



Quaternary and environmental geology of part of the West Fork Basin, Gallatin County, Montana  
by Clifford Montagne

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

Montana State University

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Abstract:

The West Fork (of the Gallatin River) lies in the Madison Range between Bozeman and West Yellowstone, Montana. It is the site of Big Sky of Montana, a proposed year round recreation and real estate development. Field work was partially funded by the National Science Foundation for a project entitled Impact of a Large Recreation Area on a Semiprimitive Environment.

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Neoglacial moraines and talus flows are found in the highest cirques.

Wisconsin glaciers, originating in the east facing cirques on Lone Mountain, reached the vicinity of the upper village site (S30, T6S, R3E). An inactive Neoglacial rock glacier now occupies the cirque. It is partially covered by an active rock glacier.

Landsliding is still active, especially where hillslope equilibrium is disturbed by construction. Excess water, alternating folded sandstones and shales, clays, steep, slopes, and till overload have caused past and present sliding.

Potential rockfalls and snow avalanches pose threats to mountain use.

The proposed upper village site lies on outwash and till which covers shale bedrock. North of this site are some active slide tension cracks. Soils mapping is correlated with the surficial geology. Many soil boundaries correspond to surficial geology boundaries. Clay soils developed on shale are poor building sites.

Some areas with unique natural habitats should be left as natural preserves.

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THE WEST FORK BASIN, GALLATIN COUNTY, MONTANA

by

CLIFFORD MONTAGNE

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

of

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in

Earth Science (Geology)

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Bozeman, Montana

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TABLE OF CONTENTS

INTRODUCTION

Location . . . . .	3
Physiographic Setting . . . . .	3
Geologic Setting . . . . .	4
Previous Geologic Work . . . . .	6
Climate . . . . .	9
Flora and Fauna . . . . .	10
Current Use . . . . .	11
Scope and Method of Study . . . . .	11
Definition of Environmental Geology . . . . .	13
Objectives of Study . . . . .	14

QUATERNARY GLACIAL AND SURFICIAL GEOLOGY

Introduction . . . . .	16
Quaternary Glacial Correlations in the Rocky Mountains . . . . .	16
Use of Soils in Age Correlations . . . . .	19
Pre-Wisconsin Glaciation in West Fork . . . . .	22
North Fork Bull Lake Glaciation and Related Sliding . . . . .	22
North Fork Pinedale Glaciation . . . . .	29
Neoglaciation . . . . .	32
Glaciation in the Hanging Valley . . . . .	33
Beehive Creek Bull Lake Glaciations and Related Landslides . . . . .	34
Beehive Pinedale Glaciations . . . . .	43
Beehive Neoglacial Features . . . . .	45
Moonlight Creek Pinedale Glaciation . . . . .	45
Lone Mountain Wisconsin Glaciation . . . . .	46
Inactive Rock Glacier . . . . .	48
Active Rock Glacier . . . . .	49
Additional Mass Movement Features . . . . .	54
Recent Sliding . . . . .	54
1970 Landslide . . . . .	55
Causes of Sliding . . . . .	56
Rockfall . . . . .	58
Snow Avalanches . . . . .	59
Pre-Wisconsin Welded Tuff and Till . . . . .	61

ADDITIONAL ASPECTS OF ENVIRONMENTAL GEOLOGY

Introduction . . . . .	66
Upper Village Area . . . . .	66
Road Building . . . . .	74
Soils Correlations . . . . .	74
Natural Areas . . . . .	79

Suggestions for Further Study . . . . .	80
REFERENCES CITED	
APPENDIX	
Stratigraphy . . . . .	87

LIST OF PLATES AND FIGURES

Plate I Environmental Geology of the West Fork Basin, Gallatin  
County, Montana

Plate II Inferred Cross-Section B-B'

Figure 1.	View of Lone Mountain Cirque . . . . .	2
2a.	Local Setting . . . . .	7
2b.	Topographic map of study area . . . . .	8
3.	Glaciation in the Rocky Mountains . . . . .	18
4.	Soils developed on Bull Lake and Pinedale Till . . . . .	21
5.	Glacial features in North Fork . . . . .	23
6a.	Picture of Bull Lake soil profile . . . . .	25
6b.	Soil developed on Bull Lake Till . . . . .	26
7.	Landslide reactivated by logging road . . . . .	27
8.	Bull Lake and Pinedale soil profiles along North Fork . . . . .	30
9.	East facing cirque carved from south facing basin . . . . .	32
10a.	Glacial and surficial features in vicinity of Beehive Basin . . . . .	35
10b.	Cirques of Beehive Basin and the Hanging Valley . . . . .	36
11a.	Concentric landslide scarps . . . . .	39
11b.	Perched swamps and ponds . . . . .	39
11c.	Till mantled slide-slump blocks . . . . .	40
12.	View from Andesite to Beehive Basin . . . . .	41
13.	Landslide scarp in Bull Lake till . . . . .	42
14.	Alluvial fill behind Beehive Pinedale terminal Position . . . . .	44
15.	Relation of Ulerys Lakes to Beehive Pinedale Terminal position . . . . .	45
16.	Glacial features of Lone Mountain . . . . .	50
17.	Active rock glacier . . . . .	51
18.	Areal view of Lone Mountain rock glaciers . . . . .	52
19.	Avalanche paths on Wilson Peak . . . . .	60
20a.	Clay soil on shale bedrock . . . . .	69
20b.	Sandy soil on sandstone bedrock . . . . .	70
21.	View of clearcut area (upper village site) . . . . .	72
22.	Creek draining clearcut area during rain . . . . .	73
23.	Correlation of soils and surficial geology . . . . .	76
24.	Map of areas undesirable for construction . . . . .	81

ABSTRACT

The West Fork (of the Gallatin River) lies in the Madison Range between Bozeman and West Yellowstone, Montana. It is the site of Big Sky of Montana, a proposed year round recreation and real estate development. Field work was partially funded by the National Science Foundation for a project entitled Impact of a Large Recreation Area on a Semiprimitive Environment.

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Some areas with unique natural habitats should be left as natural preserves.



INTRODUCTION



Figure 1. East side of Lone Mountain, showing the large cirque and rock glaciers.

#### LOCATION

This report concerns the Environmental and Quaternary geology of a portion of the drainage of the West Fork of the Gallatin River, midway between Bozeman and West Yellowstone, Montana. The West Fork basin is the proposed site of Big Sky of Montana, a recreation and living development. The particular area under study is bounded on the south by the Middle Fork of the West Fork, on the north by the Spanish Peaks, and on the west by a northward bearing from Lone Mountain to the Spanish Peaks.

#### PHYSIOGRAPHIC SETTING

The area lies at the southern end of the Northern Rocky Mountain Physiographic Province, a subdivision of the Rocky Mountain System (Thornbury, 1964). Local relief encompasses elevations from the Gallatin Canyon at 6,000 feet; to the summits of the Spanish Peaks and Lone Mountain at over 11,000 feet. It is an area of high relief, with peaks, cirques and moderately incised canyons which discharge to the alluvial level of the Gallatin River. The topography is controlled by bedrock structural features and modified by glaciation and other mass movement. Some striking examples of stream superposition exist. The terrain is in the youthful to early-mature stage of geomorphic development.

## GEOLOGIC SETTING

The material for this section has been taken from Swanson (1950), Hall (1961), and McMannis and Chadwick (1964). Figure 2a is a sketch map showing the local setting and some structural features. Figure 2b is a topographic map of the study area.

The Madison-Gallatin uplift is a broad anticlinal uplift and faulted block with exposures of Pre-Cambrian to Tertiary rock. The Gallatin River flows north along a structural low in the middle of the uplift, separating the Madison Range on the west from the Gallatin Range on the east. The West Fork basin (structural and topographic) lies in the Madison Range and is bordered by the Gallatin River on the east, the Spanish Peaks on the north, the Gallatin-Madison Divide on the west, and the Buck Creek anticline on the south.

