Environmental geology of part of the West Fork Basin, Gallatin County, Montana

by Alan Everett Kehew

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

Abstract:
The geology of part of the West Fort Basin was studied to obtain practical information relating to the proposed development of a large recreational facility. Both bedrock and surficial geology were mapped to discover relationships which have environmental significance.

The exposed stratigraphic units, in this area, consist of Cretaceous strata with interbedded igneous sills, including the Kootenai Formation through part of the Colorado Group. The three-member Kootenai Formation, mainly sandstone and shale, is the most resistant unit in the area. In contrast to the Kootenai, the overlying weak formations including the Thermopolis Shale, Muddy Sandstone, Albino Formation, and an unnamed sandstone and shale unit,generally provide a poor bedrock base for construction. Various types of mass-gravity phenomena which affect much of the surface underlain by these units, contribute to their poor adaptability to man-made alterations. Varying climatic conditions through Recent geologic history have controlled the character of these mass wastage processes. Microclimatic variations due to different slope orientation affect vegetative growth and geo-morphic processes.

Mass-gravity phenomena show a definite correlation with lithology. Flowage or slump masses are the normal surficial cover for areas underlain by the Thermopolis Shale and the Albino Formation, even when tilting of the strata is slight. Although most of these movements are stabilized under present climatic conditions, their equilibrium is delicate and modifications should be planned with caution. Rockslides and mudflows are less common features, but may involve all stratigraphic units. Slow flowage mass-gravity movements such as talus flow, colluvium and rock glaciers are mostly found on steeper slopes. Rock glaciers present are classified as active and inactive. It is recommended that the active rock glacier in the cirque on Lone Mountain be studied to determine its movement, if any, before the proposed ski lift is installed.

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ABSTRACT

The geology of part of the West Fort Basin was studied to obtain practical information relating to the proposed development of a large recreational facility. Both bedrock and surficial geology were mapped to discover relationships which have environmental significance.

The exposed stratigraphic units, in this area, consist of Cretaceous strata with interbedded igneous sills, including the Kootenai Formation through part of the Colorado Group. The three-member Kootenai Formation, mainly sandstone and shale, is the most resistant unit in the area. In contrast to the Kootenai, the overlying weak formations including the Thermopolis Shale, Muddy Sandstone, Albino Formation, and an unnamed sandstone and shale unit, generally provide a poor bedrock base for construction. Various types of mass-gravity phenomena which affect much of the surface underlain by these units, contribute to their poor adaptability to man-made alterations. Varying climatic conditions through Recent geologic history have controlled the character of these mass wastage processes. Microclimatic variations due to different slope orientation affect vegetative growth and geomorphic processes.

Mass-gravity phenomena show a definite correlation with lithology. Flowage or slump masses are the normal surficial cover for areas underlain by the Thermopolis Shale and the Albino Formation, even when tilting of the strata is slight. Although most of these movements are stabilized under present climatic conditions, their equilibrium is delicate and modifications should be planned with caution. Rockslides and mudflows are less common features, but may involve all stratigraphic units. Slow flowage mass-gravity movements such as talus flow, colluvium and rock glaciers are mostly found on steeper slopes. Rock glaciers present are classified as active and inactive. It is recommended that the active rock glacier in the cirque on Lone Mountain be studied to determine its movement, if any, before the proposed ski lift is installed.

INTRODUCTION

METHOD OF STUDY

The field work for this report was done as part of an environmental research project undertaken by the Montana State University Center for Environmental Studies. Geology represented one of several disciplines which were involved in a study of many aspects of the physical and cultural environment of a sparsely populated area soon to receive a large recreational development. The object of the overall project is to observe environmental changes, having obtained a detailed knowledge of original conditions.

The goal of the present paper is twofold. First, the general geological relationships such as stratigraphy, structure, and geomorphology were examined. This is an attempt to describe briefly the stratigraphic sequence, the structural setting, and geomorphic features of the area mapped. This information is included in the report to give the reader a brief overall geologic background of the area.

