern Montana into Wyoming. This major structural feature is a high angle reverse fault on which Precambrian crystalline rocks are thrust southward over steeply dipping to overturned sedimentary rocks of Lower Basin syncline. Strata forming the syncline range in age from Cambrian to Late Cretaceous. Steeply dipping carbonate layers on the north flank of the syncline form a hogback ridge which locally attains an elevation greater than 9,000 feet.

The minimum stratigraphic displacement or relief of the Precambrian surface on the fault is about 9,000 feet. The amount of structural relief due to folding before faulting developed cannot be determined. In secs. 29 and 32, T. 6 S., R. 4 E. normal fault trends almost perpendicular to the Spanish Peaks fault, (Plate I).

A sharply asymmetrical anticline with a steep southwestern limb is located south of the map area. The axial trend of this fold is parallel to that of Lower Basin syncline. The two structures probably formed simultaneously. Wilsey (unpublished field notes, 1848, supplied by W. B. Hall) named this fold the Buck Creek anticline, and Hall (1961) continued its usage.

On the southwest flank of Lower Basin syncline, near the mouth of Beaver Creek, faulting has developed in the Cretaceous section above the Kootenai. Proper interpretation of the structural relations in this area depends largely on the correct identification of the various Cretaceous sandstones and shales. Plate I represents relationships based on the units as identified.

Conventional geologic structure symbols have been used in preparing Plate I. However, a thin line has been used to show major fracture zones which have no observable displacement, or faults on which the relative movement could not be determined. These lines of weakness have affected the topography, particularly the drainage patterns and the position of mass-gravity movements, and add to the overall understanding of the regional pattern of deformation.

Study of the geomorphic and structural features of the lower part of West Fork basin, especially as interpreted on airphotos, strongly suggests that at least the lower mile of West Fork has followed a fault trace which trends almost due east, diagonally across the upturned beds at the east end of Dudley Ridge. This postulated fault has not been indicated on the surficial geology map because bedrock is everywhere buried beneath outwash gravels, except perhaps beyond the map area to the east of West Gallatin River. If such a fault is present, and if one assumes it extends due westward under the valley gravels and landslide deposits, it would align perfectly with an anomalous east-west cliff on the south side of Flatiron Mountain. Kehew (1970) considers this steep slope to be the headwall scarp of a landslide (block-glide type) in a synclinal depression.

To the north and east of the study area, Eocene volcanics are present in the Gallatin Range to elevations greater than 9,000 feet. McMannis and Chadwick (1964) indicate that the volcanic flows and breccias buried the pre-existing topography and the Gallatin River established its present course on the relatively flat volcanic surface. Since Eocene time there has been modification of relief by southeastward tilting and warping due to regional uplift and normal faulting on the northwest and southeast borders of the Gallatin Range. Therefore, the present position of the Gallatin River is due to both superposition and antecedence. If one assumes that the volcanic terrain extended west into the Madison Range (Becraft, and others, 1966), the cross-cutting relation of West Fork could also be viewed as one of superposition. Several remnants of these volcanics are present high on the east end of the Spanish Peaks, but apparently there is no remnant in West Fork basin or the highlands directly adjacent.

SURFICIAL UNITS

Chronology and Terminology

Charles Lyell in 1839 applied the word "Pleistocene" to the "most recent" epoch of geological history. Presently, Pleistocene is considered to be part of the Quaternary, an epoch characterized by repeated glaciations of certain areas of the earth's surface. Ericson and Wallin (1964) and Oakley (1964) have tentatively placed the beginning of the world-wide Pleistocene Epoch at not less than 800,000 and possibly 1.5 to 2 million years before present. In the Yellowstone Park area Christiansen (oral communication, 1970) places the 2 million year old Huckleberry Ridge Member of the Yellowstone Tuffs in the Quaternary.

During the Pleistocene there were four to five principal glaciations each of which may have included three to four separate cold stades with minor interstadials. The last of these glaciations is the Wisconsin, divided in this region into the Bull Lake and Pinedale glacial stades (Blackwelder, 1923). Drift deposits from Bull Lake and Pinedale stades and from more recent glacial events are considered to represent time since the end of the last major interglacial. Both the Bull Lake and Pinedale stades were compound (more than one phase). The Pinedale in places was followed by camparatively late minor glacial readvances.

As discussed by Hall (1960a) the Madison Range shows evidence of Bull Lake, Pinedale, and more recent glaciation as well as possible pre-Wisconsin glaciation. Elevation, lithologic material, morphology, position, soils, artifacts, and ash layers are all criteria upon which glacial deposits are dated. Within the study area soils, morphology, position, lithology, and elevation were used for age determinations of the glacial deposits. Within the Yellowstone Park area, recent work by Richmond (1970) seems to indicate that the Bull Lake extended from approximately 110,000 to 70,000 years before present. The post-Bull Lake and pre-Pinedale interstadial is considered to have lasted from 70,000 to 25,000 years b.p. Pinedale glaciation was initiated approximately 25,000 years ago, reaching its peak about 18,000 to 15,000 years before present. The bgeinning of the post-Pinedale interval is thought to have been about 11,000 years b.p.

Evidence in the mapped area documents at least three distinct episodes of alpine glaciation during Wisconsin time. At present they are assigned to one Pinedale and two Bull Lake stades. The higher portions of the Madison and Gallatin Ranges display strong evidence for at least one episode of pre-Wisconsin glaciation of sufficient magnitude to form an ice cap over most of the lower valley divides, leaving only the highest portion of the range protruding (Hall, 1960a). Higher ridges adjacent to the mapped area also show deposits of till much higher and farther upvalley than the youngest recognized Pinedale depostis. These are younger than Pinedale, are viewed as post-Altithermal, and are equivalent to the Gannet Peak-Temple Lake neoglacial event of other Rocky Mountain areas (C. Montagne, oral communication, 1970).

The classification of glacial landforms in the map area is based on the descriptions of typical forms given by Flint (1957). A summary of the terms used as defined by Flint is as follows:

1) Valley glaciers are streams of ice that flow downward through valleys in highlands. The term valley glacier is synonymous with mountain glacier and alpine glacier.
2) Drift is a term used collectively for glacial deposits.
3) A moraine is an accumulation of drift having a constructional topographic expression in detail that is independent of the surface underneath it, and having been built by the direct action of glacier ice.
4) A Terminal moraine is a ridge-like accumulation of drift built along the downstream or terminal margin of a glacier lobe occupying a valley.
5) Any terminal moraine built along the lateral margin of any glacier lobe occupying a valley is a lateral moraine.
6) A kame terrace is an accumulation of stratified drift laid down chiefly by streams between a glacier and adjacent

valley wall and left as a constructional terrace after disappearance of the glacier.

7) Outwash is pro-glacial drift stream-built deposits found beyond the toe of the glacier.

In the following paragraphs the surficial deposits will be described by drainage basins rather than by landform categories for all basins. Mass-gravity phenomena are here omitted from discussion, but are considered in a separate section of the study.

Dudley Creek Drainage Basin

Within Dudley Creek valley, a narrow glacial trough, evidence for at least three glaciations is present. Amphitheater shaped depressions east of Wilson Peak (Figure 7) were the gathering basins for the valley glaciers. The floors of the cirques are approximately 9,200 feet in elevation. Early Wisconsin, or possibly pre-Wisconsin, till is located on a Meagher limestone shoulder at the mouth of Dudley Creek. This deposit appears quite fresh but lacks hummocky topography. The morphology is that of a slightly flattened bench-like surface with enormous boulders.

