



Quaternary glacial geology and geomorphology of the Teton drainage area, Teton County, Montana  
by Ann Leslie Chalmers

A thesis submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree of  
Master of Science in Applied Science with a major in Geology.

Montana State University

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Abstract:

In the Teton River drainage area, Teton County, Montana, the Bull Lake substage of Wisconsin glaciation does not have readily definable moraines. From the data available in the mapped region, it appears that the Bull Lake mountain and Bull Lake continental ice met at Choteau. Previous to their melting, a lake was present in early Bull Lake time which became smaller as the two ice sheets met. The Bull Lake continental ice reached nearly to the top of the Flaxville Terrace, an elevation of 3980 feet, and extended farther west and south than was previously thought.

The Pinedale mountain ice has well defined limits and extended about four miles east of the mountain front. The lake deposits are of Pinedale age, as indicated by the ash deposits found by the writer, and tentatively identified in the field by Dr. Ray Wilcox, U.S.G.S., Denver, Colorado, as ash deposits of both Mount Mazama and Glacier Peak. The Pinedale continental ice has attenuated edges which enter the northeast section of the mapped area.

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by  
Ann Leslie Chalmers

A thesis submitted to the Graduate Faculty in partial  
fulfillment of the requirements for the degree of  
Master of Science in Applied Science  
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## ABSTRACT

In the Teton River drainage area, Teton County, Montana, the Bull Lake substage of Wisconsin glaciation does not have readily definable moraines. From the data available in the mapped region, it appears that the Bull Lake mountain and Bull Lake continental ice met at Choteau. Previous to their melting, a lake was present in early Bull Lake time which became smaller as the two ice sheets met. The Bull Lake continental ice reached nearly to the top of the Flaxville Terrace, an elevation of 3980 feet, and extended farther west and south than was previously thought.

The Pinedale mountain ice has well defined limits and extended about four miles east of the mountain front. The lake deposits are of Pinedale age, as indicated by the ash deposits found by the writer, and tentatively identified in the field by Dr. Ray Wilcox, U.S.G.S., Denver, Colorado, as ash deposits of both Mount Mazama and Glacier Peak. The Pinedale continental ice has attenuated edges which enter the northeast section of the mapped area.

## PART I

### GENERAL COMMENTS

#### CHAPTER I

##### A PROSPECTUS

History. The southernmost boundary of known continental glacial drift was first mapped across the entire United States in the late 1880's. The eastern half of the boundary was quite well known as much as twenty years earlier from the work of previous observers. The most striking feature of the western boundary of the continental drift is the fact that it does not extend as far south as its easternmost counterpart. The west segment of the drift may be up to 550 miles less in southward extent than the eastern half. This phenomenon may be accounted for by the more arid climate of the Great Plains and the wide Cordilleran belt, as far west as the Cascades, which had the effect of limiting the mountain and continental glaciation in Montana and farther west. The probable reason for the drier climate east of the Cascades is that their elevation was sufficiently high, at that time, to create a rain shadow on their leeward side. The prevailing west wind carried moist air from the oceans over the land to the mountains, where orographic lifting occurred, resulting in condensation and precipitation on the windward side. Thus, the air being

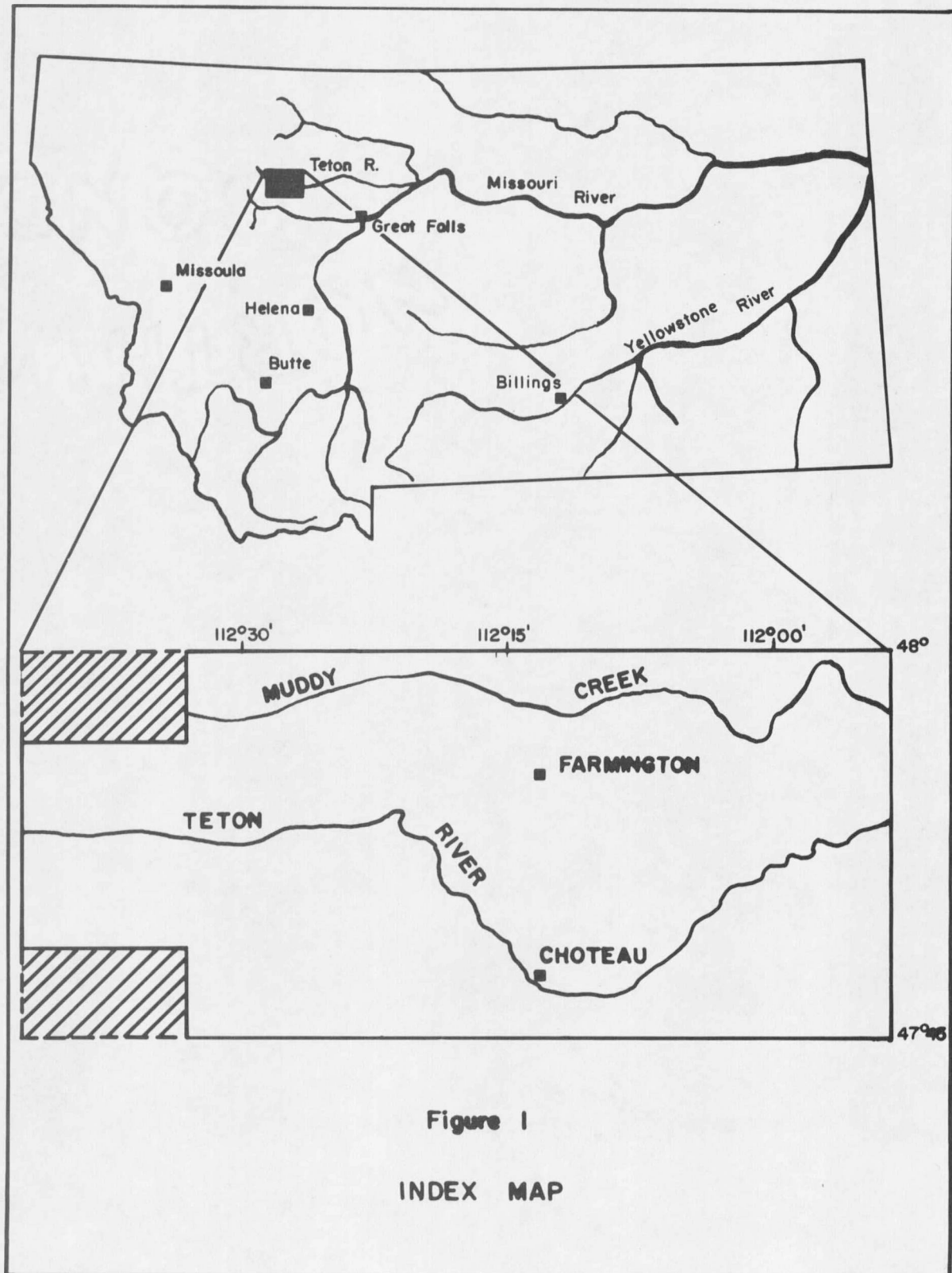
pushed over to the east side of the Cascades was drier, resulting in a somewhat arid climate in the region just described. Farther east maritime tropical air probably moved north and mixed with polar continental air. This would explain the more abundant moisture in the east, which gave rise to a greater accumulation of ice in the east, and farther extension south than the western segment of the continental moraine.