The Spanish Peaks Fault is a high angle reverse fault which runs in a northwest direction along the north side of the West Fork basin. The crystalline Spanish Peaks rise on the north side of the fault, which has at least 10,000 feet of displacement. It elevated the Spanish Peaks in Cretaceous to Eocene time. The Spanish Peaks Fault is overlapped by Tertiary volcanics east of the Gallatin River. The fault system may extend as far as Gardiner, Montana.

South of the Spanish Peaks, folded sedimentary rocks are exposed. The Lower Basin syncline parallels the Spanish Peaks Fault and forms most of the West Fork basin. The Buck Creek anticline, also trending

parallel to the Spanish Peaks Fault, extends to the Snowflake fault zone near the boundary of Yellowstone National Park. Most of the exposed sedimentary rocks in the West Fork basin are sandstones and shales of Cretaceous age. A stratigraphic description is found in the Appendix.

Andesite anticline is cut at both ends by faults. It may be related to the Lone Mountain intrusive complex.

Lone Mountain is a multiple horizon laccolithic intrusion, in which Andesite porphyry alternates with sedimentary layers. Fan, Cedar, and Pioneer Mountains to the southwest are similar to Lone Mountain. Andesitic sills are found in the western portion of West Fork basin and are probably related to Lone Mountain.

East of the West Fork basin, the Gallatin Range has been covered by a pile of volcanic pyroclastics and sediments, which extends south beyond the Yellowstone Park boundary. The southern Gallatin Range consists of folded sedimentary rocks and intrusives. The southern Madison Range consists of folded sedimentary rocks and exposed basement rock.

Thus the West Fork basin is a structural low of folded and faulted sedimentary rocks, with the crystalline Spanish Peaks on the north and the multiple intrusive, Lone Mountain, on the west. The basin is filled with relatively non-resistant rocks, whereas the Spanish Peaks complex is an uplifted block of relatively resistant rock, hence the

topographic difference.

#### PREVIOUS GEOLOGICAL WORK

Early geologic exploration in the region was done in the late 1800's by F. V. Hayden, A. C. Peale, J. P. Iddings and W. H. Weed. A. C. Peale (1893) also mapped the Three Forks (Montana) Quadrangle, an area about the size of Yellowstone Park which includes the West Fork area. Peale's work in the West Fork remained the only work until R. W. Swanson (1950) mapped a part of the Three Forks Quadrangle, including the area of this study. His map was used as the basis for the bedrock geology of this study. J. A. Wilsey Jr. (1948) mapped in the upper Gallatin area in the late 1940's, but didn't finish the work before his death. W. B. Hall, now of the University of Idaho, carried on Wilsey's work with his own Ph. D. thesis (Hall, 1961) and other publications. Wilsey's and Hall's work is concentrated in an area to the south of West Fork. However, thier work, and W. B. Hall's personal consultations have been a great aid to the writer.

W. J. McMannis and R. A. Chadwick, of Montana State University, mapped the geology of the Garnet Mountain Quadrangle, which is directly east of the Spanish Peaks Quadrangle and West Fork (McMannis and Chadwick, 1964).

# LOCAL SETTING OF PROJECT AREA

SCALE 1:250,000

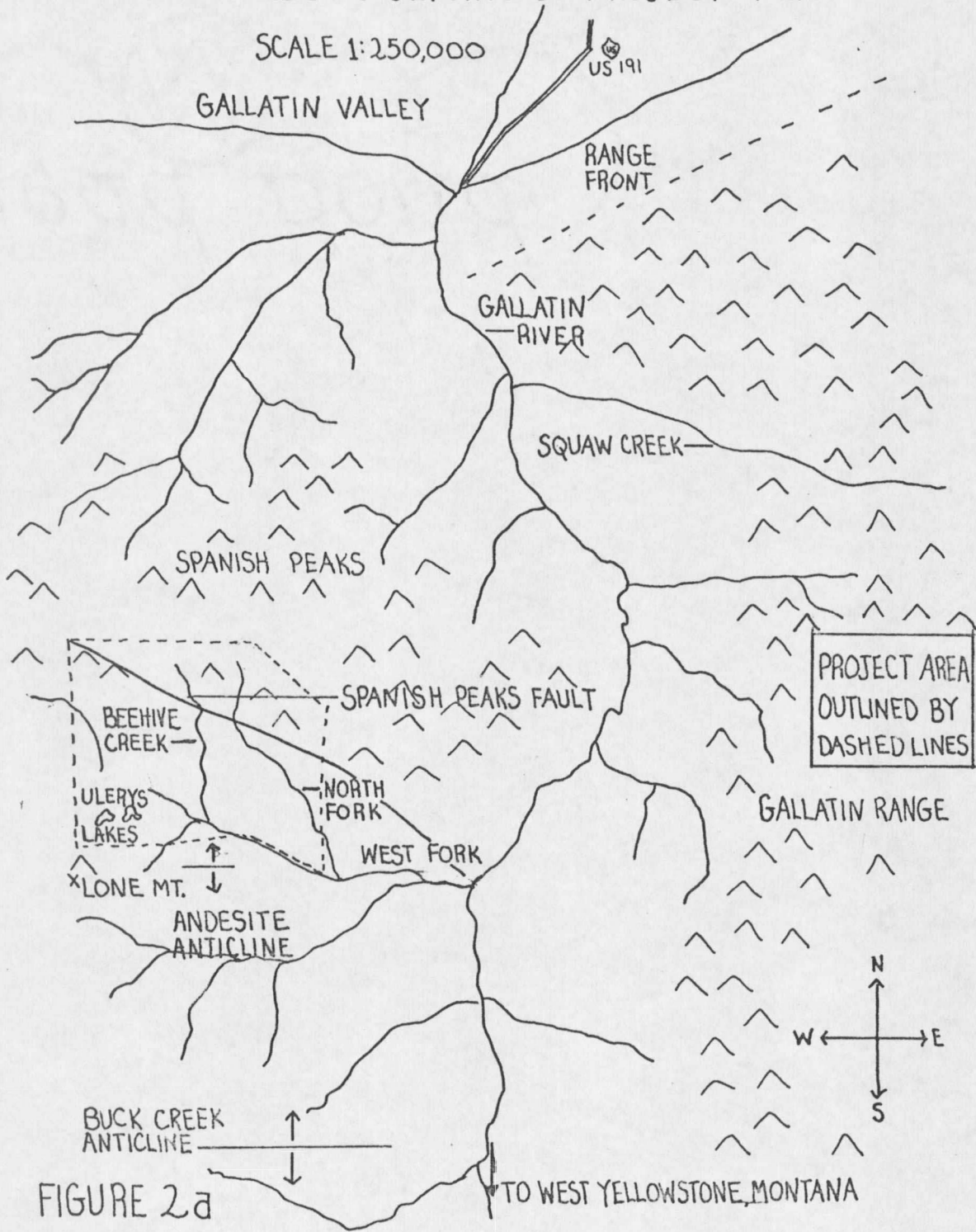


FIGURE 2a





Figure 2b. Topographic map of the study area. Boundaries are indicated by solid line.



## CLIMATE

The climate is typical of a mountain basin in the Northern Rocky Mountains, with long winters and short summers. Summer temperatures seldom exceed 85 F, and winter temperatures drop well below 0 F. At an elevation of 8,150 feet in Bear Basin (SW1/4 S9, T6S, R3E) the April 1 snowpack averaged 22.5 inches of water from 1963 to 1969. In Carrot Basin, approximately 15 miles south of West Fork at 9,000 feet elevation, the April 1 snowpack averaged 42.5 inches of water for 1967 to 1969 (USDA and SCS, 1970).

Climatological records from the Fred Pessel ranch, about 10 miles southeast of Lone Mountain on Beaver Creek (S 18, T7S, R4E) at 6,700 feet elevation give an indication of the climate in the West Fork Basin. The following data are for the Pessel ranch.