Bull Lake glacial deposits are present along the eastward flowing portion of Dudley Creek. Moraines and ice-marginal kame terraces are present. The terminal moraine has a crescentic form and displays subdued drumlinois topography. Kame terraces rise on the south

Figure 5. Glaciated trough of Dudley Creek.

Figure 6. North Fork Bull Lake moraine resting on West Fork plain, ice-marginal channel in foreground.

side of the valley from the margin of the Bull Lake terminal to an elevation 500 feet above the valley floor. The kame terraces are morphologically distinctive only in that they have a flattened bench-like upper surface. Both the morainal forms and the kame terraces are densely tembered. Till deposits located down-valley from the Bull Lake terminal moraine are considered to have their source in an amphitheater structure in the Deer Creek drainage basin adjacent to Dudley Creek on the north. From careful study of aerial photographs and from field evidence a possible spillover ice-fall can be postulated, flowing southwest from the cirque in Deer Creek drainage into Dudley Creek. Evidence supporting such an ice-fall is the position of the till deposits (oblique to the present valley floor) and erratics located in a topographic swale between the cirque-like depression and Dudley Creek.

The only Pinedale glacial deposit within the map area is a morainal form in NW 1/4, sec. 19, T. 6 S., R. 4 E. This terminal moraine is fresh in appearance, has hummocky topography and little soil development.

At the mouth of Dudley Creek there is a small deposit of glacial outwash, unsorted gravels of Precambrian material in a matrix of unconsolidated silt and sand. This outwash appears to be concordant with and therefore probably the same age as the Bull Lake moraines.

North Fork Drainage Basin

North Fork at present flows southeastward from a cirque located approximately three miles to the north and west of the map area. This cirque, Bear Basin, was the major source of ice for North Fork during the Bull Lake and Pinedale glacial stades. The only glacial deposits derived from North Fork that lie within the map area are high moraines of Bull Lake age. These Bull Lake lateral moraines consist of more than one hundred feet of material, including clasts of Precambrian gneiss, schist, and quartzite with some Paleozoic limestone. The laterals are located some two miles downstream from the Pinedale moraines (C. Montagne, oral communication, 1971). What is thought to be an ice-marginal channel cuts through the moraine on the north side of North Fork. This meltwater channel trends southeasterly across the moraine and joins the lower end of Crail Creek (Plate I).

Crail Creek fan is directly east of the North Fork Bull Lake moraines. This landform is mapped as a Quaternary alluvial fan. Examination of a soil pit excavated in this feature suggest that Crail Creek "fan" is reworked till, or fan-form moraine, developed by modification of the Bull Lake terminal moraine, which extended out onto West Fork basin floor. The pit was approximately seven feet deep. The material in the upper five feet shows some alignment and sorting, whereas the material in the lower portion of the pit is unsorted, rounded Precambrian cobbles and boulders in a clay and silt matirx. The "fan" is partially mantled by float and colluvium derived from the adjacent Dudley Ridge to the north. The fan-like morphology was probably achieved during the Bull Lake wet post-glacial period. The Bull Lake terminal rests on the basin floor. The frontal end of the moraine has a terrace-like form due to late meltwater planation and subsequent (Pinedale or later) trimming back of the flattened morainal toe by West Fork.

South Fork Drainage Basin

Till deposits are present at the western-most end of the West Fork plain. These deposits display little morainal morphology and have been modified by mass-gravity movements. The soil development is to a depth of 23 inches, greater than that found by C. Montagne (oral communication, 1971) in Pinedale deposits of North and Middle Forks. Approximately eighty percent of the morainal material is andesitic, faceted, rounded to subangular cobbles. The non-andesitic components all appear to be lithologies typical of or recognizable in the Cretaceous section. The source area for the andesitic materials is the laccolithic multiple-sill complex developed about the four intrusive centers, Cedar, Fan, Pioneer, and Lone Mountains some three miles west of the study area. Within these intrusives there are distinct variations in composition and texture of the andesite (percent and size of plagioclase and hornblende phenocrysts). The mineralogy of the andesite discussed in greater detail in the section of this report on igneous rocks. The different lithologies are represented in the glacial and fluvio-glacial deposits in West Fork basin.

A soil pit was dug in the Bull Lake moraine at the western-most end of West Fork plain. Weathering of the andesitic materials is extensive. All the near surface cobbles had thick clayey weathering rinds, or were so deeply weathered that they would crumble upon application of even slight pressure. The deep weathering has increased the clay content of the soil, as further demonstrated by its sticky, plastic nature. A soil profile of this deposit is given below.

Date: August 22, 1970
Soil Type: Michel cobbly loam
Area: West Fork of the West Gallatin River
Location: On hill-top back of Michel Ranch
Natural vegetation: Big sagebrush, Blue grass, Bromes, and annual and perennial forbs
Parent material: Andesite and some sandstone till
Physiography: Glacial till, Bull Lake age
Relief: Normal
Elevation: 6,600 feet
Slope: Three percent
Erosion: Slight
Permeability: Moderate
Drainage: Well drained
Ground water: Deep
Salt or alkali: None
Stoniness: None on surface to class 1.

Typifying Pedon: Michelson cobbly loam

(Colors are for dry soil unless otherwise noted)

A1	0 - 7"	Dark grayish brown (10 YR 4/2) cobbly loam, very dark brown (10 YR 2/2) moist; weak coarse granular separating to strong fine granular structure; slightly hard, friable, nonsticky and nonplastic; noncalcareous; clear smooth boundary.
B21	7 - 13"	Light brownish grey (10 YR 6/2) cobbly clay, dark grayish brown (10 YR 4/2, 4/3 crushed) moist; strong fine subangular blocky structure; hard, firm, sticky and plastic; noncalcareous; clear wavy boundary.
B2t	13 - 23"	Dark grayish brown (10 YR 4/2) moist; clay; strong medium prismatic separating to strong subangular blocky structure; extremely hard, very firm, very sticky and very plastic; noncalcareous; prisms occur in vertical and slanted positions; gradual wavy boundary.
C1	23" +	Colors are the same except there is an increase in yellows; clay; extremely hard, very firm, very sticky and very plastic; noncalcareous; andesite cobbles and stones occur below 23 inches which are highly weathered or rotten; exfoliation is apparent, and there appears to be weathering in place from andesite to clay in the contact zone between the andesite rock and clay matirx; slickensides occur immediately below the prisms in the B2t horizon.

The deposits of Bull Lake till resting on the apex of West Fork outwash plain are so minor as to give little indication of the amount of ice that must have flowed eastward from the heads of South Fork and its subsidiary drainages. South Fork heads in a cirque on the east side of Cedar Mountain (Figure 2). Its tributaries are

Muddy Creek and First, Second, and Third Yellow Mule creeks; all of which head in amphitheater-shaped depressions on the northeast flank of Buck Creek Ridge. Figure 7 is a conservative interpretation of the distribution of Bull Lake ice tongues which furnished till and outwash materials to West Fork basin. The hypothetical distribution of glaciers in Figure 7 is derived by delineating glacial features on air photos when apparent in the various drainages. Pinedale ice may have accumulated in some of the same basins, but its extent if present has not in all cases been determined.