The center or source region for the Wisconsin continental ice sheet is known as the Keewatin center. This center developed when the ice on the plains reached the same level as the ice field in the mountains at about 55° north latitude, thus developing another center of outflow. This center changed position with the varying thickness, shape, and extent of the ice. During the most extensive Wisconsin glaciation, the center evidently lay on a line just east of Athabasca and Great Slave Lake (Antevs, 1934). This, then, is the source region for the continental drift in the Teton River drainage area. A plausible explanation for the creation of the great expanse of ice is found in Appendix A.

Introduction. The large area known as the Great Plains, with its vast smooth ground area, slopes gently upward to the west. Here and there the smoothness is interrupted by a coulee, or a stream cutting downward in the never-ending process of erosion. It is a land of few trees which, where found, are mainly along rivers or

coulees. The northern edge of the Great Plains in the United States is not so smooth, but rather is characterized by knobs and low spots, in some areas holding water in their hollows. This is where once huge glaciers dominated and now are gone. Beyond the western edge of these plains are the headwaters of the Missouri River, the Jefferson, Madison, and Gallatin Rivers meeting to create it, with the Sun, Teton, and Marias joining later to add their waters to the already large river. Even the Missouri River did not escape the effects of the ice and during the Wisconsin stage of glaciation was moved south, out of the bed where the Milk River now flows, to its present position.

The Teton River and its drainage area also came under the influence of ice, and evidence of this can be readily seen. The Great Plains meet the mountains (Figure 1) in the vicinity of the Teton River drainage. The plains in the Teton area rise to the mountains from an elevation of 3440 feet in the east with a slope of approximately thirty-five feet to the mile, until the area is reached where the transformation from plains to mountains occurs, with the plains finally attaining an altitude of about 4800 feet and a slope of about eighty feet per mile. Here also can be seen flat-topped benches and buttes which rise 250 to 500 feet above the plain. The mountains tower some 4000 feet above the structurally complex and topographically subdued western edge of the Great Plains. As the Teton River leaves the lofty peaks of the Rocky Mountains and rushes out onto the sudden





flatness of the plain, it first makes its way more than four miles through hummocky terrain sheltering small lakes in its irregularities. It then flows on beyond the "hills", which arch out from the mountains, and continues east on a flat plain protected by a layer of cobbles, well-rounded by miles of fluvial transport. It cuts into the basal slopes of the higher, flat-topped plains and hills. About nineteen miles east of the morainal area it begins to cut into soft, very thinly layered lacustrine silts and clays having a layer of ash about eight to ten feet below the top. Flat-topped hills lie close on both sides for about two miles, and to the east the river cuts its way into the soft sediments creating cutbanks fifty feet in height; in places these banks slide, creating shear faces and a hummocky topography. Some of these slides have temporarily blocked the river and stopped its flow, but it eventually cut through the material of the slide or changed its course and circumvented it. Some of the slides are fresh and show a brown gash of newly exposed thinly layered beds, and others are somewhat modified by rounding and protected by a mantle of grass. For nearly ten miles this situation prevails, and then the river runs through increasingly more hummocky terrain which becomes stronger in character eastward. The cutbanks here reveal unsorted materials containing clay, sand, silt, small and large rocks, even up to several tons in weight, all mixed together. Perched up on the humps are more huge boulders, some as much as five to seven feet across. The river continues eastward, in places cutting into river terraces, to where

it enters the Marias River.

Location. The area just described extends westward from the town of Choteau into the marginal part of the Rocky Mountains (Plate 1, in pocket), and runs east from Choteau nearly seventeen miles. It extends northward about twelve miles to Muddy Creek and goes southwest and thence west until it is four miles north of the Teton River, and from there the boundary is drawn westward to the mountains. The southern boundary east of Choteau extends along the Teton Ridge, thence westward through the T L Gap and westward along the Belleview Road into the mountains.

The area mapped comprises nearly 520 square miles. Another 500 square miles were generally examined to more accurately analyze the relationships which were observed in the area outlined above. Most of the area is accessible for field work all year, but parts are accessible only during the dry season or when frozen in winter. Easy access to much of the area is available by way of Highways 89, 287, and 221, which intersect at Choteau. There are many gravel roads which crisscross the eastern part of the area. To the west access consists of two main gravel roads and some cow trails.