January mean maximum temperature	29.0 F
January mean minimum temperature	7.5 F
July mean maximum temperature	78.4 F
July mean minimum temperature	37.9 F

### Average monthly precipitation

January	1.66"
February	.71"
March	1.39"
April	1.43"
May	2.52"
June	2.96"
July	1.78"
August	1.37"
September	2.27"
October	1.39"
November	1.48"

December 1.41"

Average yearly precipitation 20.43"

(U. S. Dept. of Commerce, Weather Bureau, Climatological Data Montana,  
Jan. 1963 - Jan. 1971).

#### FLORA AND FAUNA

The area is 90 percent forested. Lodgepole Pine (Pinus contorta Dougl.) is the present dominant taxon of the forest overstory. Also common are Englemann Spruce (Picea engelmannii Parry) on wet north slopes, Rocky Mountain Douglas Fir (Pseudotsuga menzeisii var. glauca (Beissn.) Franco), and at high altitudes above 8,500 feet, Limber Pine (Pinus flexilis James) and Whitebark Pine (Pinus albicaulis Engelm.). Some aspen groves (Populus tremuloides Michx.) are found on lower slopes. Big sagebrush (Artemesia tridentata Nutt.) and Idahoe Fescue bunchgrass (Festuce idahoensis Elmer) occupy the lower open areas while mountain meadows are common at higher elevations. Upper timber line is at approximately 9,000 feet. Some meadows occupy sidehill colluvial sites, but most are found associated with meandering streams, bogs, wet areas, and filled in ponds. The forests show evidence of previous fires, but much of the timber is mature and there is no evidence of recent fires. Much of the lower area has recently been logged, and natural recovery from this is either not occurring or is very slow. This has had a significant impact on the ecology and

surficial stability of the logged areas.

The study area has a natural faunal population ranging from insects to big game. In early to mid-summer, mosquitos impede outdoor work. Later in the summer, deerflys and horseflys are prevalent. The insect season is over by early September. Small animals include frogs, toads, garter snakes, mice, squirrels, chipmunks, coneys, porcupine, and skunks. Big game animals include deer, moose, elk, mountain sheep, mountain goats, and bear. Old beaver cuttings were found, but there was no evidence of current beaver occupation. While the clear-cut logging activity has produced some additional forage, it may have driven the remaining game animals higher into the mountains by opening the area to vehicle access.

#### CURRENT USE

The West Fork basin is currently used for logging, cattle grazing, fishing, recreation and dude ranch horseback trips. Proposed use by Big Sky of Montana calls for the construction of a paved access road, ski lifts and trails on Andesite and Lone Mountains, a ski village at the foot of Lone Mountain (S30, T6S, R3E), private house and condominium sites and associated sewage and water development. A summer village is to be situated below (east) the writer's study area.

#### SCOPE AND METHOD OF STUDY

Field study was partially funded by a grant from the National

Science Foundation to the Center for Environmental Studies at Montana State University. The grant supports an interdisciplinary study of the West Fork basin and Gallatin Canyon which will establish environmental base lines for comparison as the basin is further developed. The grant project is titled The Impact of a Large Recreational Development on a Semiprimitive Environment. Professor John Montagne, Montana State University, was the principal geologic investigator for the project. Alan Kehew, Helaine Walsh and the writer jointly studied the West Fork basin under the guidance of Professor Montagne. Kehew worked to the south and Walsh worked to the southeast of the writer's study area (see credit map on Plate I).

Field work was completed during August and September, 1970. U. S. Forest Service Series E10 (photographed in 1961-1962) areal photographs (scale 4 in. per mile) and the U. S. Geological Survey 15 Minute Spanish Peaks Quadrangle were used for field mapping. Working from a base camp at the upper (ski) village, foot field traverses served to cover the map area. Several days were spent with Alan Kehew and Helaine Walsh on problems of mutual interest. The writer also had very helpful conversations with Professors C. C. Bradley, W. B. Hall and J. Montagne, who visited in the field. Joe Armstrong of the Montana Highway Department, Sam Smeding, W. C. Visscher of Northern Testing, and personnel of Van Kyken Drilling Company also provided consultation in the field.

Prior to this project, the writer gained practical experience in Quaternary geology mapping of similar areas in Yellowstone National Park under H. A. Waldrop, K. L. Pierce and G. M. Richmond of the U. S. Geological Survey.

#### DEFINITION OF ENVIRONMENTAL GEOLOGY

The term, environmental geology, is new, and formal definitions are not available. However, it is necessary to define the term as it applies to this report. Environmental geology is the study of geological features related to man's use of his environment and the relation of geology to other features of the natural environment. A geological setting may provide materials for man's use or serve as a site for man's activities. Geology may dictate the availability of materials or the technical and economic feasibility of a proposed site use. Geology influences characteristics of the natural environment, of which man is a part. Geological knowledge of these relationships may help man define and understand his impact on the environment. Because many features of the landscape are young geologically, study of the Quaternary history and surficial geology is an important part of environmental geology.

Environmental geology in the West Fork Basin is concerned with land use for recreation, residence and resource harvest (timber). It also deals with geological influences on the natural environment and

the role of geological history in shaping the present landscape.

#### OBJECTIVES OF STUDY

The objectives of this study are twofold:

1. Map and interpret Quaternary and surficial geology and correlate it with other work in the Rocky Mountains.
2. Find and study geological aspects of the area which may influence man's use of the environment in this or similar areas.

QUATERNARY GLACIAL AND SURFICIAL GEOLOGY

## INTRODUCTION

Mapping the surficial and glacial geology comprised the bulk of the field work for this study. Correlated with the bedrock geology, surficial features are the keys to the Quaternary history and environmental geology of the area. The following chapter lists criteria by which glacial features are mapped and distinguished from one another, describes the surficial features as mapped on Plate I, and outlines postulated causes of landsliding. The glaciations and rock glaciers of North Fork, Beehive Creek, Moonlight Creek and Lone Mountain are described, as well as associated landsliding. Rockfalls, snow avalanches and deposits of volcanic tuff (associated with till) are also described.

The reader concerned only with environmental implications of this study may wish to skip the first part of this section and start with the part on rock glaciers.

## QUATERNARY GLACIAL CORRELATIONS IN THE ROCKY MOUNTAINS

The concept of multiple glaciations during the Quaternary is well accepted. One of the principal objectives of the Quaternary geologist is to distinguish between glacial deposits of different ages. Work in the Wind River Mountains of Wyoming by Blackwelder (1915) and Richmond (1965), among others, is used as the basis for such correlation work in the Rocky Mountains. Age approximations are subject to change as



work is done. Figure 3 is abstracted from a correlation chart by Richmond (1965), and shows a presently accepted classification of glaciations in the Rocky Mountains.

The Rocky Mountain Wisconsin glaciations have obliterated much of the evidence for earlier glaciations. Such evidence when found is often simply classified as pre-Wisconsin or pre-Bull Lake. These glaciations were apparently more extensive than most Wisconsin glaciations, which were commonly cirque and valley glaciers with some local ice caps. In the Rocky Mountains, the Wisconsin glaciation is commonly divided into the Bull Lake and Pinedale stages.