Although the writer feels that there is strong evidence in support of extensive glaciation of South Fork, it should be noted that the ubiquitous mass-gravity features have altered the glacial landscape so that little or no deposits with glacial morphology are seen. Since the Yellow Mule drainages are outside the study area, sufficient time was not spent in the field to accurately determine the extent of the glaciation. Detailed mapping of the area is needed before any more than a postulation can be presented.

Evidence for possible glaciation along South Fork and its tributaries are:

1) Till deposits located directly north of the Michel Ranch, sec. 2, T. 7 S., R. 3 E., and near Ousel Falls;
2) West Fork basin valley fill with apex in South Fork drainage has characteristics of outwash;

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3) South Fork heads in a cirque on the east side of Cedar Mountain at an elevation of 9,400 feet;

4) Amphitheater shaped heads of Yellow Mule and Muddy creeks exist on the north flank of Buck Creek Ridge at elevations 8,400 to 9,200 feet;

5) Interlocking spurs do not occur in the Yellow Mule and Muddy Creek drainages (single streams in great concave valleys);

6) Subangular faceted andesitic cobbles and stones characteristic of glacial drift are found at approximately 7,200 feet on the north side of South Fork one and one-half miles west of Ousel Falls.

A northeastward sloping, arcuate, gravel, fan-form outwash plain mantles the Cretaceous units in West Fork basin. The apex of this outwash is located near Ousel Falls, and its thickness is approximately fifteen feet as determined from exposures along South Fork. Braided stream patterns formed while active deposition was in progress are still present on West Fork plain. Andesitic pebbles and cobbles are the major components of the gravel. Cobbles of quartz sandstone from the Kootenai Formation are numerous, while the remaining Cretaceous units are only nominally represented. The matrix of the outwash is composed of sand, silt, and clay size particles. Clay lenses occur as ribbon-like features below the gravel surface.

Figure 8. Flattened toe of North Fork Bull Lake moraine resting on West Fork plain.

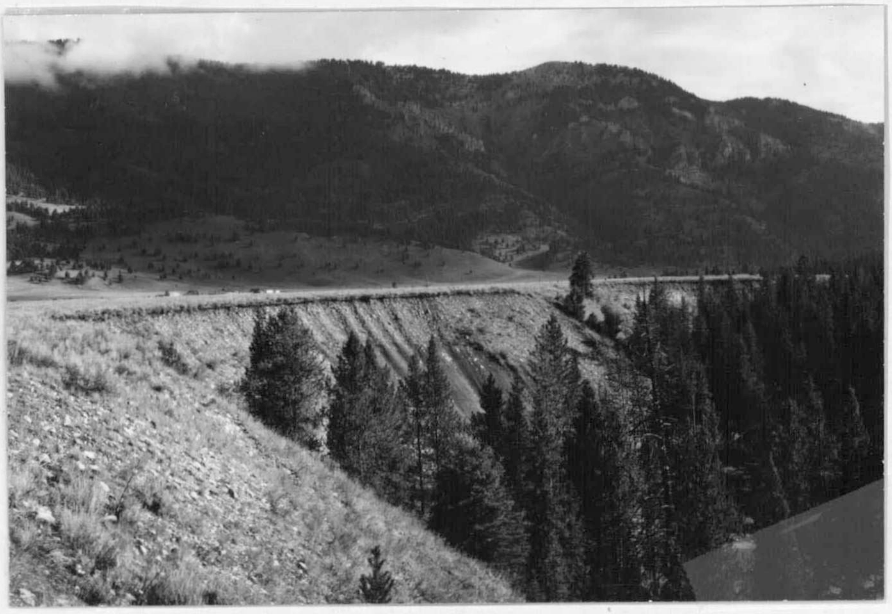

Figure 9. Outwash gravel overlying Cretaceous shale along South Fork, Dudley Ridge in background.

Precambrian lithologies are present in the outwash gravels, but only in a relatively narrow strip within a few yards of the course of West Fork. Since West Fork is at the north margin of the outwash, it is apparent that the bulk of the valley outwash contains almost no rock types from the only area of Precambrian outcrops (North Fork drainage).

Remnants of Bull Lake outwash material appear as small high terraces on the margin of the present day basin floor. These terraces have been mapped as Qt_5 and are correlated with the high terraces along the West Gallatin River using a gradient similar to the present day slope of the outwash gravels. The small area mapped as Qt_5 west of the outwash plain is concordant with South Fork Bull Lake moraine. These terrace remnants are considered to be Bull Lake in age because of their high position relative to the present elevation of West Fork basin floor. They represent the upper surface of the Bull Lake outwash gravels. Subsequent Pinedale deglaciation resulted in a similar episode of erosion and deposition. Pinedale glaciers were less extensive than those of Bull Lake, and disection associated with Pinedale activity did not remove all of the Bull Lake gravels. The Pinedale deposits did not reach the thickness of the earlier glacial outwash.

Scour channels, represented on Plate I by short arrows, indicate the direction of meltwater flow. These channels, as mentioned before, are remnants of a time of active stream transport and deposition in the basin.

Michener Creek Drainage

Michener Creek, a small stream south of West Fork, flows along a northeast trending fault in which the north block is downthrown. Mass-gravity movements are present along the length of the drainage. The pattern of alluvium demonstrates temporary stream blockage. The mouth of Michener Creek is occupied by alluvial fans which are layered deposits from minor floods.

MASS-GRAVITY MOVEMENTS

Approximately thirty percent of the study area is surfaced by mass-gravity deposits which entirely cover the underlying bedrock. The vast amount of mass-gravity movement has been a primary factor in development of the present topography. The rock types and the structural setting of the area, interbedded Cretaceous sandstones and shales in a synclinal basin, are favorable for the action of mass-gravity movements. Evidence for several types of mass-gravity phenomena, including both flow and slide mechanisms, is present.

The hazards of landslides within the Cretaceous are well known throughout the Rocky Mountain region, and they create problems in construction and maintenance of roads, buildings, and reservoirs. Development of facilities such as these may disturb the equilibrium of presently stable slopes. Since a portion of the study area is included in plans for a large recreational facility attention should be focused on the mass-gravity deposits already present in the area and the possible measures that could be taken to prevent such movements in the future when the activities of man entail modification of the terrain.

Description and General Discussion of Mass-gravity Deposits

Sharpe (1938, p. 7) categorized mass-gravity phenomena as a series of types "in which the debris load steadily increases and the water content diminishes to the vanishing point". The continuous series is given by Sharpe (1938, p. 8).

stream flow: much water, small load, low angle
slopewash
sheetflood
mudflow
earthflow
debris avalanche
landslide: Little water, large load, moderate to high angle

Based on the kind of movement and the relative rate of movement Sharpe (1938) has classified mass-gravity phenomena into three types: slow flowage, rapid flowage, and landslides. All three categories are represented in the study area. For the purpose of this discussion the definition of landslide will be as stated by Varnes (1958, p. 20), ". . . 'landslide' denotes downward and outward movement of slope forming materials composed of natural rock, soils, artificial fill, or a combination of these materials." This definition allows the term landslide to be used in a general sense for all types of mass-gravity movements. The terms soil creep, earthflow, mudflow, slump, rockfall and rockslide will be used according to Sharpe (1938). The following is a summary of the characteristics of the main types of mass-gravity deposits present within the study area.

Sharpe (1938, p. 21) has defined creep as "the slow downslope movement of superficial soil on rock debris, usually imperceptible except to observations of long duration." Soil creep has affected a large portion of the study area but has produced no mappable deposits.