Natural Setting. The economy of the region depends on grain and cattle ranching. Due to the area's location east of the Rocky Mountains it is fairly dry, classified as Bsk (A middle-latitude, cold Steppe climate). The area also has the chinook (Blackfoot meaning, snow eater) winds which often blow from the southwest. These are warm,

dessicating winds which descend the abrupt mountain slope and cut short what would otherwise be long cold spells, and give clear, sunny winter weather. The temperature may rise forty degrees or more in a short time due to these winds. Blizzards are common and may have sixty mile per hour northerly winds and snow which give zero visibility. They may last several days and pile snow into ten foot drifts.

Winter temperatures sometimes drop to fifty degrees Fahrenheit below zero, but these times are of a few days' duration only. Summer temperatures average in the eighties in the daytime and about forty-five degrees at night, averaging out to about sixty-three degrees in a normal year. There are about one hundred five frost-free days a year if the area immediately adjacent to the mountains is not taken into account.

Precipitation varies, averaging eleven and a half inches at Choteau and Bynum, whereas near the mountains it is fifteen inches. Some of the higher mountains are believed to receive sixty inches or more of precipitation. In the mountainous area more than fifty percent of the precipitation falls as snow. The measured annual precipitation is most concentrated in the period of April to September, especially in the lower areas (from precipitation records at Teton County Extension Office).

The area has a great deal of clear, sunny weather, interspersed with thunderstorms in the summer, most common during July and August. Fog is rarely observed. In winter the area receives some snow, which

rarely remains because of the chinook. All year long the area is swept by winds, usually westerly.

Flora and Fauna. The mountain glacier moraine supports a thick growth of jack pines, with grass and forbes also present. The mountains support a moderate cover of pine trees, interspersed with grassy meadows and locally swampy areas. To the east on the plains grows a sparse covering of grass and forbes, with cottonwoods and willows along the creeks and rivers. East of Choteau most of the area contains grainfields, and good exposures of subsurface materials are found only along rivers and manmade excavations. West of Choteau the area is mostly unimproved rangeland, and exposures are somewhat more common.

Various types of birds, such as Hungarian partridges, eagles, pheasants, grouse, a few prairie chickens, etc., and animals such as deer, antelope, and rattlesnakes are the most common wildlife of the plains region, although black bears and mountain lions venture as far east as the Choteau area occasionally. The mountain area and the adjacent plain have an abundance of deer, antelope, brown and black bears, grizzlies, mountain lions, bobcats, beaver, and, a bit farther east, also rattlesnakes.

Previous Investigations. The only relatively detailed study of the area under consideration was made by Alden in 1932, who published his results in U. S. Geological Survey Professional Paper Number 174. In the 1932 paper he defined some of the limits of continental and

mountain ice and also the number one, two, and three terraces, in part, but the paper was still of a reconnaissance nature. The adjacent area of Glacier Park and the land east of it has been studied by such observers as Alden and Clinton, 1912; Alden, 1924; and Hobbs, 1921. The Sun River region has been studied by Mudge, 1967, and by Martin, 1917. A glacial map of Montana east of the Rocky Mountains by Colton, Lemke, and Lindvall (1961) shows the approximate boundaries of the mountain and continental ice and Lake Choteau, as well as features in the surrounding area. These and other studies are cited in appropriate subjects in the paper.

Problem. The Bull Lake substage of the Wisconsin glacial stage has not been defined in the Teton River drainage area. Indeed, it is questionable if Bull Lake ice ever extended farther than ice of the later Pinedale substage of mountain ice. The highest extent of Lake Choteau during the Bull Lake and Pinedale substages also was not known precisely. This study was made in order to delineate the extent of the Bull Lake, Pinedale, mountain and continental ice, and also Lake Choteau. Another primary objective was to construct a map of glacial features showing the relationships, and to interpret the glacial history.

In most areas in the Rocky Mountains where Wisconsin mountain glaciation has occurred there are two very readily definable stages of glaciation. The earliest is the Bull Lake glaciation, type area

near Bull Lake, Wyoming (Blackwelder, 1915). According to Richmond, 1965, in most cases Bull Lake ice extended farther from the mountains than the next later stage of glaciation. It is characterized at the type area by two moraines having smooth slopes and large boulders sparsely scattered on the slopes. The till contains a great deal of silt and clay. It extends out from the mountains about thirty to forty miles at Bull Lake, Wyoming. The age of the Bull Lake was found to be greater than 42,000 YBP by Trimble and Carr in 1961, according to Richmond, 1965. The age was determined by dating peat found four meters below the top of the lake beds near American Falls, Idaho.

The Bull Lake in the map area has subdued knob and kettle topography with a few limestone boulders scattered on its surface. The kettles generally do not contain lakes and the terrain is not swampy. There is little limestone left in the till, possibly because it has been removed by solution.

The Pinedale mountain glaciation followed the Bull Lake and its till most commonly lies within the Bull Lake deposits. The Pinedale type area is near Pinedale, Wyoming, and generally consists of three moraines. At Pinedale the first two are close together, the third and latest farther back and closer to the source area. The end moraine seldom has lakes and may be narrowly breached by rivers. The lateral moraines are unmodified (Blackwelder, 1915).

In northern Montana the Pinedale moraine has very sharply defined lateral and terminal moraines. The slopes are hummocky and covered

by an abundance of fresh appearing limestone boulders. The inner moraines contain ponds and lakes in the hollows and also have swampy areas (Figures 2 and 3).

The continental ice, according to all available literature and as indicated by its content of crystalline metamorphic debris, emanated from the Keewatin center. Debris is characterized by large granite, schist, and gneiss erratics, but the till grades down to gravel size material. It has knob and kettle topography which diminishes in sharpness toward its outermost extension, perhaps because of saturation by waters of Glacial Lake Choteau.

Glacial Lake Choteau was formed when continental and mountain ice dammed the rivers and ponded their waters (Plate 1). The trapped water formed very finely varved clay and silt deposits which now delineate its minimum extent. The preceding properties characteristic of the Bull Lake, Pinedale and continental ice deposits and the lake sediments were used to define the extent of the glacial activity.

Hypothesis. The Bull Lake ice in the Teton River drainage extended farther east onto the plains than the Pinedale ice.