Based on his Wind River work and other experience, Richmond (1965) has developed some of the following criteria as characteristics of Rocky Mountain glacial deposits and their interglacial soils:

- |                                      |   |
|--------------------------------------|---|
| Pre-Wisconsin                        | Remnants of highly weathered sheet till often found up to 1,000 ft. above canyon floors and usually above and beyond the limits of Bull Lake till. Evidence for three pre-Wisconsin glaciations has been found.   |
| Bull Lake                            | Smooth bulky subdued moraines, filled kettles, surface boulders often buried and weathered, up to three stades noted.   |
| Soil developed on Bull Lake deposits | Mature zonal soil, B horizon red brown to brown (5YR to 7.5 YR), 3 to 1.2 meters thick, yellow brown (10YR) in north, illuviated clay, moderately developed subangular blocky structure, Pedalfer-Pedocal boundary at 7,000 ft. in central Wyoming and 5,200 ft. in northern Montana. |

# GLACIATION IN THE ROCKY MOUNTAINS

FROM RICHMOND 1965

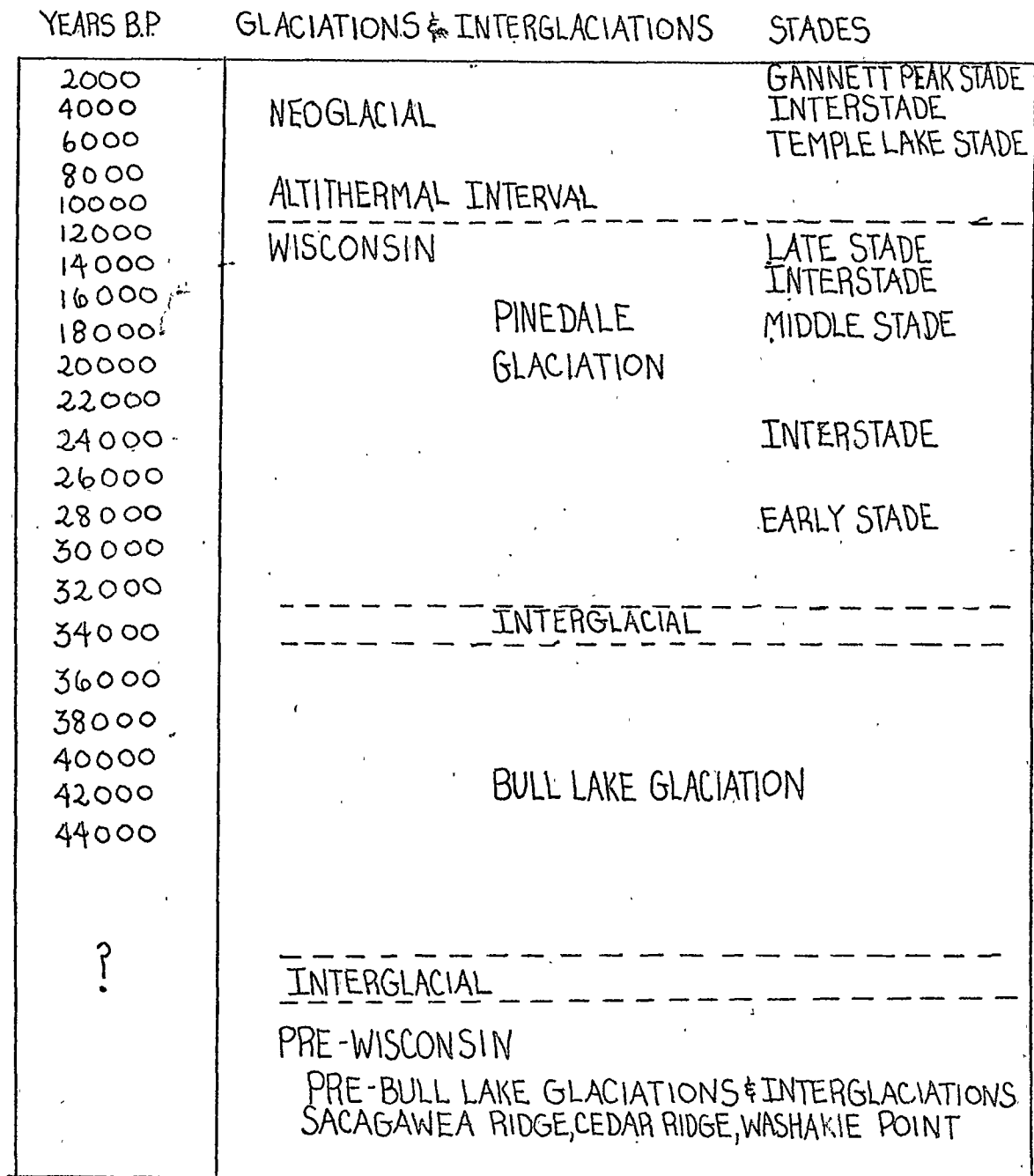


FIGURE 3

- Pinedale Moraines are steep, irregular and fresh in appearance, kettles are unfilled, surface boulders show little weathering. The moraines are usually smaller and lie up valley from the Bull Lake moraines. Three stades are known, the early and middle stade being of about the same extent. The late stade often did not extend out of the source cirque.
- Soils on Pinedale deposits Immature zonal soil, a horizon 10-15 in. thick, very little clay illuviation, weak to moderate structure, B horizon yellowish brown (10YR).
- Temple Lake Fresh moraines 18-55 ft. high with high altitude vegetation and weak azonal soil, often .5 to 1.5 miles from the cirque headwall.
- Gannett Peak Fresh rough moraines with no soil and only pioneer plants. The moraine of 1850 appears to be most extensive of several advances within the past few centuries.

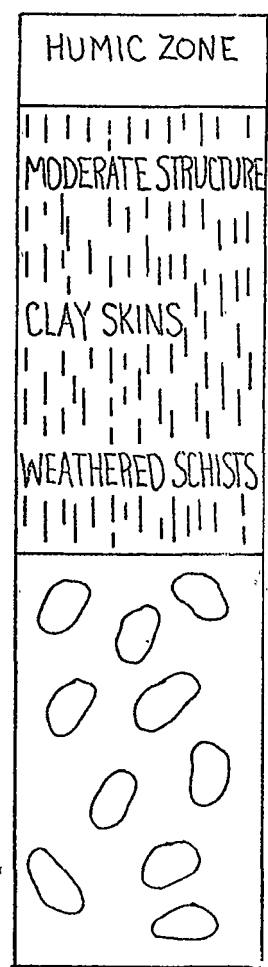
#### USE OF SOILS IN AGE CORRELATIONS

Because soil development is related to time, as well as to the factors of parent material, climate, relief and organisms, and since glaciations were followed by warm periods of soil formation, soils developed on Quaternary deposits can be a great help in age correlation. Morrison (1965) has proposed the name "Geosol" to describe ancient but preserved soils used as Soil-Stratigraphic units. Specifically, given similar factors of parent material, climate, relief and organisms, a soil profile developed on Bull Lake till, which was exposed to the post-Bull Lake interglacial climate for thousands of years, should show a higher degree of development than a profile

developed on younger Pinedale till, if not destroyed by Pinedale solifluction or other erosion. Profile characteristics include depth to the calcium carbonate horizon and development of an argillic B horizon (clay illuviation) with characteristic properties of texture and structural development. In this study, soils were used to confirm the age of glacial tills. The most useful and easily recognized characteristics were depth to unaltered parent material and the existence of an argillic B horizon. Sometimes this method of age distinction is an expedient and useful tool. However, occasionally differences are not apparent or are confusing. Figure 4 diagrams typical soil profiles developed on Bull Lake and Pinedale tills.