Earthflow is considered by Sharpe (1938) to be the slowest flow type in his rapid flowage category. Earthflow is the most significant category of mass-gravity activity and accounts for the great majority of feature mapped as Qls. Within the study area earthflows are characteristic of gentle to moderately steep slopes. Earthflow movement is slow but perceptible. Some features typical of earthflows within West Fork basin are:

1) Gentle to moderate slopes (less than 15 degrees);
2) Commonly developed on beds of silt and clay capped by porous sandstone or welded tuff;
3) Some transport of bedrock;
4) Crescentic scar at head of flow;
5) Source area is broken into a series of slump blocks;
6) Linear ridges along sides of some flow masses;
7) Commonly have a lobate toe;
8) Hummocky topography;
9) Ponds on hummocky surface.

Minor mudflow deposits are present within the area. They differ from earthflow deposits chiefly in their method of deposition and their steep gradient. Movement is more rapid than earthflow and can be catastrophic. Mudflow characteristics are as follows:

1) No visible source area scar;
2) Steep gradient in source area;
3) Recurs in same channels;
4) Involves transport of surficial unconsolidated material with little bedrock;
5) Low profile spatulate toe;
6) Smooth surface profile.

Sharpe (1938) has divided the "landslide" category of mass-gravity movements into slump, debris-slide, debris-fall, rockslide, and rockfall. Deposits resulting from slump, rockslide, and rockfall are present within the study area. A slump block usually moves as a singular unit or smaller individual units with backward rotation about a horizontal axis parallel to the headwall. Movement can be slow and intermittent or in a single rapid slip. Rockslides are rapid downward movements of bedrock debris sliding along bedding, fault planes, or any other plane of separation. Sharpe (1938, p. 78) defines rockfall as "the relatively free falling of a newly detached segment of bedrock of any size from a cliff, steep slope, cave, or arch." "Movement may be by vertical fall or by a series of leaps and bounds down a steep slope." Within West Fork basin the deposits of rockfall are minor. Those present are steep talus covered slopes. Movement of the rock debris is slow and sporadic by freeze-thaw pressures. A pile of rock debris is commonly present at the base of a talus slope. Characteristics of slump blocks and rockslide deposits located within the study area are given below.

Slump

1) Bedrock involvement;

2) Blocks located down from and ahead of source;

3) Crescentic scar at head;

4) Convex bulge in toe area;

5) Blocks are relatively intact except for attitude.

Rockslide

1) Steep slopes in the source area;

2) Smaller in area than earthflows;

3) Steep headwall scar;

4) Width of slide widens from headwall to toe.

As discussed by Hall (1960b) the mass-gravity features of the Madison Range cannot be classified as one single type. The difficulty in classification of those deposits within the study area is due to many factors. Several of the mass-gravity features located within West Fork basin and the adjacent areas are greater than one mile in length and one-half mile in width. The surface topography within one of these large deposits may vary from place to place, exhibiting slump characteristics at and near the slide head and a hummocky surface over much of the slide area. Most of the large scale deposits within the study area appear to be relatively inactive, exhibiting fresh piles of rock debris probably due in part to the 1959 Hebgen earthquake. Later mass-gravity movements on an older slide surface are also common in these larger deposits. The secondary movements do not necessarily exhibit the same features as the first. Most of the surface area of the mass-gravity deposits located within the study area are forested with Pinus contorta (Lodgepole pine), Pseudotsuga menziesii (Douglas "fir"), and Picea engelmannii (Engelmann spruce) and show no evidence of movement in historic time. As Hall (1960b) has suggested, only a relative judgement can be made on factors which Sharpe considered, such as rate of movement and probable water content, when classifying these pre-historic mass-gravity deposits.

The majority of the mass-gravity features within the study area are south of South Fork on the southwest limb of Lower Basin syncline. These slide deposits are on the dip slope (2-10° NE) of Cretaceous sandstones and shales. A large slump block is located in sec. 14, T. 7 S., R. 3 E. However, earthflow is the main type of mass-gravity activity. The earthflow deposits are relatively large; one such deposit east of First Yellow Mule Creek extends more than two miles. Most of the earthflows except those formed in beds of the Cretaceous Albino Formation are found in units of silty shale capped by sandstone or welded tuff. These are porous units and form steep ledges with large segments of tilted bedrock at heads of slides, Figure 10. In the source area portion of the slide the movement is almost entirely by slump. Earthflows formed in the clays of the Albino and in the porcellanite zone of the Albino are similar to mudflow deposits in that they exhibit no well defined crescentic scar at the source. Many of the earthflow deposits are characterized by linear flow ridges as much as ten feet high. Good examples of these ridges are located in sec. 15, T. 7 S., R. 3 E. All the earthflows display hummocky topography and small ponds occupy some of the depressions.

Landslide deposits along Middle Fork in Sec. 2, T. 7 S., R. 3 E. and sec. 35, T. 6 S., R. 3 E. are formed within the Cretaceous Albino Formation on the southwest limb of Lower Basin syncline. Crescentic scars are present in the source areas of these earthflows, although no rock ledge is exposed. Like the flows south of South Fork they display hummocky topography with some development of ponds. Springs are also present along the base of the slides.

Other mass-gravity movements within the area include minor slumping along the oversteepened bank of South Fork gorge (sec. 36, T. 6 S., R. 3 E. and sec. 31, T. 6 S., R. 4 E.), mudflow deposits along the base of Dudley Ridge in West Fork basin, and a rockslide deposit also located at the base of Dudley Ridge. Mudflow deposits

Figure 11. Earthflow located south of South Fork, sec. 1, T. 7 S., R. 3 E., in the Cretaceous Albino Formation.

Figure 12. Hummocky profile typical of earthflows in West Fork basin area.

are considered to be transitional between stream alluvium and earthflow. They have developed in zones of steep slopes (greater than 15^{o}), are sparsely vegetated, and have low toe profiles. These fanform flow deposits are probably due to very rapid runoff following recurring heavy rains. Surface debris is stripped from the slopes and carried to the base of the ridge.

A rockslide (sec. 31, T. 6 S., R. 4 E.) is the only mass-gravity deposit located within the Cretaceous Kootenai Formation. The slide mass descended some 300 feet down the dip of the unit, probably sliding on a saturated layer of slightly calcareous clay shale interbedded with limestones and sandstone. There is a steep headwall on a slope of about 23 degrees. As indicated from study of the channel scar patterns on the surface of West Fork basin plain, this rockslide was probably caused in part by undercutting of the Kootenai by South Fork.

Talus slopes produced by rockfall are present in the study area. Most of the slopes are between 26 and 32 degrees. One good example is in the Kootenai Formation and consists of coarse irregular blocks of salt and pepper sandstone and chert pebble conglomerate resting on a slope of about 30 degrees in sec. 32, T. 6 S., R. 4 E., Figure illustrates another example of talus that has developed below the Mississippian limestones in sec. 23, T. 6 S., R. 3 E.

Significance of Earthflow Deposits

Earthflow deposits are the most significant of all the mass-gravity deposits located within the study area. These deposits have a form (unchanneled overland flow) and topography (hummocky surface) which suggests the mass moved as a highly viscous fluid. Slip surfaces at the base of the flows are not visible. The slide material is composed of rock fragments, sand, and plastic clay. The original water content of the slides cannot be determined from the present deposits. In view of the known sequence of Pleistocene glaciation and subsequent deglaciation, it seems likely that these flows resulted from slope failure probably due in part to saturation of rock material with consequent increase in pore-water pressure and decrease in shearing strength. As stated by Varnes (1958), buoyancy in the saturated state decreases effective intergranular pressure and friction. Saturation destroys intergranular pressure due to capillary tension.