The second objective of the study concerns the application of some of this information to the practical problem of productive man-made alterations of the landscape. The writer feels that certain aspects of the subjects mentioned above, as well as their interaction with climatic and biologic processes will be useful in planning the recreational complex.

Approximately ten weeks were spent in the field during the summer of 1970. The geology was mapped on 1:20,000 scale air photos, and transferred by use of a Salzman projector to 1:24,000 scale topographic maps.

Approximately fifteen representative thin sections were studied with the petrographic microscope. Two clay samples were analyzed using X-ray diffraction techniques.

To encourage the use of this report by non-geologically trained persons, a glossary of some of the technical terms used has been included in the appendix.

DESCRIPTION OF AREA

The area mapped includes about sixteen square miles in part of the drainage basin of the West Fork of the West Gallatin River, in the Madison Range. The West Fork is formed by three smaller streams, the North, Middle, and South Forks of the West Fork, which rise in mountainous terrain near the Madison-Gallatin drainage divide, and flow eastward to form the West Fork on a broad plain approximately two miles west of U. S. Highway 191. The specific area of this report is located between the South Fork and Middle Fork, extending northwest of the lower plain to the crest of Lone Mountain (See index map, Plate I). Elevations range from 6600 feet to 11,166 feet at the top of Lone Mountain. Maximum relief is approximately 4500 feet.

The mouth of the West Fork is located approximately 43 miles south of Bozeman, roughly one half the distance between Bozeman and West Yellowstone, Montana, along U. S. Highway 191 which parallels the

West Gallatin River. Gravel roads extend along the South Fork to the Ousel Falls campground, and up both sides of the Middle Fork to Andesite Lookout Tower on the south, and to the head of the Middle Fork near the Madison-Gallatin drainage divide, on the north. These roads will be substantially improved in the near future, to provide for a much greater volume of traffic in connection with the development of the recreational complex.

PREVIOUS WORK

Hall (1961) has summarized the early exploration of the upper Gallatin region, as well as the pioneer geologic work. The first important study was made by Peale (1896) in his study of the Three Forks quadrangle. Two other more recent works were extensively relied upon in the present study of the area. R. W. Swanson (1950), compiled a bedrock map including the area to be studied here. Several rather insignificant corrections were made in the bedrock geology of this map, and the detail was expanded in several ways. The portion of the Colorado Group present, mapped by Swanson as "upper Cretaceous undifferentiated" was divided into smaller units. In addition, the surficial geology was mapped in detail for the first time. W. B. Hall's excellent general work (1961) on the upper Gallatin region included this study area in a reconnaissance structural map. His discussions of the stratigraphy, structure, and geomorphology in the above paper, as well as in two smaller more specific papers (1960 a,b), were invaluable in the preparation of this report.

TOPOGRAPHIC SETTING

Dominating the area at its western boundary stands Lone Mountain, an impressive peak of 11,166 feet. Eastward, from the base of this mountain, lies a prominent northeast trending anticlinal ridge, named Andesite anticline for an outcrop of an igneous sill at the highest point along its axis, near which a lookout tower is located. This ridge is separated from Lone Mountain by a small synclinal valley, and bordered on the east by a portion of a syncline. Between this syncline and the Middle Fork is a large flat-topped hogback, sloping east-northeast, which is locally known as Flatiron Mountain. Beyond the map area to the east lies a broad flat plain which was mapped by H. Walsh under the auspices of the M.S.U. Center for Environmental Studies.

STRATIGRAPHY AND ENVIRONMENTAL ASPECTS

GENERAL STATEMENT

In keeping with the environmental theme of the project, the stratigraphy is discussed mainly as it relates to the evolution of the existing landscape.

Most stratigraphic study within the West Fork basin is difficult due to the extreme scarcity of bedrock exposure. Timber cover throughout the Madison Range is very heavy. The most important reason for the lack of outcrops, however, is the nature of the rocks themselves, because in this specific area, a large part of the exposed section consists of shale, claystone, and other extremely non-resistant rocks. Only the thin sandstone units within the shales are resistant enough to crop out at all. The only consistent exposures are located along stream valleys and even here shales are commonly covered by colluvium and vegatative growth. Due to the properties of these rocks, they are very conducive to mass gravity movements, another factor which contributes to the poor exposure of bedrock.