# BULL LAKE AGE SOIL

# PINEDALE AGE SOIL

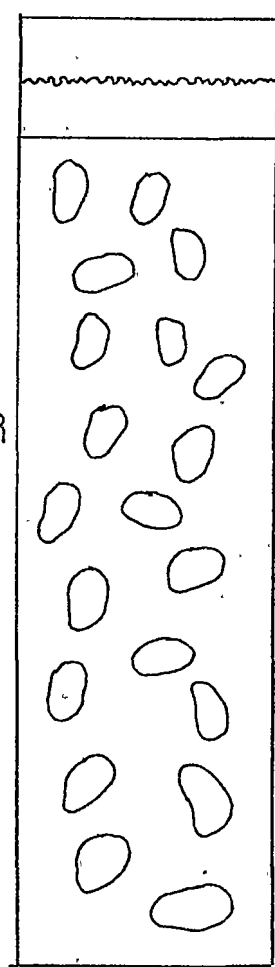


A 0'-12"  
BLACK MOLLIC  
EPIPEDON

B 12'-35"  
REDDISH BROWN  
ILLUVIAL CLAY,  
MODERATE SUBANGULAR  
BLOCKY STRUCTURE,  
WEATHERED SCHISTS  
ccā

C 35"+  
GRAY OR YELLOW  
PARENT TILL

GRASSLAND AND  
SAGE COVER



A 1'-15"  
HUMIC & DUFF  
A<sub>3</sub> COLOR CHANGE  
AT START C HORIZON  
(B HORIZON VERY  
THIN IF PRESENT)

C UNALTERED PARENT  
TILL

LODGEPOLE PINE  
FOREST COVER

FIGURE 4 SOILS DEVELOPED ON BULL LAKE AND PINEDALE TILL

#### PRE-WISCONSIN GLACIATION IN WEST FORK

Patches of high level topographically isolated till imply that the area was almost completely ice covered at one time. However, the most obvious glaciations consisted of mountain valley glaciers. By regional correlation with features in the Wind River Mountains of Wyoming, (Blackwelder, 1915; Richmond, 1965), these features are of Wisconsin and recent age. Pre-Wisconsin glacial features have been largely obliterated by the extensive Wisconsin glaciations in the area. Additional information on the pre-Wisconsin glaciation in the West Fork will be given in subsequent pages. Deposits of this glaci-ation are associated with a welded tuff.

#### NORTH FORK BULL LAKE GLACIATION AND RELATED LANDSLIDING

Figure 5 diagrams glacial features in North Fork.

The largest of the Wisconsin glaciations in the North Fork drain-age terminated below the junction of the Middle and North Forks in an area mapped by Walsh (1971). The terminal position is approximated by a large smooth end moraine between Lone Mountain Ranch and Crail Ranch (S22, T6S, R3E). Approximately three miles above the terminal position, at an elevation of 8,000 ft., the lateral moraine consists of at least 100 ft. of till capping the bedrock ridge core. The ridge is mantled with till on both sides.

A small terminal moraine directly north of the Lone Mountain Ranch

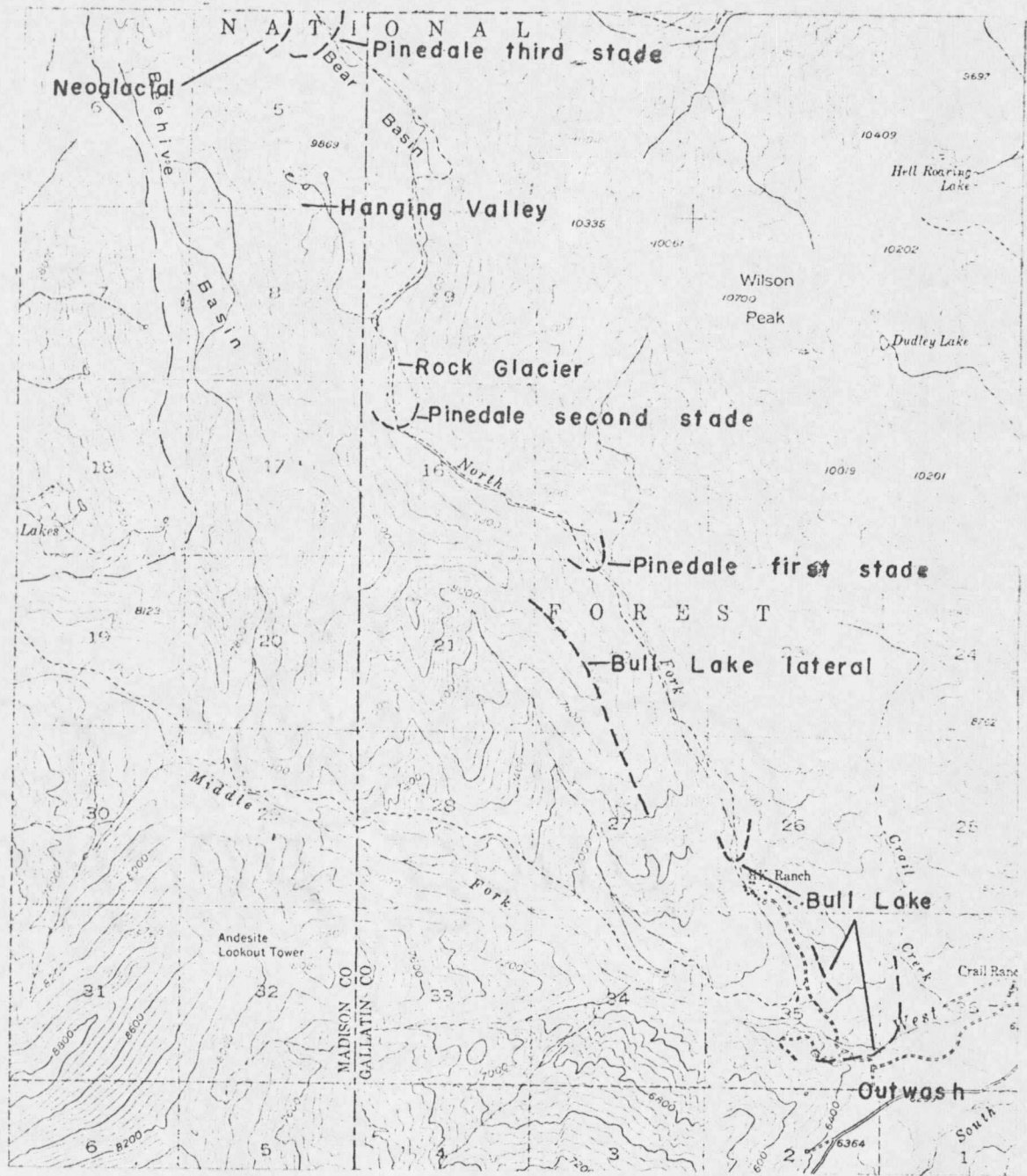


Figure 5. Glacial features in North Fork.

(SW1/4 S26, T6S, R3E), which has a rounded mature form similar to that of the main terminal moraine, indicates at least one smaller stade of Bull Lake glaciation. A soil on till just above this terminus is similar to soil on the main terminal moraine. A Bull Lake soil profile on the main terminal moraine is illustrated and described in Figures 6a and 6b.

On both sides of the west ridge of the North Fork canyon, unmodified topography developed in till is characteristic. The topography consists of hummocky morainal type forms and unfilled depression. Scarps and slump blocks characteristic of landsliding are present. Cretaceous shale is exposed in places underneath the till and is a basic factor in the sliding. The upper scarp of one of the slides (S21, T6S, R3E) cuts the high lateral moraine at 8,000 ft. and exposes in the midsection of the slide some 300 vertical feet below and to the east.

Figure 7 shows the Middle Fork logging road cutting through a large slide area on the west side of the North Fork ridge approximately 1.2 miles above the North Fork road crossing. The slide is located in S27, T6S, R3E and has a sharp upper scarp and very hummocky fresh topography. It is covered with 5 to 10 feet of till and very little bedrock is exposed. The road cut pictured in Figure 7 exposes about 15 feet of what is thought to be Cretaceous Thermopolic Shale, which is presently actively sliding. The new road surveyed by the





Figure 6a. Soil developed on Bull Lake till north of Crail Ranch. Note black mollic epipedon, brown B2t horizon and yellowish parent material which is till of crystalline rocks from Bear Basin.