Kehew (1970) sampled the Albino Formation in West Fork basin and found the clay fraction to be entirely composed of montmorillonite. High montmorillonite content has been shown by Grim (1962) and other workers to result in low permeability, due in part to the small size of the clay particles and in part to the ability of montmorillonite to orient water molecules, rate of compressibility, high rebound on load removal, and loss of strength in the presence of moisture.

Zaruba (1969) discusses the factors producing slide movements. Of the many factors which Zaruba identified, the following appear to be important in West Fork basin.

1) Changes in water content due to precipitation and meltwater.
2) Earthquake shocks.
3) Sudden increase of slope gradient (oversteepened slopes).
4) Deforestation (man's activities).

If it is accepted that the majority of mass-gravity deposits within West Fork basin were initiated during the Pleistocene, then it can be argued that the wet interglacial climatic conditions played a major role in the development of such movements. The precipitation and meltwater probably produced a saturated state in the strata, increasing the pore-water pressure and decreasing cohesion and internal friction. Slope stability is greatly reduced, allowing for formation of landslides. During deglaciation there undoubtedly were numerous small scale solifluction type movements within the upper thawed portion of soil area. But such features would necessarily have been confined to the thawed portion, so not over three to six feet deep and hence much smaller in scale than the features here mapped. As the climate changed from that conducive to glaciation to the present the permanently frozen portion of the ground thawed, thus supplying moisture and producing a saturated state in the strata.

The main mass-gravity movements probably occured as the permafrost melted.

Earthquake vibrations can initiate landslide movements. Earthquake tremors would probably not be especially significant in areas of such low dip and moderate average slope, except for the fact that the clay is mainly montmorillonite - the main clay mineral of quick clays (Liebling and Kerr, 1963). Quick clays under conditions of agitation can easily fail with less than one degree slope of the failure plane. Faulting has been active throughout the Quaternary in the Rocky Mountain region. Normal faults cut the two million year old welded tuff in the Michener Creek part of the study area. In 1959 the Hebgen Lake earthquake caused fresh rock debris to be deposited on older mass-gravity features located at many places in the Madison Range.

Because a major recreational complex has been proposed for construction in West Fork basin, the construction activities may disturb the rather delicate equilibrium conditions which characterize most old earthflows. Reactivation of the earthflows could result from excavation in the toe of slides, or modification of the water table conditions.

QUATERNARY HISTORY

By late Tertiary time the larger elements of the present West Fork landscape were already partially delineated by the erosional processes then active. (River gravels are located 450 feet above the present day West Gallatin River.) The major ridges were outlined by Pliocene time, and the streams had dissected the region into relatively strong relief. Upon this mountainous topography, perhaps somewhat resembling the terrain of today, the Crown Butte rhyolitic ash-flow tuffs were deposited some two million years ago, approximately at the beginning of the Pleistocene Epoch. Nowhere in the region have these tuffs been found in place resting as low as the present day valley floors, and nowhere have they been identified in place resting on ground higher than 8,240 feet. R. A. Chadwick (oral communication, 1971) has mapped a welded tuff of similar tuff at 9,600 feet at the head of Big Creek near the Gallatin - Yellowstone drainage divide. This unit, however, has not been studied in sufficient detail to determine whether it correlated with the Crown Butte sequence. In most places the Crown Butte ash-flow sequence is found in positions of intermediate elevation, and probably never covered the higher portions of the late Pliocene landscape. The known remnants of these deposits, although quite discontinuous at present, indicate that they must have buried a large part of the valley systems of the time.

At numerous places in the region one can see the old valley floor gravels preserved beneath the lowest unit of the Crown Butte tuffs. An accessible example in the study area is located on the south side of a hill near the mouth of Michener Creek, at an elevation of approximately 6,400 feet, in sec. 5, T. 7 S., R. 4 E., and only one-half miles west of Highway 191. The old stream gravels beneath the ash-flow tuff at this place afford a measure of the lowering of the area during the past two million years. The gravels are presently about 450 feet higher than the gravels along the present Gallatin River, thus this amount of lowering has been accomplished since the tuff accumulated. Erosion since the ash-flows filled the late Pliocene-early Pleistocene valleys has taken place in part alongside the filled lows, and present stream floors are lower than the old valleys, so that there is a semi-reversal of topography from this sequence. The Michener Creek sub-ash flow gravels show by the compositional range of the cobbles that the stream drained areas both west and north of the present West Fork basin. There are fragments of several Cretaceous sandstones, Precambrian metamorphic rocks, and of andesite similar in lithology both megascopically and in thin section to those found in West Fork basin. Faint imbrication indicating transport to the east can also be seen in the gravel exposures. C. Montagne (oral communication, 1971) has mapped high level till and welded tuff in sec. 28, T. 6 S., R. 3 E., but which may possibly be remnants of former river gravels from some ancestral stream emanating from the Spanish Peaks area.

After the obliteration of the local valley floors by the Crown Butte ash-flows, the former "West Fork" altered its course to flow along the north side of the fill, and thus assumed its present position relative to West Fork basin.

Surrounding areas in the Upper Gallatin region contain much evidence for at least one stage of high level glaciation. Hall (1960a) has provided a relatively complete summation of this evidence for the area. Some observations which support an early and extensive glacial event include:

1) Drumlinoid ridges and grooves at 7,600 feet elevation on the shoulder between Cache Creek and Deadhorse Creek ten miles south of the map area in secs. 3 and 4, T. 9 S., R. 3 E.
2) High level till, such as the Apex Till at 9,500 feet in secs. 27 and 34, T. 9 S., R. 3 E.; the Marble Point Till at 8,049 feet in secs. 3 and 4, T. 9 S., R. 4 E., about eleven miles south of the study area.
3) Precambrian erratic boulders at an elevation of 8,720 feet on the divide between the heads of Porcupine and Buffalo Horn Creeks, near Fortress Mountain in sec. 4, T. 8 S., R. 5 E., seven miles southeast of the study area.

Within the West Fork basin study area itself no evidence has been found that is attributed to this early episode of ice accumulation. Almost all the area is low enough that the early ice with effective catchment must have entirely covered the area. Such an all-covering ice sheet would have less tendency to accumulate extensive surficial blocks avalanching along canyon walls, a situation not conducive to the deposition of significant deposits. The processes of erosion, solifluction, slumping and sliding that characterize periods of glaciation and deglaciation have effectively removed every trace of erratic fields that formerly existed.