In the following discussion, regional stratigraphic correlation and depositional history of the units are only briefly mentioned. Only descriptions concerning physical properties of the rocks found in this specific area are important in considering development of the area. The reader is referred to Hall (1961) for pertinent information concerning the regional relations of these sedimentary rocks.

The importance of studying stratigraphy concerns its relation to the topographic expression of various units. In a regional sense, climate is perhaps the most important factor in determining the manner in which a certain rock type will relate to the topography. It determines which erosional processes will occur and at what intensity. In a small area, however, in which the climate is generally constant, the response of the physical properties of the rock to the climate is important in defining the different landforms associated with different rock types.

The effect of climate on exposed sedimentary strata is extensive. All mass gravity phenomena in this area were, and are, controlled or influenced by water. Under the present climatic conditions in the West Fork drainage, most landslide features are relatively stable. Scarps are less topographically prominent features than scarps on those slides which are known to have occurred recently. Vegetation on the slump blocks or slide deposits is established in a normal manner. Most features have no scarps or tension cracks related to recent movement.

One of the contributing causes of landsliding is a gradual decrease in the amount of shearing strength, or the resistance of a mass of material to failure and downslope movement, by prolonged periods of high water availability to the sediments. This water increases the pore pressure within the rock, which eliminates the cohesive effect of a small amount of water in the pores. Certain time intervals in the Pleistocene such as the periods of glacial melting and retreat would provide water to initiate a relatively high frequency of sliding. More specifically, the fresh hummocky topography of many earthflows, a type of mass-gravity movement related to landsliding, might indicate an age of late Wisconsin (Pinedale) time, the age of the last major glacial episode, from about 10,000 to 30,000 years before present. Landslides have occurred since then, although at less frequent intervals, due to a dryer climate. Mass movements showing evidence of recent movement such as distinct scarps and "drunken forests" are few in comparison to the older features. Several man-induced landslides show that such stability can be quickly altered if the natural state is disturbed. An example of this can be seen on a logging road which was built diagonally up the south side of Flatiron Mountain. In the several years since this road was built, the slope has failed and erased a portion of the road. Apparently the slump was an adjustment by the slope to the effect of the road cut. Other examples can be seen in adjoining areas.

One interesting sidelight is the difference in micro-climate between slopes facing north and slopes facing south. North-facing slopes receive less direct sunlight than south-facing slopes, and thus retain some of the moisture that would be lost by evaporation with more sunlight. The difference in the vegetative patterns and geomorphic processes between these slopes is striking.

The comparative lack of moisture on south-facing slopes is manifested in a lack or sporadic distribution of tree growth in certain areas. This phenomena was discussed by Patten (1963, 1970). He found that in addition the slope orientation, fine grained sedimentary rocks or alluvium prevent good forest establishment due to low moisture availability. Patten states (1970), that lodgepole pine is presently invading these open areas due to more advantageous climatic conditions. An excellent example is found in the north canyon wall (south-facing slope) of the South Fork. The fine-grained, clay rich rocks of the Albino Formation form several bands of tree-less sage covered zones along the entire length of the ridge (See Figure 7). Well drained sandy zones in similar settings support tree growth that cannot exist on the clay-rich shale beds due to the low moisture availability of the latter. One factor involved in the moisture availability is probably the impermeability of the rocks. These same impermeable zones support quite dense tree growth on north-facing slopes, which indicates that direction of slope face is a more important factor than is the presence of impermeable beds.

The two types of slopes also exhibit different forms of downslope movement of debris. The north and south sides of Flatiron Mountain can be compared to understand these relationships. The south-facing slope with its general lack of vegetation, maintains well developed talus piles at the foot of outcrops. The north-facing slope, however, with a dense low vegetation in addition to trees, probably moves a greater volume of material downslope and results in a noticeable lack of outcrops of resistant sandstone units in contrast to south-facing slopes.