The continental ice extended farther west and south than is presently thought.

Alternate Hypothesis. In the Teton River drainage the Bull Lake ice did not extend as far from the mountains as the Pinedale



Figure 2. Pinedale moraine looking east with Pine Butte, Number Two Terrace, in near upper right horizon. The knob and kettle topography in foreground is all Pinedale moraine with lakes contained in some hollows.





Figure 3. Pinedale moraine showing a large limestone erratic approximately seven feet high and fifteen feet in length in the foreground. Notice the fresh appearance of the moraine.

ice. The extent of the continental ice is essentially as it was generally mapped by Colton, Lemke, and Lindvall in 1961.

#### Propositions.

1. A glacial lake was formed in the area of Choteau by the damming of rivers by ice.
2. Volcanic ash which is interbedded with lake deposits along the Teton River on Highway 287 just south of Choteau may be of value in determining age of deposits.
3. Continental ice extended at least as far south as Muddy Creek and is identifiable by its content of granite, gneiss, and schist.

Procedures. A search of available glacial literature pertaining to Montana has been made. In the field, known standard criteria for identifying glacial features and relations were employed. For example, continental moraine was identified by its crystalline metamorphic debris; Pinedale by its fresh appearing moraine and great abundance of limestone, Bull Lake was very tentatively identified as having characteristics described beginning on page 30, and the lake deposits were easily identified by their thin laminae and clay and silt composition. Flying over the area and adjacent areas was a great help in determining large scale relationships and also strategic points to examine in detail. Air photos were also used. Detailed descriptions of pre-Bull Lake, Bull Lake, and Pinedale glacial features follow, with the geomorphology of the mapped area described first.

## CHAPTER II

### GEOMORPHOLOGY, GENERAL AND SPECIFIC

As one enters the Teton River drainage area the first and most striking features are the numerous flat-topped ridges and hills which lie at several levels. These represent several stages of probable uplift and erosion, and are products of erosion which reduced the nearly flat-lying Cretaceous formations of the plains and the folded, upturned strata of the mountain front indiscriminately (Figure 4).

Flaxville Plain. The Flaxville Plain, named by Collier and Thom in 1917, is also sometimes referred to as Terrace Number One or Blackfoot peneplain (Alden and Stebinger, 1913). It is represented by the Belly River Ridge east of Waterton Lakes and by high plains in the Browning and Blackfoot quadrangles. It is 1000 to 1500 feet below the elevation of the Cypress Plain near the front of the mountains. The Cypress Plain, represented by the Cypress Hills of southern Canada, has a cap of river gravel and sand lenses containing Oligocene fossils. The Cypress Plain appears to correspond to subsummit peneplains of the Beartooth and Big Horn Mountains (Alden, 1924). The Flaxville Plain is the next to highest remnant of what was once a widespread alluvial fan and terrace system near the mountain front and which, farther east,



Figure 4. Flat-topped ridges and hills. The hill in the middle right is capped by twenty feet of gravel and represents Number Two Terrace. The hill in the center, horizon, is capped by magnetite-bearing sandstone and probably represents the Number Two Terrace.

became a system of great coalescent alluvial fans. Fossils of Pliocene and Miocene age were found together in sandy lenses in the Flaxville gravel and indicate that rivers were flowing on the Flaxville Plain late in the Tertiary (Alden, 1932). During this time the mountains and plains were at a great enough elevation due to previous orogenic episodes to impart strong river gradients toward Hudson Bay. The piedmont fans formed then came together to create extensive gravelly plains, of which a few remnants remain, having a slope of twenty to forty feet per mile twenty-eight miles east of the mountains at an elevation of 4180-4200 feet.

Number Two Terrace. An uplift, or perhaps climatic conditions became such that the rivers began cutting down and eroding the Flaxville Terrace to a lower level. Evidence to decide which occurred has not been found to date. Mountain glaciers formed and extended out onto the Flaxville Plain before it was greatly eroded, as evidenced by a very few striated argillite pebbles. This is indicated by finding the gravel cap containing the aforementioned pebbles over a wide area. This cap is found essentially at the same level on all high level remnants observed by Alden in 1924. There are no deposits or erosional features in this region, which may be regarded as Pleistocene, that are older than the pre-Wisconsin till on the Flaxville Plain (Alden, 1924). This may mean that the Mio-Pliocene age of the Flaxville Plain is subject to question. The amount of elevation was

probably not very great; thus the river gradients were fairly low, and the rivers eroded broad, shallow valleys which cut into the Flaxville Plain. These were subsequently named Number Two Terrace by Alden and Stebinger in 1913 where they were studied east of Glacier Park. If one takes an overall view of a large area it is discovered that the slopes of the Flaxville Terrace surfaces do not slope in the direction of the present drainage system but rather to the north, indicating that at the time of its formation the rivers were indeed flowing towards Hudson Bay; perhaps the climate was more moist than at present and more source water was available for the rivers as they eroded broad, flat areas, now known as Number Two Terrace. The slope of the Number Two Terrace does coincide with the present drainage, which indicates that the direction of drainage changed radically between the formation of the Flaxville Plain and Number Two Terrace. The present drainage follows the lines of drainage of the Number Two Terrace stage, but at lower elevations. Gravel-capped terraces, which are now 150 to nearly 300 feet above the present low lying land, were formed during a long period of quiescence after the uplift or change to a more arid climate. These terraces have a slope of about thirty feet per mile twenty-six miles east of the mountains, at an elevation of 4000-4080 feet, sixty feet per mile seventeen miles east of the mountains at an elevation of 4780 feet, and eighty feet per mile four miles east of the mountains at 5000 feet. The Number Two

Terraces really are at two levels and are 150 to 300 feet above the highest present drainage near them. However, these two levels, the higher of which is as much as 100 feet above the lowest, cannot everywhere be identified. In most places it is found that the lower of the two, where identifiable, is the better preserved.