SOIL DEVELOPED ON BULL LAKE TILL FROM NORTH FORK  
ON BENCH NORTHWEST OF CRAIL RANCH

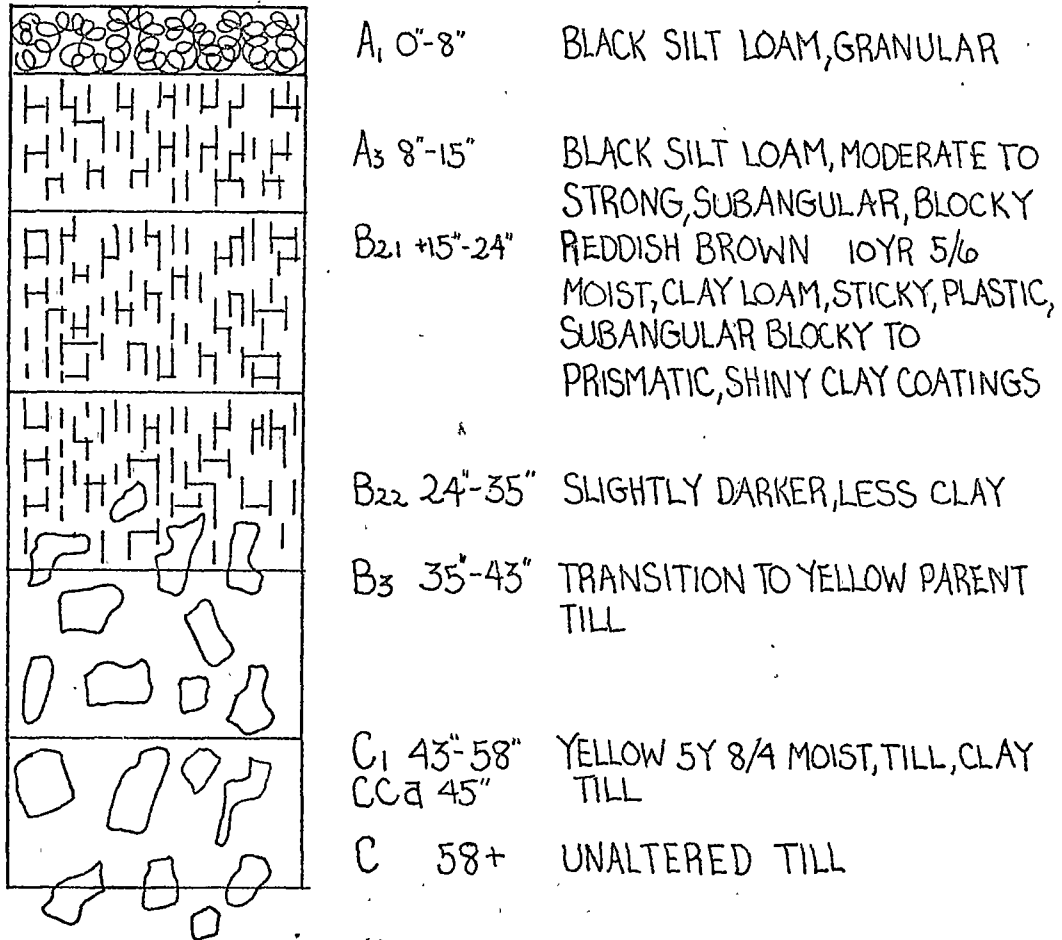


FIGURE 6b

LOCATION S36, T6S, R3E ON GLACIAL  
FLUVIATILE BENCH WEST OF CRAIL CREEK,  
COVER OF SAGEBRUSH AND GRASS,  
ELEVATION 6400-6500 FEET





Figure 7. Landslide reactivated by logging road. It is developed in Cretaceous Thermopolis Shale and mantled with Bull Lake glacial till.

Montana Highway Dept. will avoid this unstable slide area (Joe Armstrong, Mont. Highway Dept. Geologist, Personal communication, August, 1970).

In summary, the North Fork Bull Lake glacier was of significant size, terminating about 9 miles from the parent cirque in Bear Basin. It was fed from the main east facing cirque, the upper valley walls, and the hanging cirque valley to the west of Bear Basin (S5, 8, T6S, R3E). Midway to the terminal position, the ice was at least 600 feet thick. Till, consisting of crystalline material, spilled over the west ridge of the North Fork canyon and covered the hillside. The till overburden, deposited in early Wisconsin time (Bull Lake), covered the Cretaceous sandstones and shales. During the late Wisconsin (Pinedale) glaciation and deglaciation, the Cretaceous bedrock became unstable and slid. This was probably due to increased fluvial activity and the weight of the till overburden. The sliding was evidently not catastrophic, but behaved as a slow flow. It has continued to the present day in some areas. The slides usually have well defined upper break-away scarps and characteristic fresh lumpy topography. This till-covered topography appears to be Pinedale glacial deposits until it is recognized as a landslide.

The writer assigns the above described glaciations an age of Bull Lake or early Wisconsin for the following reasons:

1. Form        The till has the classic rounded mature Bull Lake form, with few unfilled depressions and lack of fresh, lumpy topography. Most of the boulders are partly buried.
2. Soils       Soil profiles on this till are well developed with regard to B horizon clay illuviation, and are much deeper than Pinedale soils which often only have A-C horizonation.
3. Position   This till lies below any other major moraines in the North Fork thus it must be older than those which are assigned an early Wisconsin (Pinedale) age. It also did not have the great extent of at least one previous glaciation in the area (pre-Wisconsin).
4. Sliding    The sliding activity was partially the result of Bull Lake till resting on sandstone and shale during Pinedale fluvial activity. One does not find such large scale sliding occurring in the Pinedale tills of the area. Thus, till of Bull Lake age is associated with Pinedale age sliding.