Throughout the Rocky Mountain region two glacial stades developed during late Pleistocene time. The earlier more extensive stade has been designated as Bull Lake (Blackwelder, 1923; Richmond, 1957). Richmond (1970) considers the Bull Lake glacial stade in this region to have extended from about 110,000 to 70,000 years before present. In the West Fork basin and in the adjacent areas Bull Lake glaciers carved cirques in Beehive and Bear Basins on the south side of the Spanish Peaks, in most of the high area of the Spanish Peaks, on the flanks of the laccolithic complex of Cedar, Lone, Fan, and Pioneer mountains, and probably also at the heads of valleys on the northeast flank of Buck Creek Ridge. Bull Lake till deposits on the floor of West Fork basin indicate that ice at that time did reach as far as the present confluence of North Fork and Middle Fork (Figure 7). The ice tongues originating in Beehive Basin and on Lone Mountain flowed eastward along Middle Fork only a short way, and did not reach the North Fork confluence, (C. Montagne, oral communication, 1970). In Dudley Creek the Bull Lake ice reached almost all the way to its mouth, within a mile of the West Gallatin River. The writer believes that much more ice accumulated in the South Fork drainage system than in the North and Middle Forks. Bull Lake till is present at the Michel Ranch bench, in sec. 2, T. 7 S., R. 3 E. Ice must have reached this point from some logical source area of accumulation. The only reasonable source for such ice would be the Yellow Mule valleys which head on the northeast side of Buck Creek Ridge, and the upper parts of South Fork valley itself. All of these valleys have large amphitheater-like heads, and are wide straight troughs for several miles below. They appear to be ice-modified, but are so affected by Pleistocene mass-gravity action that the glacial evidence is largely obscured. However, the fact that these troughs have been the sites of such strong post-glacial landsliding should not be taken as detracting from the concept of their being glacial troughs originally. Indeed, it is likely that the glacial scour so over-steepened the soft Cretaceous units of these valleys that they were especially susceptible to mass wastage failure during the west post-glacial periods.

As the Bull Lake glaciers began to melt they produced an ever increasing supply of meltwater to the West Fork basin. During this time the relatively confined meltwater easily cut the relatively flat swath across the soft Cretaceous rocks of the South Fork area. As the meltwaters began to wane they were no longer able to sweep the valley clean, and deposition of the West Fork gravels began. By the end of Bull Lake glaciation the gravel sheet from the South Fork system alone reached a thickness of some sixty feet, resting on the truncated Cretaceous units. In this area evidence has not permitted a determination of the number of Bull Lake advances. However, extensive and detailed work by Richmond,(1970), Pierce (1970), and others in nearby regions has documented two to three definite ice advances which have been included in the Bull Lake. It would therefore seem likely that this area also had a similar history. It is possible that Dudley Creek, on the northern margin of the study area, would be the most likely area to study intensively for evidence of mulitple Bull Lake ice advances due to the resistant nature of the Precambrian gneisses and schists. Probably extensive mass wastage was initiated during the wet conditions which followed the waning of Bull Lake ice. The rocks are unusually susceptible to gravity failure, and in this period they must have been nearly saturated in many areas. The devegetated and oversteepened slopes were very favorable sites for landsliding, and it is likely that the major slide areas of the present were initiated as the Bull Lake ice melted.

Pinedale glaciation was in most areas of the region less extensive than the Bull Lake, and it would seem that this was also true for the West Fork area. Ice developed in some of the same valleys which previously held Bull Lake glaciers, but the Pinedale tongues were not as large, and did not extend so far down the valleys. No evidence has yet been found to show that Pinedale ice ever reached the floor of West Fork basin. Pinedale ice must have modified some of the landslide deposits in the Bull Lake troughs, or even removed some of the slide material. The landslide deposits in the middle portions of some of the Yellow Mule troughs certainly appear to be drumlinized. Terminal moraines regarded as Pinedale were deposited in North Fork and Dudley Creek valleys, upstream from the Bull Lake till. Pinedale ice apparently formed within the South Fork drainage system, as documented by the extensive outwash gravels from the basin, but the ice itself did not reach into the study area. The terminal moraines of Pinedale age must still lie obscured by mass-gravity deposits and heavy forest cover in the region just south and west of the study area.

The Pinedale deglaciation was more significant in terms of the present West Fork basin floor development than any other comparable time period. Meltwaters from the Pinedale ice were nearly as efficient as those from the Bull Lake ice in their actions. The Pinedale meltwater first nearly completely stripped out the Bull Lake gravel sheet from the South Fork drainage. Only a few terraces remain of the former outwash sheet, as at the bench in sec. 2, T. 7 S., R. 3 E. Once again, as the volume of meltwater began to diminish, the Pinedale outwash gravels began to accumulate, and filled in the swath cut through the Bull Lake deposits. Pinedale ice was not as great, and the outwash therefore only fifteen to thirty feet thick, but covered nearly as great an area. The present gravel sheet of the West Fork basin is essentially Pinedale outwash derived from the South Fork part of the basin. It is evident from the slope of the gravel surface, and from the many details of channel boundaries and scour lines, that the waters which brought the gravel came from the southwest, not from Middle or North Fork area. It would appear that during Bull Lake and Pinedale time the South Fork was the dominant stream of West Fork basin. This situation remains true at the present time, although the disparity in flow at present is not so dramatic.

It was probably during this wet post-Pinedale period that South Fork was diverted from a position along the west margin of the gravel fill of the valley to its present course along the southeastern margin of the gravels. The record is not complete enough to create a conclusive reconstruction of the events, but one possible sequence of events which appears reasonable is given here:

1) South Fork flowed across its outwash gravel, following final melting of Pinedale ice; massive earthflows moved northward

down the gentle slope of the West Fork basin, toward the valley floor.

2) Large amounts of water in the form of springs and seeps discharged along the toes of these large slide masses, as can be seen along many of them today.

3) The water from the toe areas came out nearly to the natural depression south of the normal depositional crown on the outwash. The outwash surface sloped to the northeast, thus the water would have been channeled in this direction.

4) This new stream flowed into the West Fork somewhere in the area of the present South Fork confluence, farther west. The new stream then cut through the thinner gravels of the southeast margin, and into the soft units of the Cretaceous sediments below.

5) The new stream cut headward, and captured the upper part of South Fork, approximately in the area of the apex of the gravel outwash, in sec. 2, T. 7 S., R. 3 E.

6) The abandoned channels are still plainly visible on the airphotos of the gravel plain. Once captured, South Fork water together with the earthflow seepage water cut down well below the old gravel surface. Cutting is still progressing, and the gorge has very steep walls (Figure 13). The large earthflows still push northeastward and have

Figure 13. Muddy Sandstone ledge along South Fork, secs. 2 and 11, T. 7 S., R. 3 E.

encroached over the low terraces of South Fork in some spots, and keep the stream pushed against its northwest bank.

Normal faulting has displaced the Crown Butte ash-flow tuff in this area, as was also the case with the equivalent tuff in the area just to the south, as reported by Hall (1961). Because these ash-flow tuffs are believed to be approximately two million years old, the faulting must be considered late Pliocene or Quaternary. Linear trends visible on the airphotos follow the known trace of this faulting but cross areas of mass-gravity deposits that surround exposures of the tuff. These trends are too evident to ignore, but are not identifiable on the ground in such areas, hence may not be definite fault traces. If these trends represent the true faults either some of the faulting was post mass-gravity or some linear movement took place along the fault since the slides developed.

COMMENT ON ENVIRONMENTAL AND QUATERNARY GEOLOGY

The term "land" is used by Stewart (1968, p. 1) to refer to "a wide array of natural resource attributes . . . climate, landform, soil, vegetation, fauna, and water." Stewart (1968) also notes the mobility of water in contrast to the other attributes, the self-regenerating nature of vegetation and fauna, and the consumable nature of physical resources such as soil and minerals. The "land surface" is a product of effects of past and present climates and geomorphic processes acting through the time of geologic parent material. "Environmental geology" is considered by the writer to be the study of the interdependence of the activities of man and the physical natural resource attributes of the land.