Number Three Terrace. Uplift or a more humid climate followed this second stage of erosion and caused dissection of Number Two Terrace, evidenced by the river cutting down again instead of meandering and creating broad valleys. Before Number Two Terrace was very much dissected, mountain ice extended over it and deposited pre-Wisconsin till (Alden, 1924). The dissection of the terrace continued and created broad, open valleys during the quiescence that followed. This third set of gravel-capped terraces then was dissected by the rivers. At an elevation of about 4700 feet near the mountains, this most recent terrace has a slope of about sixty to eighty feet per mile, decreasing to twenty-five feet per mile at Choteau at an elevation of 3800 feet.

At the time that the Wisconsin ice advanced from the mountains onto Number Three Terrace, continental ice was present farther east. The mountain substages receded and left behind them an irregular topography which interrupts the smooth, gently sloping surface of the terraces. Above the terrace is an anticline that was probably breached by ice marginal streams (Figure 5).





Figure 5. View north from the south Pinedale lateral moraine showing a breached anticline and ice polished shoulder across Teton Canyon on the mountain front. The breached anticline probably was caused by water flowing along the ice edge.



Farther east of the mountains the smooth plain of the terraces is again interrupted by different but related features. In this case the plain gives way to knob and kettle topography of the till formed by continental ice as it extended outward from the Keewatin center.

Between the mountain and continental moraines are flat-lying outwash deposits and lake deposits formed in the lake trapped between the two ice sheets (Plate 2).

Effects of Ice Activity on Drainages. At the time of invasion of ice on the Number Three Terrace the Keewatin ice sheet of Wisconsin age diverted the Missouri River in Montana south of its present position.

Since the last glacial invasion the recent drainage system has cut into Number Three Terrace from fifty to two hundred feet. Part of this erosion was accomplished by melting waters of the Bull Lake, Pinedale and more recent glaciers in the mountain cirques. The rest of the downcutting is probably due to uplift. There is no evidence to indicate that the climate has been any more humid during the past 6000 years than at present. The climate in the area is now semi-arid and does not supply enough moisture to increase vegetation to reduce sediment being carried to the rivers, or to increase the amount of water in the rivers enough to cause downcutting.

W.

E.

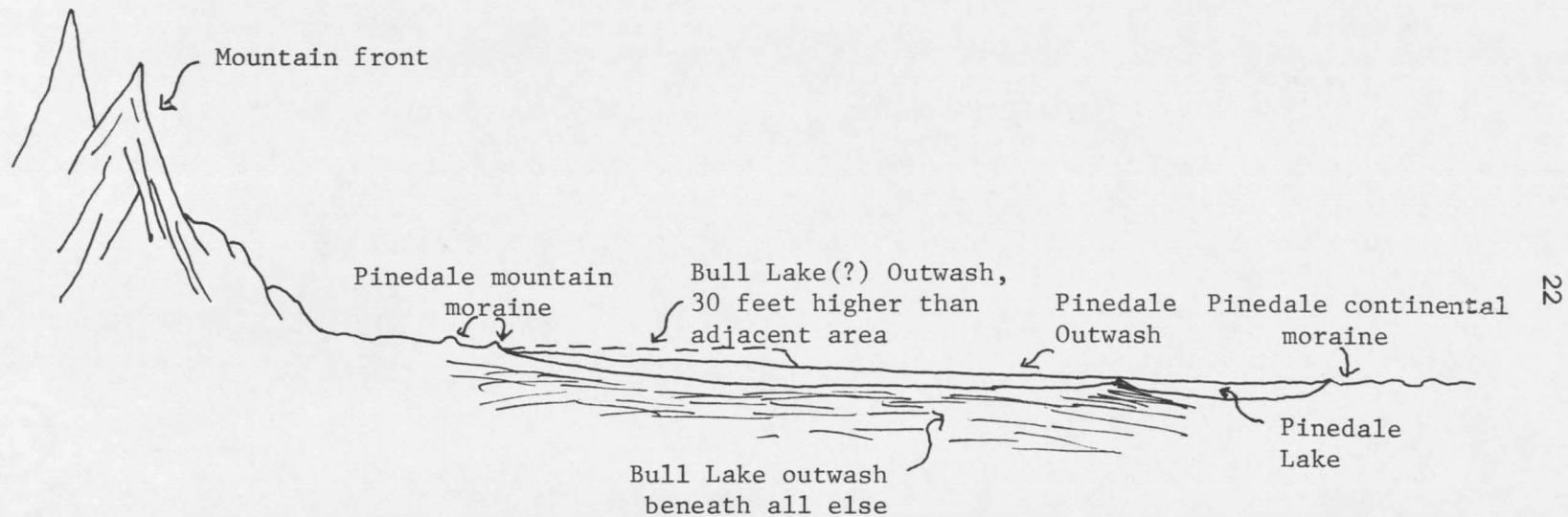


Plate 2. Diagrammatic sketch showing the relationships of the moraines, outwash and lake deposits of Bull Lake (?) and Pinedale.

Correlation of High Level Surfaces. Westward from the attenuated edge of the continental moraine the region is a great treeless plain, nearly flat, but in places becoming rolling to hilly and rising gradually to meet the mountains. In the eastern part, standing above the plain here and there are butte-like prominences and long flat-topped hills and ridges with abrupt, incised slopes. These prominences are up to several hundred feet above the valleys. Further west isolated flat-topped hills and ridges come gradually together to form more or less broad plateaus and ridges of greater extent. The assembled and projected profiles of these sloping surfaces indicate that a high, fairly level plain once existed. However, there are several projected plains having different elevations which once sloped gradually eastward from the mountain's base. These higher plains, which correlate with Number One (Flaxville) and Number Two terraces, comprise about twenty-five percent of the land surface, although it is doubtful if all the flat-topped hills can be related to former important planar erosion features. Those plains which are doubtfully remnants of Number Two Terrace are those capped by a magnetite-bearing dark-brown weathering sandstone layer marking the top of the Virgelle Sandstone (type area, Virgelle, Montana), which is the basal member of the Eagle Sandstone in central Montana, (named by Stebinger, 1914). It is Late Cretaceous in age. This is a very resistant cap that forms a stripped