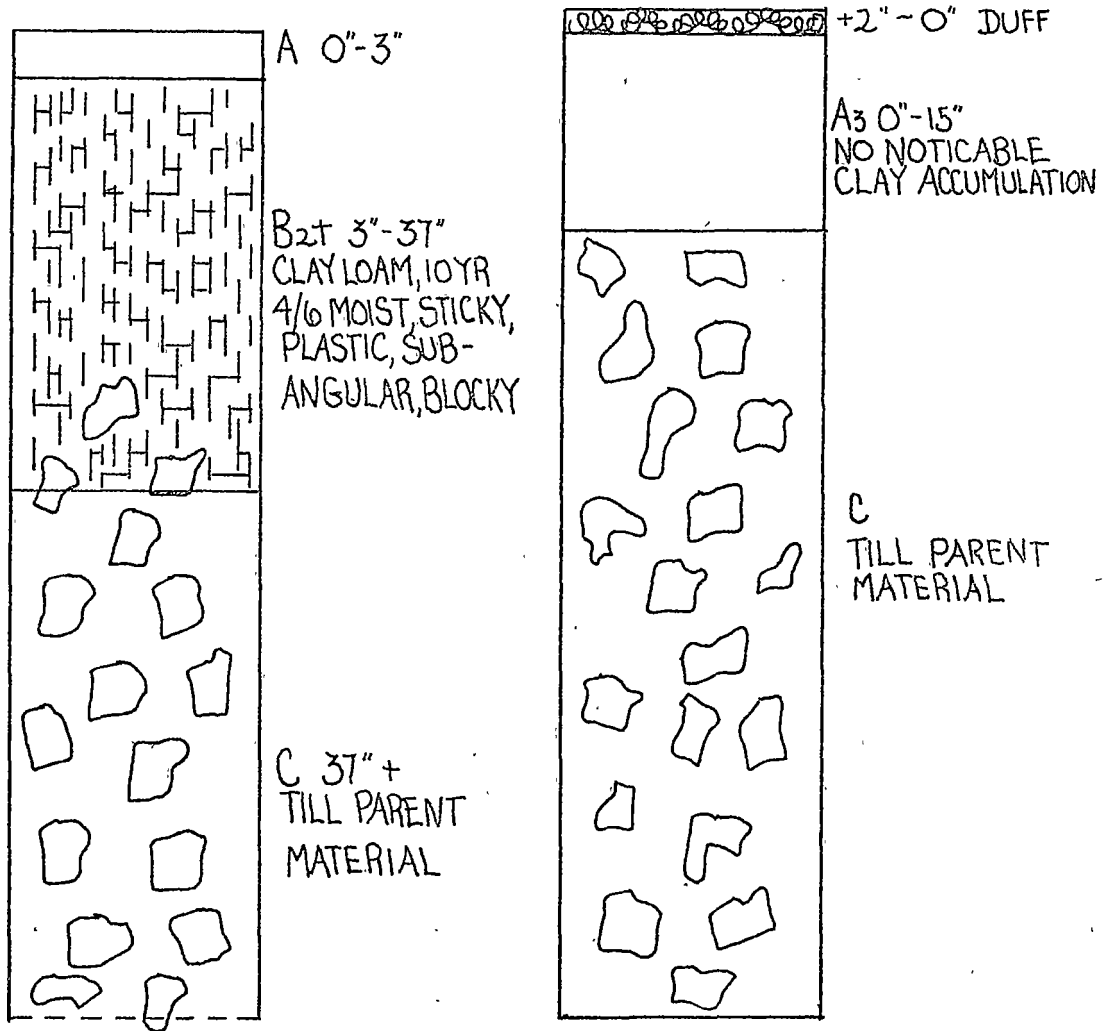
#### NORTH FORK PINEDALE GLACIATION

At least three Pinedale glaciers occupied the North Fork canyon, but were smaller than the Bull Lake glaciers.

Evidence for Pinedale glaciation in the North Fork is found in S22, T6S, R3E. Here, fresh lumpy till with unfilled kettles lies on the canyon floor. This till dammed North Fork. Alluvial fill behind the dam forms a meadow. The soil profile on this till differs from a profile on Bull Lake till a short distance down the canyon. The two profiles are diagramed in Figure 8.

No lateral moraines have been found descending the canyon walls to

# BULL LAKE AND PINEDALE SOILS ALONG NORTH FORK



BOTH SOILS ARE LOCATED ON TILL OF CRYSTALLINE ROCKS JUST  
 ABOVE CREEK LEVEL AT ELEVATION 7200'-7400' ~ S 22 E 15  
 T 6 S R 3 E ~ VEGETATION IS LODGEPOLE PINE FOREST  
 FIGURE 8

this point; however, the west canyon wall is a slide at this location and the east wall is a bedrock cliff with talus and alluvial debris. This position appears to mark the furthest extent of the Pinedale first stage, which was the most extensive of the three Pinedale stages.

A possible terminal position of the second Pinedale stage is located in S16, T6S, R3E, where the North Fork canyon makes a sharp bend. A large till plug occupies the valley bottom here and is associated with a kame terrace which extends down canyon. Possible remnants of lateral moraines appear to be descending to this position on both sides of the creek. The exact terminal position can not be determined because of sliding on the west side of the canyon.

Further evidence for a Pinedale valley glacier terminus here is seen in the remnants of lateral moraines high above and up the creek. They incline downstream at angles of 20 degrees. Projection of these forms downstream leads to the terminal position described above. This terminal position is just below a Pinedale (based on freshness) rock glacier and alluvial fan. These two features, on opposite sides of the canyon, meet at the creek. They are features of the third stage of Pinedale glaciation which occurred after the second stage, which terminated just below.

The third stage of the North Fork Pinedale glaciation is represented high in Bear Basin, the parent cirque. In Bear Basin, which is

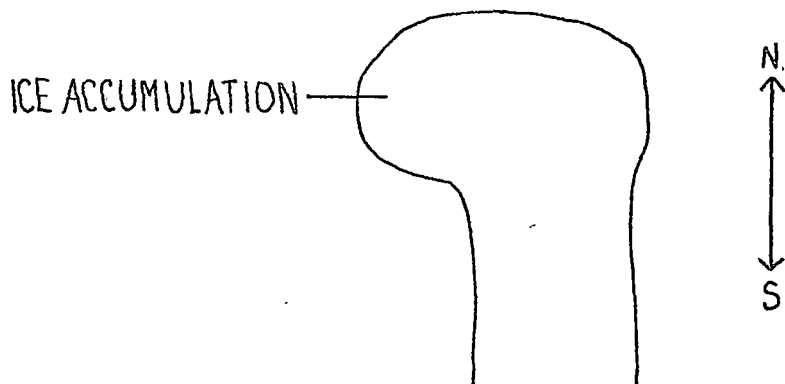


Figure 9. Diagram of an east facing cirque carved from a south facing basin.

predominantly south facing, the main ice accumulation was in a subsidiary east facing cirque. This is typical of such south facing accumulation basins and results in east facing cirques at the heads of the basins.

Moraines of the third stade are found on the floor of Bear Basin, having barely advanced out of the source cirque. They appear very fresh with lumpy topography, unfilled depressions and boulders on the surface. Vegetation is well established, but a minimum of soil formation has taken place. The soils were not closely examined. This small valley glacier was nearly .5 mile long and 200-300 feet in maximum thickness.

#### NEOGLACIATION

Above the Pinedale third stade terminal position are small well



defined moraines of a more recent glaciation which are correlated with the Temple Lake stade of Neoglaciation. These moraines are very fresh, with sharp well defined form, and have only a thin grass cover. These east facing glaciers were up to 1/4 mile in length and perhaps 100 feet thick. Two such moraines have been mapped in the upper cirque of Bear Basin. Semi-permanent snow fields occupy the backslope areas of these moraines. Additional study might reveal evidence for the Gannett Peak stade in this area.

#### GLACIATION IN THE HANGING VALLEY

The hanging valley in S5 and 8, T6S, R3E, which drains from the west into North Fork, contributed Bull Lake and Pinedale ice to the North Fork glaciers. Suggestions of a Pinedale third stade terminal position have been found in the lower part of this valley, and ground moraine is abundant in the upper part of the valley. Several small lakes occupy glacially gouged flat areas in the basin floor.

This hanging valley also faces to the south like Bear Basin. There is evidence that most of the ice accumulated on the east facing part of the cirque. Midway up the valley on the west side (east exposure) are fresh morainal forms which barely reach the basin floor. They are arcuate forms, concave toward the hillside, 50 feet in height, and with backslope depressions of 15 feet. They are composed of large (5 feet diameter) gneissic boulders, with a possible matrix of finer

material within. The rocks are well lichened, but the fine grained material between the rocks has only a sparse grass cover. On the basis of fresh form and position above the Pinedale till, the features are assigned to the Temple Lake stade. They may be either true glacial moraines or pro-talus ramparts. There is no doubt that they were caused by snow and ice either as permanent snow fields or as glacial ice during the Temple Lake stade of Neoglaciation.

#### BEEHIVE CREEK GLACIATIONS AND RELATED LANDSLIDES

Features in Beehive Creek are diagramed and illustrated in Figures 10a and 10b. Beehive Creek was occupied by Bull Lake and Pinedale glaciers. During the Pinedale deglaciation, large areas of Cretaceous bedrock mantled with Bull Lake till slid, creating extensive landslides mapped on Plate I.