In considering the "environmental geology" of the study area, emphasis has been placed on landscape genesis and the surficial features of the geological aspect of the environment. The major factors involved are groundwater, earthflows, and glacial till. The Big Sky recreational complex that is planned for the area will involve such activities as excavation, construction, and sewage disposal.

Large scale earthflows, already discussed, are located within the study area, south of the proposed "summer village" of the recreational complex. Although there are no mass gravity deposits located near the building sites, caution will have to be exercised in excavation of access roads. In addition to consideration of activities taking place on the project land, concern should be directed toward tracts of land owned by cooperating agencies such as the Forest Service. If roads must be constructed over the earthflows, they can probably be successful if built up upon the existing surface and nowhere cut into old slide masses. One particular area of concern is the gravel road to Andesite Lookout Tower four miles west of the basin itself. Greater than fifty percent of this road lies on old earthflow deposits. With the influx of people into West Fork basin, vehicle traffic on this access road will increase. Some maintenance of the road will be necessary since at present it is impassable when wet. The susceptibility of this slide material to frost heaving will have to be taken into account as well as possible slide reactivation by undercutting.

Groundwater extraction will necessarily be dependent in large part on the projected number of persons that will occupy West Fork basin at any given time. The present landowners within the basin procure their water from wells drilled into Cretaceous sandstones and shale as well as from springs amanating from earthflows. Consideration should be given to the massive earthflow deposits adjacent to the construction sites as possible sources for water.

Irrigation in the basin will not adversely affect most sites unless they are located on old landslides, where the additional moisture could act as a lubricant decreasing ridigity and internal shear strength, thereby causing creep if not flow activation. Irrigation will probably be necessary after construction in all areas of regrowth, especially if species not native to the area are to be introduced. There should be an extensive program of planned replanting, especially around the village site and along the proposed golf course.

The soils within lower West Fork basin in the area of the summer village site have no severe limitations to construction. As mapped these soils are the Bigel cobbly loam soils and Bearmouth gravelly loams along with other well drained soils in the Bigel - Hobacker Association. These soils have moderately slow permeability in the upper part and rapid permeability in the substratum. These shallow depths (10-40 inches) down to rapidly permeable materials may provide a water pollution hazard in septic tank areas. To handle a large number of people it will be necessary to have complete sewage treatment facilities. If waste water is of the same or higher quality than the original water the environment will not suffer. Some form of tertiary treatment should be considered.

All sub-alpine and intermontane environments are comparatively delicate and transitory owing to the complexities of interdependence of topography, geologic materials, climate, soil, and vegetational cover. A study of Quaternary geology is largely a study of surface form and surficial materials - the most obvious part or "visible" part of the environment. Whatever landforms and soils and vegetational cover comprise a particular region, they represent a temporary balance or equilibrium between dynamic features. Any change in the arrangement of materials or in operation of any of these features must produce corresponding changes in the dependent components. Therefore, it is certain that any significant or long term construction, modification of surface, removal of soil, or interference with the groundwater regime - all of which accompany "development" of a major recreational complex - must and will produce major alteration of the present environment.

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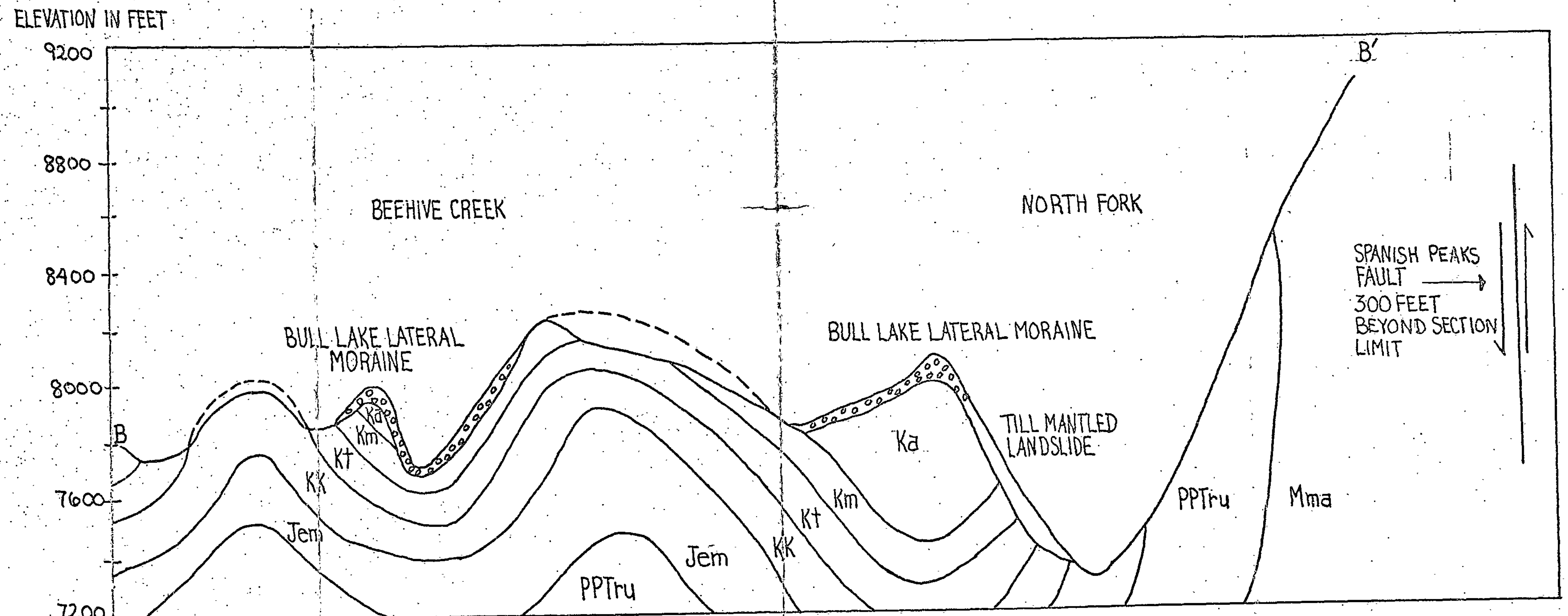
INFERRED STRUCTURAL CROSS SECTION B-B′ ON PLATE I