It probably cannot be proved, but the more rapid forms of landsliding may vary according to facing of slopes. Flow forms such as earthflow would be expected more frequently on north-facing slopes because of greater water content, while slumping or sliding should be more prevalent on south-facing slopes. Exceptions to this would relate to the other factors involved, such as inclination of the slope, stratigraphic units involved, and structure of the beds.

Several lithologic factors combine to influence the landform of a particular rock type. Grain size, mineral composition, porosity, and degree of consolidation or cementation all determine the resistance of a rock to weathering, and mass movement. The stratigraphic section will now be discussed in relation to these factors. Figure 2 illustrates the units in question.

MORRISON FORMATION

Rocks representing the Morrison Formation of Jurassic age (Kimmeridgian according to Imlay, 1952), are exposed at one location within the present map area. This place is at the core of Andesite anticline below the Kootenai Formation where the Middle Fork cuts through the anticline (See Plate I). Only the very top of the formation is exposed here. This unit is non-resistant and is mostly covered by colluvium, talus from the Kootenai Formation, and heavy vegetative growth. The lithology consists of dark gray to black fissile shale which weathers into very small shale chips and covers the surface below, and dark gray to black siltstone which is more resistant than

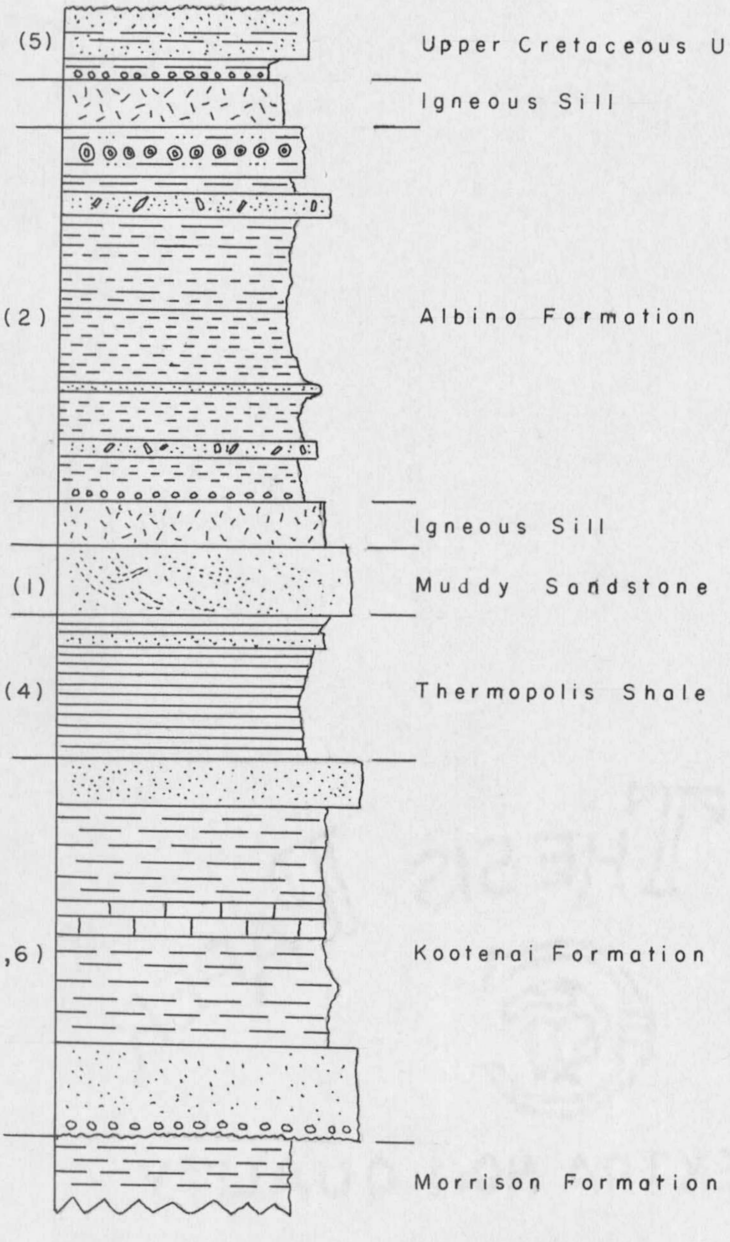

Figure 2. GENERALIZED STRATIGRAPHIC SECTION OF UNITS EXPOSED BETWEEN THE SOUTH FORK AND MIDDLE FORK

Lithologic descriptions in text. Numbers refer to specific mass gravity movements discussed in text. Scale - 1 inch = 200 feet.

the shale. The Morrison Formation is of little importance environmentally in this area due to its extremely small outcrop area.