structural plain. These sandstone-capped flat-topped hills are not covered by gravel. They are bedrock, with some grass growing in sand from the weathering bedrock. Many of the sandstone fragments have caliche on their undersides. Below the striking flat-topped hills is another fairly flat sloping surface about forty feet lower than the magnetite-bearing sandstone cap. One very weathered limestone cobble, well-rounded, which was nearly three inches in diameter was found on this lower surface. A few very deeply weathered, rounded, buff cobbles of foreign sandstone were found on the resistant magnetite-bearing cap on the bluffs west of Choteau (Figure 4, page 14). Well-rounded limestone cobbles, up to six inches in diameter, were found on the flat-topped hills composed of Virgelle Sandstone located about three miles west of Bynum. These limestone cobbles may have been deposited by Bull Lake mountain ice, or outwash, extending east onto the plains. The elevation of the surface upon which the cobbles are found is higher than Number Three Terrace. Therefore, they would have had to be deposited before the formation of Number Three Terrace, unless they were deposited by ice over-riding them at a later time. For a limestone cobble resting upon the surface to survive solution weathering since before the formation of Number Three Terrace, is doubtful. These surfaces are pre-Bull Lake, but whether they represent Number One or Number Two Terrace cannot be positively determined by the data obtained in the mapped area. A greatly expanded area may yield the clue to give the answer. From the limited

data available in the mapped area, the writer tentatively assigns the foregoing flat-topped hills to Number Two Terrace.

Ice Marginal Stream Features. Some of the magnetite-capped hills are interrupted by wind gaps. Examples (Plate 1) are found in sec. 13, and 24, T. 25 N., R. 5 W. (on the border between the two), and SE  $\frac{1}{2}$  sec. 23, T. 24 N., R. 6 W. The Number Two Terrace locally known as the Bole Bench, has a similar feature on its north side, in SW  $\frac{1}{2}$  sec. 34, T. 24 N., R. 3 W. Another is noted on that part of the north side of Flaxville terrace known as Teton Ridge. They probably represent old ice marginal stream channels.

Outwash Channel and Outwash. Just north of Eureka Reservoir in the resistant magnetite-bearing sandstone cap of the hills is a break which is about one mile wide, known as Ralston Gap. Just east of the gap is a fan-shaped deposit composed mainly of limestone and quartzite gravel and cobbles. The fan is about eleven miles wide from north to south and seven miles long in eastward extent. A gravel-covered plain extends west from Ralston Gap to where it meets the crescent-shaped, hummocky terrain created by the Pinedale mountain glacier. This represents an outwash channel cut through the rim of the bluffs eastward to the plains proper. Details of the glacial features will be discussed in the following sections. These, then, are the more prominent geomorphic features.

## PART II

### GLACIAL DEPOSITS AND THEIR DESCRIPTIONS AND RELATIONSHIPS

#### CHAPTER III

##### PRE-BULL LAKE GLACIATION

Flaxville Terrace. Pre-Bull Lake ice extended onto the Flaxville Terrace before it was greatly eroded by streams after the area underwent uplift (Alden and Stebinger, 1913), thus leaving a glacial till and river gravel cap on the surface. The terrace is covered with pebbles ranging in size from a fraction of an inch to eighteen inches in diameter. The rocks are well rounded, many being slightly flattened to much flattened, with rounded edges, and are composed mostly of tan, white, red, and pink-banded quartzite, maroon argillite, green argillite, and a small amount of limestone, named in order of abundance. Some of the argillite pebbles show what may be faint glacial striae on their undersides.

About one mile north of Agawam the Flaxville Terrace (Alden, 1924) is represented by a flat hill capped by about thirty feet of gravel. This cap is of unsorted coarse and fine gravel with sand. It is semi-consolidated and is very slightly stained buff in color. The rocks range from a fraction of an inch to eight inches in diameter and are composed mainly of quartzite, argillite, and some limestone, as

described above. Upon careful examination it was found that some of the argillite had faint striae, indicating that the material is glacial in origin. The till is among the older of Pleistocene deposits in the area. This material may subsequently have been reworked by streams, although there is no conclusive evidence for or against it being a reworked till.

Number Two Terrace. An uplift of the Flaxville Terrace or a change to a more humid climate resulted in the eventual formation of Number Two Terrace. Before this terrace was greatly eroded by downcutting of the rivers caused by an increased gradient due to another uplift of the region or caused by more velocity due to more outflow of water for the same river because of a wetter climate, it was covered partially by mountain ice extending eastward. The glacier and rivers deposited a cap of unsorted gravel very much resembling the gravel of the Flaxville Terrace. The gravel is composed of well-rounded rock fragments ranging in size from a fraction of an inch to about eight inches across. Most are at least slightly flattened. The composition is the same as those on the Flaxville Terrace, except that slightly more limestone is present, about five to seven percent. This cap is about ten feet thick on the Bole Bench. To the west, on the Teton Buttes (Figure 6) the gravel cap is present also, about twenty feet thick, and has nearly forty percent limestone, twenty-five percent quartzite,



Figure 6. Number Two Terrace remnants in foreground, angling upward to the right, having twenty feet of gravel capping them. Farther west in upper left is Pine Butte, Number Two Terrace.



and the remainder being argillite and chert that probably weathered out of the limestone. Glacial striae occur on some of the argillite fragments; some of this material may be reworked Cypress Plain, Flaxville and Number Two Terrace deposits. Included here also are the magnetite-bearing, sandstone-capped hills directly west of Choteau on which a few limestone and rotten sandstone pieces up to three inches in diameter are found which are not the same composition as the bedrock sandstone upon which they lie. Just east of the Bynum Reservoir quite an abundance of limestone cobbles up to eight inches in diameter were found which were well-rounded; also farther west, well-rounded Kootenai conglomerate and some quartzite cobbles which may have been glacially deposited were found lying on the Cretaceous sandstone bedrock.