Beehive Basin was an area of ice accumulation second only to Bear Basin in the study area. The topographic map or areal photograph of U-shaped Beehive Basin reveals it as a major ice source, although it faces directly south. Beehive Peak, 10,742 feet elevation, borders the north or upper end of the basin. The upper basin floor, at 9,400 feet, grades in a southerly direction for three miles to an elevation of 7,800 feet, where the canyon narrows to steep high walls. One mile below this point, at 7,200 feet, Beehive Creek discharges into the Middle Fork. Beehive Basin has well defined flat floor areas separated

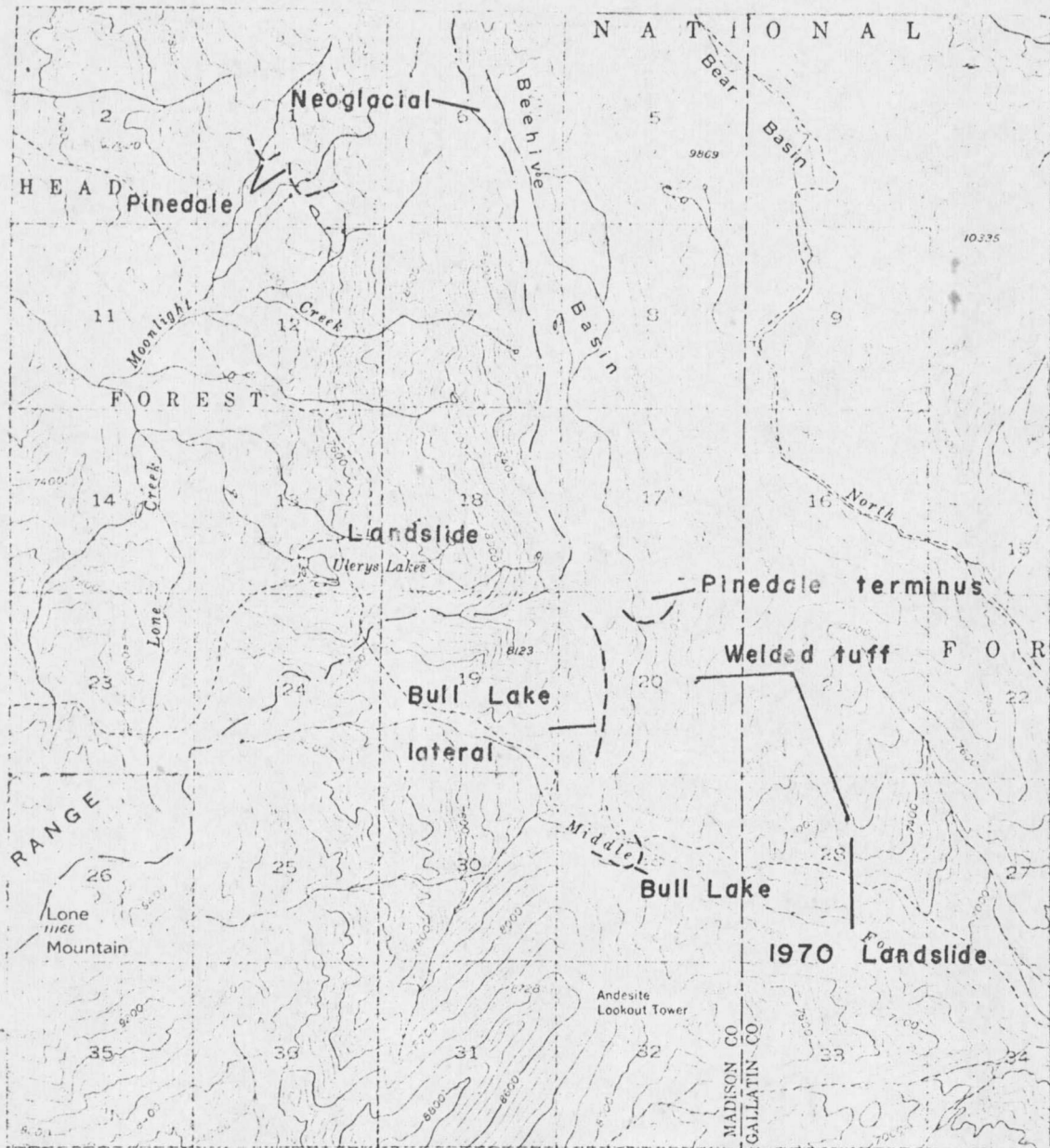


Figure 10a. Glacial and surficial features in vicinity of Beehive Basin.



Beehive Basin

Hanging valley

Figure 10b. Areal view showing the cirques of Beehive Basin and the hanging valley draining into North Fork.



by segments of steeper slope. This is likely due to differential rock resistance, as the Paleozoic and Mesozoic sediments are inclined steeply here.

Immediately below the junction of Beehive Creek with Middle Fork is a large rounded plug of till composed of crystalline rocks. This till can be traced up to a well defined knife edged lateral moraine above the lower Beehive Creek canyon (S20, T6S, R3E). The moraine is pictured on Figure 12. The rounded form and position of the till plug suggest that it is of Bull Lake age. It lies approximately 5 miles from the source area, and thus compares favorably in length with the North Fork Bull Lake glacier which had a larger and more easterly source cirque and a supplementary ice supply from the hanging valley. There is no evidence that Wisconsin ice extended further down Middle Fork than the Bull Lake till plug.

The elevation of the knife edge lateral moraine indicates that the ice was at least 300 feet thick. The position of the lateral indicates that ice did not spill over the ridge to the west from this lower position. The upper limit of glaciation on the east side of the canyon is well defined and mapped on Plate I.

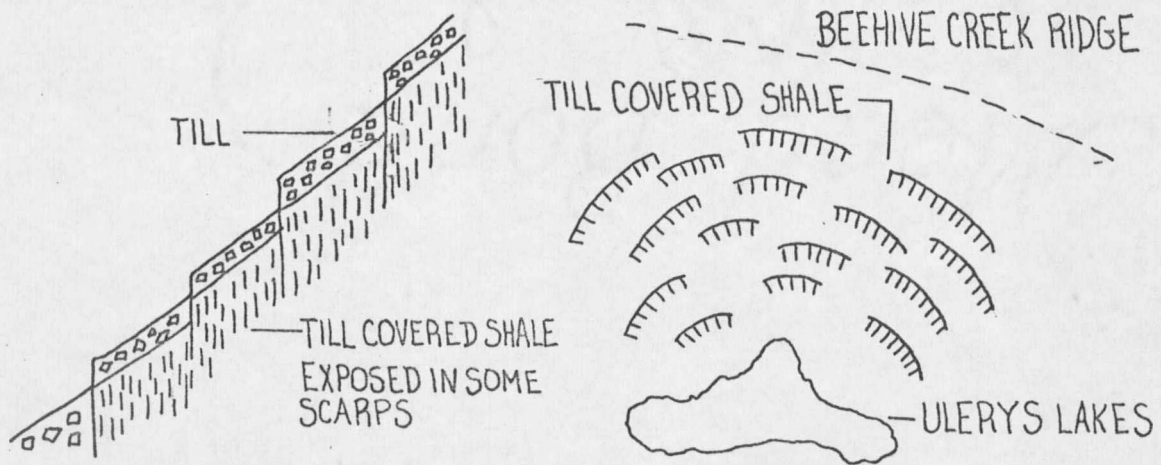
To the west of Beehive Creek, between Ulerys lakes and Moonlight Creek, is a large till mantled landslide. The slide area extends from the Beehive Creek ridge (Madison-Gallatin divide) west to the junction of Moonlight Creek and Lone Creek, which form Jack Creek. The slide

is up to 1.5 miles in width from Ulerys Lakes to Moonlight Creek, and is mapped in two parts which are separated by till mantled bedrock. Flow lines into Moonlight Creek from Beehive Basin and lack of a lateral moraine on the upper Beehive Creek ridge (at the head of the slide) indicate that Bull Lake ice from Beehive Creek spilled over and mantled the hillside with till. During the Pinedale deglaciation, increased fluvial activity saturated the Cretaceous bedrock with water. With the additional till mantle, the hillside reached a new equilibrium by slowly sliding and slumping. The slide probably wasn't catastrophic in nature; perhaps it took thousands of years for total movement to take place. Some scarps are still quite fresh and indicate possible movement at the present time. Movements of similar slides, but not till mantled, have been recorded by Kehew (1971) and Walsh (1971) south and east of this location.

The writer envisions possible downslope movement of 500 to 1,000 feet. There are up to 5 concentric headward scarps, but a very shallow gradient at the lower end. Minimum movement may be on the order of 50 to 100 feet.

Following are some features of these landslide areas:

1. Concentric scarps on the hillside above Ulerys Lakes.



2. Perched swamps and ponds.