KOOTENAI FORMATION

The Kootenai Formation of Early Cretaceous age, (Aptian according to Cobban and Reeside, 1952) rests unconformably on the Morrison Formation (Imlay, 1952). This unit is extremely important in the map area, forming almost the total outcrop area of the eroded surface of Andesite anticline, as well as being the unit through which the South Fork is presently flowing from Andesite anticline eastward to the lower plain. South of the map area, the exposures on the north flank of Buck Creek anticline are composed of the Kootenai Formation.

The Kootenai Formation was divided into three members in the Upper Gallatin region by Hall (1961, p. 64-66). His description of the units is partially reproduced below:

" 1. A lower member 80 to 150 feet thick consisting of coarse, massive, salt-and-pepper sandstone, often very conglomeratic near the base, cross bedded, with many light to dark gray chert grains and pebbles. In thin section the conglomeratic sandstone is composed of about 50 percent subangular to subrounded quartz grains and 50 percent subangular chert grains. Percentages of either the quartz and chert locally may increase up to 85, and many of the quartz grains show secondary quartz overgrowths on rounded antecedent grains. The chert is apparently largely derived from siltstone and fine sandstone, and the original fabric of the parent material can often be seen in the microscope . . .

2. A middle member, about 250 feet thick, consisting of yellowish tan to red or maroon nodular claystones, limestones, and limy siltstones below; 20-60 feet of fresh-water lime-

> stones in the middle; and more red to maroon claystones, limestones, and limy siltstones above. The limy unit in the center of the sequence may have gradational contacts at top and bottom, but does have intraformational conglomerate beds occasionally. This unit is the "gastropod limestone" of other parts of western Montana and is probably equivalent to the "lacustrine limestone" of the "Moulton zone" of Cobban (1955, p. 108). The "gastropod limestone" is a noteworthy bed, characterized by a chalky appearance, and multitudes of small gastropod steinkerns and shells covering the bedding planes . . . Some beds contain ostracods by the millions, along with many small ooids like oolites without concentric structure. Other beds in the fresh-water limestone unit appear to have no fossils, but possess a peculiar assortment of fine clear calcite veinlets arranged in an angular "runic" (?) pattern. . . .
>
> 3. An upper sandstone member, about 50 feet thick, composed of well-sorted, fine-grained, clean, clear sparkling quartz arenite. . . Usually this upper sandstone member weathers to a distinctive dark red-brown due to a concentration of hematite cement in a layer about 1/8 to 1/4 inch deep on all exposed rock surfaces, and for this reason is called the "case-hardened sandstone" member of the Kootenai. . ."

The Kootenai Formation as a whole is the most resistant unit in the section. Of its three members, the lower sandstone-conglomerate and the upper sandstone form resistant ledges. The middle unit is less often found cropping out and usually can be recognized by its reddish soil and a tree-less open area, influenced by the impermeable nature of the shale. An example of the Kootenai weathering characteristics can be found on Andesite anticline. Here the dominant form of erosion is the downslope movement of large rectangular to cubical blocks of sandstone that are weathered from the bedrock.

The Kootenai Formation is here considered, in general, to be the most favorable lithologic unit for construction in the section studied.

This is concluded mainly from the type of mass-gravity processes which affect the Kootenai in this area. The Kootenai as a whole has a comparatively high resistance to downslope movement. The ability of a rock to withstand natural erosive processes is a good indication of its potential for utilization by man-made structures. The properties which contribute to this strength are its composition of quartz and chert, its coarseness and well-sorted grains, and its degree of consolidation and cementation. The shales, however, in the middle part of the formation, show a low resistance to erosion and therefore should be regarded as less favorable units for construction.