Number Three Terrace. Number Three Terrace is the lower terrace and has on it the deposits made directly by ice and the lake sediments of Wisconsin Age. Most of it has a limestone gravel cap or is capped by lake clays and silts. Continental till caps the eastern edge of the area. The present drainage systems have now cut into the terrace from fifty to 200 feet.

Summary. The highest and oldest flat surface is known as the Cypress Plain. It is represented by the Cypress Hills of southern Canada and has a cap of river gravel and sand lenses containing Oligocene fossils. Following the development of the Cypress Plain,

a succession of varied amounts of uplift alternated with periods of repose or climatic changes from humid to dry to humid, caused the rivers to deeply dissect and then erode broad valleys or areas, thus developing remarkably smooth, gravel-covered terraces. Upon these terraces mountain ice seems to have advanced and left deposits before each terrace was greatly dissected as evidenced by the few striated fragments found. Piedmont alluvial fans also were formed. The foregoing, after the formation of the Cypress Plain, may be grouped into three sets which serve as datum plains.

The first and earliest terrace is known as the Flaxville Terrace or Number One Terrace; the next oldest is known as Number Two Terrace. Both Number One and Number Two Terraces have quartzite and argillite tills or river gravels capping them; some limestone is also present. Also in the Number Two Terrace remnants are included the magnetite-bearing sandstone-capped hills to the west of Choteau. Because of the sparse evidence found in the area, it is not certain that they may positively be correlated to Number Two Terrace. The youngest terrace is known as Number Three Terrace, upon which the Wisconsin ice advanced.

## CHAPTER IV

### BULL LAKE GLACIATION

Mountain. There is little evidence to show definitely the extent of the Bull Lake mountain ice. Only a few hints as to its outlines in the area mapped are present, and the writer makes only tentative statements regarding them.

On the northeast side of Rattlesnake Butte, NE  $\frac{1}{4}$ , sec. 7, T. 23 N., R. 4 W. a subdued ridge trends northeastward which is composed of gravel from about one inch to eighteen inches in diameter; fragments are well-rounded, with white, yellowish, and reddish quartzite; light gray to white sandstone; and some limestone. These clastics are in an unconsolidated sand and clay matrix, and lie about 3900 to 4000 feet in elevation. Upon careful examination no glacially striated pebbles were found that would absolutely prove the deposit as being glacial, although it is morainic in appearance because of the jumble of unsorted material within it.

In the NE  $\frac{1}{4}$ , sec. 4, T. 23 N., R. 4 W., there is a cutbank exposed by the Teton River (Station 198, Figure 7) which is about thirty feet high and is very nearly vertical. At the base of the cut lies an apparently reworked glacial till which contains angular and rounded rock fragments from one fourth to three inches in diameter. These are composed of reddish, white, and yellowish