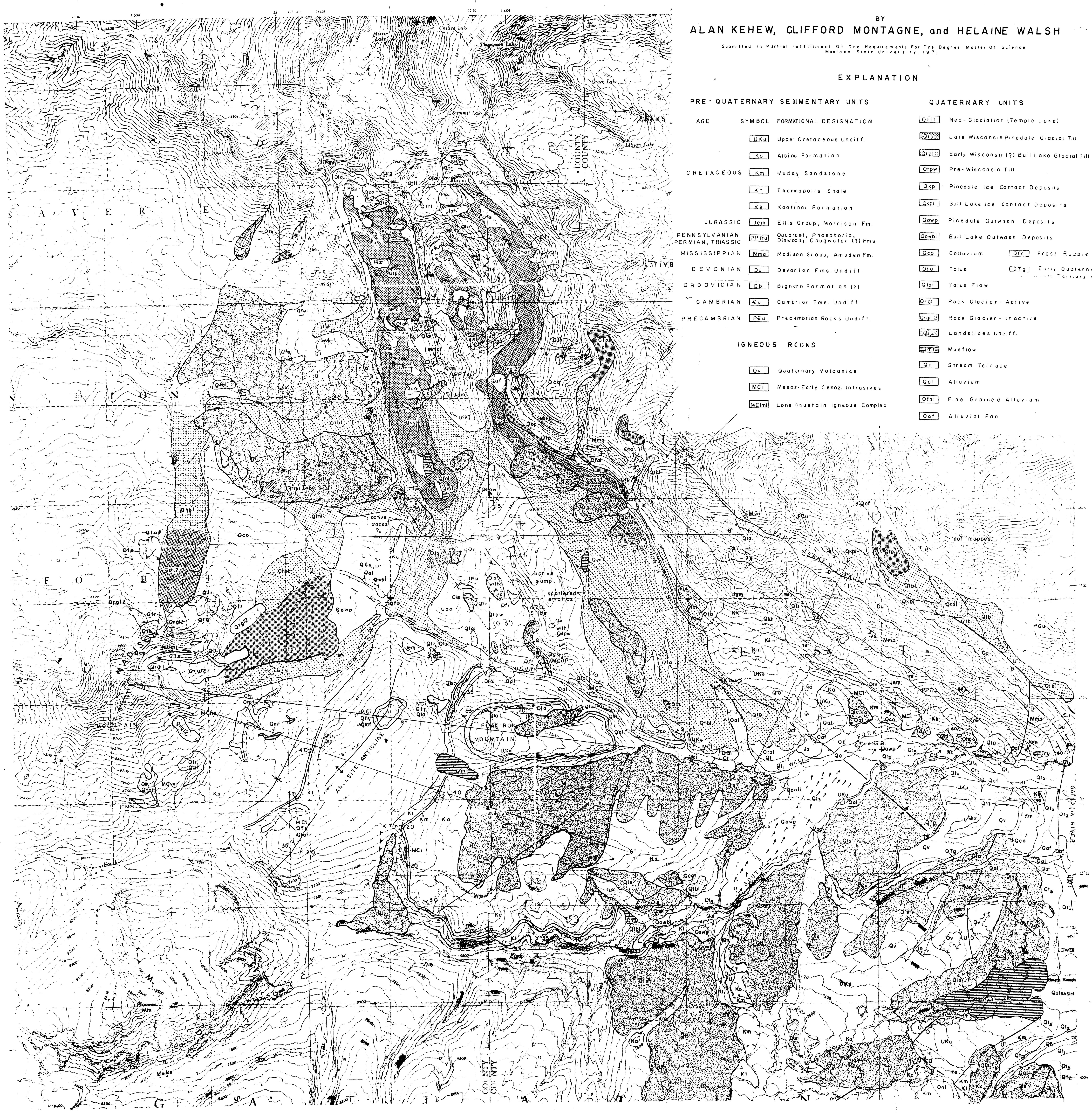


LINEAR SCALE 1:24,000
PLATE II

ENVIRONMENTAL GEOLOGY OF THE WEST FORK BASIN
GALLATIN COUNTY, MONTANA

BY
ALAN KEHEW, CLIFFORD MONTAGNE, and HELAINE WALSH

Submitted In Partial Fulfillment Of The Requirements For The Degree Master Of Science
Montana State University, 1971



EXPLANATION

PRE-QUATERNARY SEDIMENTARY UNITS

AGE	SYMBOL	FORMATIONAL DESIGNATION
	UKu	Upper Cretaceous Undiff.
	Ka	Albino Formation
CRETACEOUS	Km	Muddy Sandstone
	Kt	Thermopolis Shale
	Kk	Kootenai Formation
JURASSIC	Jem	Ellis Group, Morrison Fm.
PENNSYLVANIAN PERMIAN, TRIASSIC	PPTru	Quadrant, Phosphoria, Dinwoody, Chugwater (?) Fms.
MISSISSIPPIAN	Mma	Madison Group, Amsden Fm.
DEVONIAN	Du	Devonian Fms. Undiff.
ORDOVICIAN	Ob	Bighorn Formation (?)
CAMBRIAN	€u	Cambrian Fms. Undiff.
PRECAMBRIAN	P€u	Precambrian Rocks Undiff.

IGNEOUS ROCKS

Qv	Quaternary Volcanics
MCi	Mesoz-Early Cenoz. Intrusives
MCImi	Lone Mountain Igneous Complex

QUATERNARY UNITS

Qttl	Neo-Glaciation (Temple Lake)
Qtp	Late Wisconsin Pinedale Glacial Till
Qtbl	Early Wisconsin (?) Bull Lake Glacial Till
Qtpw	Pre-Wisconsin Till
Qkp	Pinedale Ice Contact Deposits
Qkbl	Bull Lake Ice Contact Deposits
Qowp	Pinedale Outwash Deposits
Qowbl	Bull Lake Outwash Deposits
Qco	Colluvium
Qfr	Frost Rubble
Qta	Talus
QTg	Early Quaternary-Late Tertiary Gravels
Qtaf	Talus Flow
Qrgl 1	Rock Glacier - Active
Qrgl 2	Rock Glacier - Inactive
Qls	Landslides Undiff.
Qmf	Mudflow
Qt	Stream Terrace
Qal	Alluvium
Qfal	Fine Grained Alluvium
Qaf	Alluvial Fan

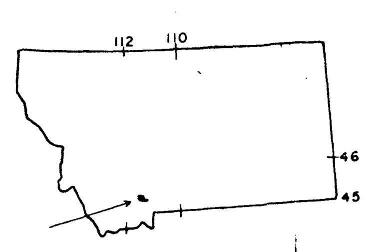
SCALE 1:24,000

0 2000 4000 6000 8000 10,000 FEET

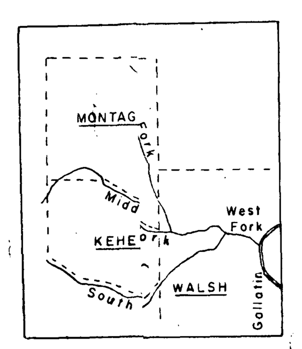
CONTOUR INTERVAL 20 FEET
DATUM IS MEAN SEA LEVEL

Bedrock Geology Modified From Swanson (1950)
Base Map - U.S. Department of Interior Bureau of Reclamation, Missouri Basin Project Sheets 116, 126

N MN GN 0°16' 18½



MAP LOCATION



INDEX MAP

SYMBOLS

———	Formational Surficial Unit Boundary
— — —	Inferred Uncertain Boundary
⊥ ⊥ ⊥	Landslide Scarp (Hachures Point Downhill)
- - -→	Landslide Flow Direction
A ~~→	Snow Avalanche Path
——→	Ice Flow Direction
U	Upthrown Block
——— - - -	Fault (Dashed Where Obscured)
D	Downdropped Block
A—A'	Location of Cross Section
—·—·—	Morainal Form
	Anticlinal Axis
	Synclinal Axis
·········	Pre-Quaternary Bedrock Boundary Within A Surficial Unit

PLATE I

DATE DUE

APR 18 RECD		JAN 11	
		REC JAN 1	1 200
		FEB	22 2002
JUL 11	1987	REC'D MAR 1	4 2002
		MAY 2 3	2002
		REC'D JUN 1	2002
NOV		INTERLIBRARY LOAN	
			8·5·03
		SEP 1 7	2003
DEC 24 REC'D MAY		REC'D SEP 1	1 2003
			2003
		AUG	0 5 2004
		AUG 05	
		REC'D AUG 1	6 2005
NOV 1 5	2007	REC'D NOV 1 3 2007	

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