The potential of the Kootenai as a good acquifer is higher than the other units above due to its grain size, roundness and high degree of sorting, expecially in the upper sandstone. No studies, however, were made of groundwater production in the Kootenai in this report.

COLORADO GROUP

The remaining overlying part of the section in the area, consisting of approximately 700 feet of strata with interbedded igneous sills, is included in the Colorado Group. The four lithologic units present include, in ascending order, the Thermopolis Shale, the Muddy Sandstone, the Albino Formation, and an unnamed sandstone and shale unit. Cobban and others (1959) divided the Colorado Group in the Sawtooth Disturbed Belt area of northwestern Montana into two formations, the Blackleaf Formation of Early Cretaceous age, and the Marias River Shale of Late

Cretaceous age, each consisting of four members. Hall (1961) discussed the possibility of correlating the first four lithologic units above the Kootenai in the Upper Gallatin region with the four members of the Early Cretaceous Blackleaf Formation because of their many similarities. However, plant fossils collected by Hall from the Albino Formation were dated Late Cretaceous. Thus the correlation between these rocks and the Blackleaf Formation remains uncertain.

Thermopolis Shale

Above the Kootenai Formation are found approximately 150 feet of extremely non-resistant dark gray, fissile, carbonaceous shale, interbedded with thin slightly more resistant siltstone. This unit is regarded by Hall (1961, p. 66) as "the terrestrial or brackish water equivalent of the marine Thermopolis Shale of Wyoming."

Because of the non-resistant nature of this unit, it is very rarely exposed; in fact the only actual outcrop of the Thermopolis in the project area is found in the vicinity of Ousel Falls along the South Fork of the West Fork, (sec. 10, T. 7 S., R. 3 E.), beneath a glacial outwash deposit.

The Thermopolis Shale has just as distinctive a topographic expression as the Kootenai Formation. This unit forms a low swale between the Kootenai and the Muddy Sandstone. Subsequent streams generally develop along the strike of the Thermopolis. Another prominent characteristic of this unit is its association with mass-gravity movement. It is rarely exposed as bedrock. When it is present on a steep slope such as valley wall, slumping is common. The very narrow slide in the draw east of Andesite anticline on the Middle Fork was probably initiated by a downslope movement in the Thermopolis. Where the Thermopolis is found downslope from the Kootenai, as on an eroded anticline such as Andesite anticline, it provides a favorable base for downslope movement of the Kootenai float and talus.

Muddy Sandstone

The Thermopolis Shale passes gradationally upward into a sandstone unit approximately 50 feet thick which Hall (1961) has correlated with the Muddy Sandstone in Wyoming. This unit is thin to medium bedded, with well developed cross bedding, and weathers to a platy appearance in outcrop due to thin dark, fissile, shale layers interbedded with the sandstone. The composition of the sandstone is variable, ranging from a medium gray, moderately well sorted, fine to medium grained rock consisting of subangular to subrounded quartz grains, dark rock fragments, and feldspar grains, to a very argillaceous, greenish gray sandstone.

Contrasted with the weak Thermopolis, the Muddy Sandstone forms a resistant ledge along the South Fork, and a prominent thin hogback ridge bordering Andesite anticline. The float from the Muddy which accumulates on the talus slopes beneath the outcrop, consists of thin platy slabs. The Muddy for the same reasons as the Kootenai would provide a sound base for utilization in building. Its thinness restricts its potential somewhat in this respect.

Albino Formation

The remaining 500 or 600 feet of section represent, in the opinion of the writer, the Albino Formation named by Hall (1961), and part of the overlying unnamed sandstone and shale unit described by Hall (1961). This part of the section is very difficult to study in this area because of the extreme paucity of exposures. This is related to the weakness and incompetence of the rocks in general, which here leads to extensive mass-gravity action. In addition to this problem, these rocks have been intruded by igneous sills related to the Lone Mountain Intrusive Complex. It has not been proven in this study whether all of these sills are intruded parallel to bedding, or whether they cut across bedding at some small angle. The varying extent of these sills from their point of intrusion at Lone Mountain increases the difficulty of correlating the section in different locations.

The following discussion is a very limited outline of the Albino lithologies. The writer feels that any attempt at a detailed description of the Albino Formation in this area would not be justified because of the uncertainties in the field resulting from poor exposure of the units and the lack of lateral persistence of the lithologies present. The exact location of the upper contact of the Albino Formation, as mapped in Plate I, is uncertain because a distinct mapping criterion to place the contact was not recognized. The reasons for its position as mapped will be explained later.

The initial 20-30 feet of section directly over the Muddy sandstone is not exposed at any place in the area. The lower half of the Albino, perhaps 100-200 feet thick, consists of pastel colored claystone, mudstone, and shale. There is at least one approximately 5-foot thick sandstone bed in these soft rocks. There are also a few siliceous shale beds and hard brittle tuffs, both more resistant than the shale and claystone, in this zone. A very interesting conglomerate was found in the lower Albino in sec. 3, T. 7 S., R. 3 E. This conglomerate occurs as float in a slump block, hence it is not possible to determine its exact location in the section. Lithologically it is poorly sorted and cemented, and is composed of subangular coarse sand and pebble sized grains with a reddish, probably hematitic fine grained matrix. The rock has a distinctive reddish appearance in hand specimen.

In order to determine the clay mineralogy, two samples of the very loosely consolidated claystones were analyzed using X-ray diffraction. The silt and sand sized particles were first separated from the clay fraction and were not examined further. The clay was then saturated with several different cations to distinguish clay minerals in the resulting X-ray pattern. The clay fraction consists almost entirely of the smectite group of swelling clays. The clay is probably montmorillonite, a member of the smectites. These clay minerals are known for their ability to absorb water on the surfaces between their thin layers, which expands the structure of the mineral. This determination is in accord with the theory that volcanic ash is the parent material for bentonite. Montmorillonite is a known alteration product of volcanic ash in the Wyoming bentonites, also of Cretaceous age. Grim (1968) discusses this alteration process.

Above the very soft claystone, lie about 100 feet of black shale containing numerous shiny, well preserved fish scales. These are small, nearly circular, and ornamented with concentric rings. Fish scales are found in several black, homogenous shales in this part of the section. In these zones thin, gray and orange bentonite seams approximately 1 to 3 inches thick are interbedded with the shale.

The upper portion of the Albino Formation is considerably sandier and more resistant than the lower part. Especially resistant here is a 30-foot thick very well cemented salt-and-pepper sandstone. In thin section, this rock contains fine to medium sized, subangular to subrounded quartz grains. It also contains grains which appear gray or cloudy in plain light (possibly altered volcanic fragments), and a few plagioclase grains. The very small amount of fine material present is probably microcrystalline silica cement.

Above this sandstone, is about 20 feet of dark fissile shale. The remaining uppermost 40 to 60 feet of the Albino Formation as defined here, consists of gray siliceous shale with interbedded very hard, white, fine grained, homogeneous tuff or siliceous shale, grayish green argillaceous sandstone, and siltstone. One zone several feet this is notable for the abundance of its fossil material. One thin bed in this zone seems to consist almost entirely of a mass of plant leaves and stems, while other beds contain a combination of plant material and possibly nearshore marine pelecypods. Above the fossil beds, there are about 10 to 20 feet of undetermined covered material overlain by a prominent sill zone which will be described later.

This section of the Albino Formation has basic similarities to that described by Hall (1961), but there are also several differences. Hall found plant fossils in hard siliceous tuff 20 to 140 feet below the top of the Albino. In the section described above, if the upper contact of the Albino were placed at the contact with the sill, the fossil zone in my area would approximate the location of Hall's fossiliferous zone. On that basis, the Albino contact was mapped in this area. The fossils here, however, are found in different lithologies than were those of Hall. Although the hard tuffs are present in this zone, no organic remains were found in them. Another problem is that none of the bright red tuffs described by Hall were found in this zone or any other part of the section, with the exception of a few pieces found in float in various places. Thus the placement of the upper Albino contact is not made with much confidence, although the described position seemed the most reasonable horizon at which to place it. The sill mentioned above thins to the east and is not present in the section along the South Fork. In this location, additional black fissile shale lies above the sandy zone.

The age of the Albino is questionable. Ferns collected by Hall from the hard tuffs were dated as Late Cretaceous. However, Hall has described the similarity of the Albino to the Vaughn Bentonitic Member of the Blackleaf Formation as defined by Cobban (1959). This is also the "red speck zone" of the Colorado Shale named by Cobban (1951) for abundant minute grains of heulandite, a secondary zeolite found throughout the unit. Cobban (1951) considers the "red speck zone" or Vaughn Bentonitic Member of the Blackleaf Formation, to be equivalent to the Mowry Formation of Wyoming which contains fish scales and bones. The fish scales found in this area are one bit of substantiating evidence for this relation. If the Albino were determined to be equivalent to the Mowry, the upper sandy part of the Albino here described, may correlate with the Frontier Formation of early Late Cretaceous age in the Livingston area, reported by Roberts (1965).

The alternating weak and comparatively strong rocks of the Albino Formation present a classic situation for landsliding. In addition, the weaker clay and bentonite predominate in the lower portion of the section, with a greater percentage of sandstone near the top. Several samples of the almost unconsolidated clay in the lower part of the section were found to consist almost entirely of montmorillonite. The expandable nature of this clay mineral may be a contributing factor to the mechanism of sliding. Deeply buried clay horizons are likely to be saturated with water and should remain at a fairly constant state with respect to changes in volume. On the other hand, if the potential horizon of failure is located in the vicinity of the water table, fluctuations in the water table may initiate expansion and contraction which could tend to induce or support mass wastage.

Above the sill, which has a maximum exposed thickness of approximately 50 feet, are rocks which probably represent the unnamed sandstone and shale unit above the Albino as described by Hall (1961). This unit is mapped as Upper Cretaceous undifferentiated on Plate I, in the section of the map done by this writer. A very distinctive chert pebble conglomerate, 6 inches thick, is found several feet above the upper contact of the sill in the Middle Fork canyon. About 10 to 25 feet of shale with a few interbedded hard white tuff layers overlie this conglomerate. Above these rocks is a resistant sandstone and shale sequence about 50 feet thick which forms a prominent ledge at the rim of the Middle Fork canyon. These sandstone beds seem mostly nontuffaceous and containe some large pelecypods.

This unit overlying the Albino Formation is resistant to erosion. It would seem to provide a good base for construction. As it does overlie the Albino, however, it would participate in any large scale mass movements initiated in the Albino.

The stratigraphy of Lone Mountain involves alternating layers of andesitic sills and sedimentary rock. Much work remains to be done to correlate the sedimentary sequence of Lone Mountain with those in the basin. It is probable that the sedimentary layers represent still younger beds than those previously described.

IGNEOUS ROCKS

Igneous rocks in the area consist of sills related to the Lone Mountain Igneous Complex. Their combined thickness is greatest at Lone Mountain, the center of the complex. Sills are also found throughout the map area at several reasonably persistent positions in the section, and at frequent non-persistent intervals.

The sills vary in lithology, ranging from basalt porphyry to latite porphyry in those types identified. The most common type, however, is andesite porphyry. A thin section of this rock shows altered plagioclase, K-feldspar, pyroxene, and biotite, and minor amounts of quartz and opaque minerals.

A thin section of a basalt porphyry sill contains phenocrysts of clinopyroxene in a groundmass of lath-shaped plagioclase and pyroxene. In outcrop, the mafic sills are commonly found as a disintegrated, unconsolidated soil-like mass of grains. In places, however, they are resistant enough to crop out as rock.

The lowest sill exposed in the section is andesite porphyry and is located above the Kootenai formation, and found cropping out on various portions of Andesite anticline, such as near Andesite Lookout Tower. This rock type is the one described above and is the most common type in the area.

The next major sill is a mafic rock intruded above or within the upper part of the Muddy Sandstone. This sill is 75-100 feet thick east of the plain bordering the South Fork (sec. 2, T.7 S., R. 3 E.).