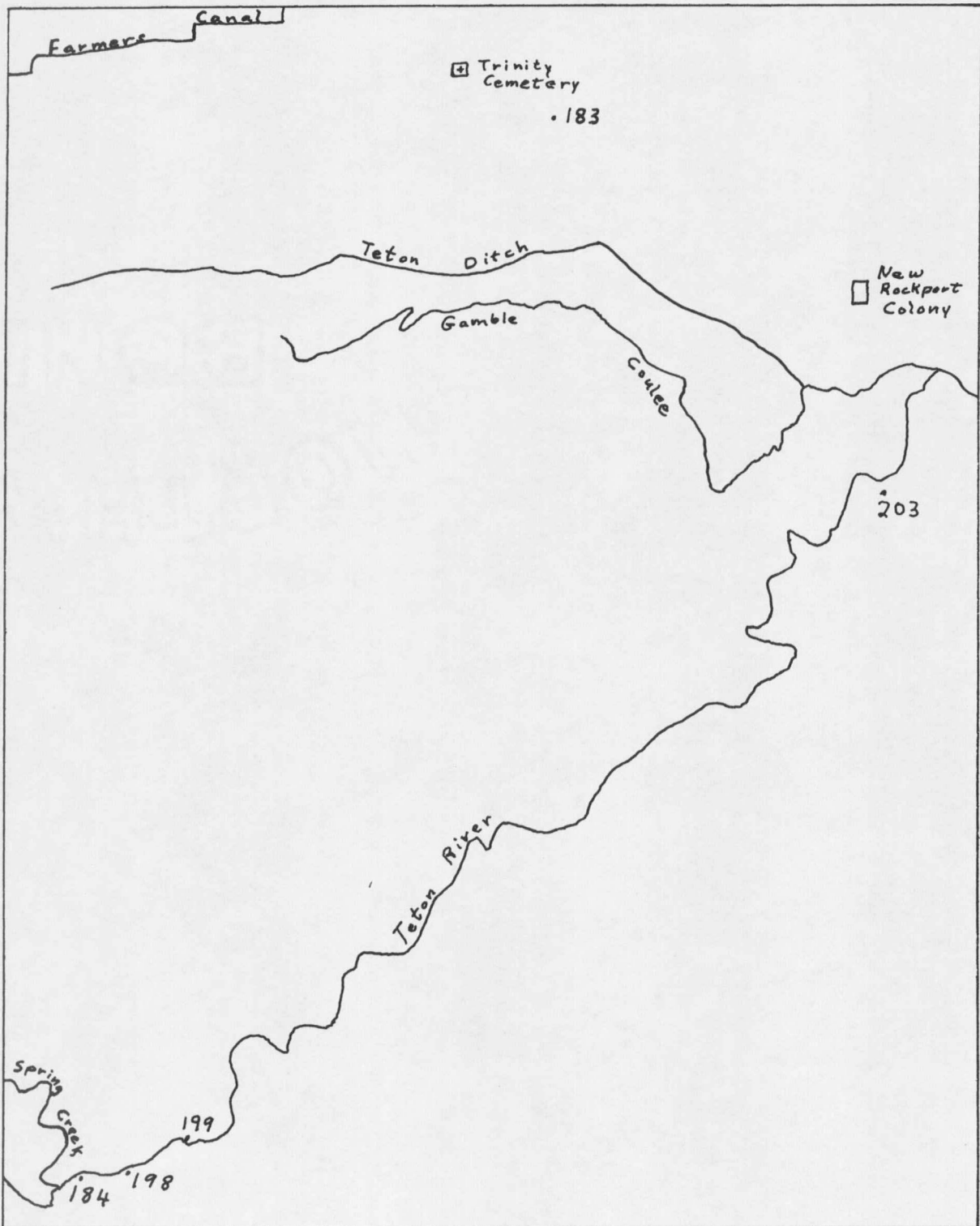


Figure 7. Index Map for Stations

quartzite; sandstone; granite; and some coal in a sand to clay size matrix. Some of the rocks are flattened. The surface of this layer is irregular (Figure 8) and varies in relief by about three to four feet. This layer contains lenses of sand and at one point a thin deposit of an old stream channel, with clean-washed angular to rounded clastics about one-quarter inch in diameter. This stream deposit is nearly eight feet wide in cross-section and four inches thick. A source for the quartzite is the mountains to the west and also material brought in from the Flaxville Terrace and Number Two Terrace. The source for the granite is the Canadian Shield. It is proposed that the Bull Lake continental and the Bull Lake mountain ice met in the area and, as the ice began to melt, the deposit was reworked by outwash streams. It is possible that the mountain and continental ice did not meet and that only their outwash met. Lake water of Pinedale age later covered this deposit and saturated it, causing more modification of the deposit by solution. Below this apparently reworked till deposit is a thinly laminated silt layer which is of unknown thickness, but may represent an early Bull Lake lake, which disappeared when the mountain and continental ice met.

The Burton Bench probably contains Bull Lake outwash beneath the Pinedale outwash now on the surface. The drainage for the outwash was probably through Ralston Gap as indicated by its position in relation to the Pinedale outwash composing the



Figure 8. Apparent, reworked till of Bull Lake(?) age, having an irregular surface, lying beneath Pinedale Lake sediments (surface shown by arrow).

surface of Burton Bench. This would mean that the Ralston Gap was at least partially formed during Bull Lake glaciation. The Bull Lake ice on the north edge of the map area is interpreted to have come as far east as about one mile east of the Bynum Reservoir because of the presence of relatively abundant solution-weathered limestone cobbles and Kootenai conglomerate cobbles found on the bedrock hills on the east edge of the Bynum Reservoir. These may have been deposited by Bull Lake outwash, although it is somewhat doubtful.

A probable Bull Lake outwash plain is found in the N  $\frac{1}{4}$ , sec. 24, T. 25 N., R. 8 W., where it lies approximately thirty-feet above the Pinedale outwash plain. It slopes to the east at forty to sixty feet per mile. The later Pinedale moraine, which has a northwestward trend through the same section, ascends the rather sharp slope and has its lateral moraine on the aforementioned plain (Plate 1). The Bull Lake plain is composed mostly of limestone fragments occurring locally in zones of flat pebbles imbricated toward the east, indicating that water flow was from west to east at the time of deposition; above and below, the material is generally unsorted, with round and subangular cobbles of limestone up to six inches across in sand, silt, and clay. The material is very slightly cemented, due to leaching and redeposition of calcium carbonate. The gravels of this plain were probably deposited during the Bull Lake recession. This is thought to be so because it is

deposited on Number Three Terrace and yet is slightly higher than known Pinedale deposits. These facts suggest that Bull Lake mountain ice extended this far to the east, at least. The evidence is scant and the foregoing statements are hypotheses suggested by the few clues found.

Further evidence for the extent of Bull Lake mountain ice is found on Pine Butte, which rises rather abruptly from the plains just one and one-half miles east of the mountains (Figure 9). The butte is a synclinal remnant now eroded to form one of the high surfaces rising over 500 feet above the surrounding area. It is composed of Horsethief sandstone (type area Horsethief Ridge, Blackfoot quadrangle, Montana) of the Montana Group in northwestern Montana, named by Stebinger in 1914. It is Late Cretaceous in age. The weathered bedrock is a source for the thin sand layer resting on the bedrock in places. At 4900 feet were found several limestone pebbles up to six inches across. In the mountains proper a few limestone erratics up to two feet in diameter were observed outside the Pinedale lateral moraine which are considered to be Bull Lake in age. The foregoing limestone pebbles and erratics are considered to be glacially transported because this seems to be the agent that would deposit them in the manner and location in which they were found. The smaller fragments found on Pine Butte may be outwash remnants, but they are much higher than the probable





Figure 9. View westward with Pine Butte in center foreground. Limestone pebbles were found on fastaceous sandstone bedrock in the south windgap.

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recessional Bull Lake (?) outwash upon which part of the Pinedale moraine rests.

Continental. The evidence for the farthest extension of Bull Lake continental ice as described below is somewhat more positive than that for the mountain ice.

Along the north rim of Teton Ridge (Flaxville Plain) at an elevation of 3980 feet, pink granite and schist fragments mixed with quartzite and argillite are found which are angular to rounded and from an inch to eighteen inches in diameter. One may follow the upper edge of the deposits containing angular crystalline rock fragments along the west end of Teton Ridge and on around to the south side, where the deposit decreases in elevation to 3960 just west of the Number Two Terrace extending south in sec. 36, T. 24 N., R. 1 W. The extent of the continental ice beyond this location was not investigated at this time. This extends the deposits formed by continental ice more than ten miles farther south than they have ever been mapped. The farthest south extension still has not been determined although it is known that the deposit extends southeastward through the T L Gap to an undetermined position. The deposit containing granite and schist again was traced around the north side of the Bole Bench (Number Two Terrace) at an elevation of 3980 feet (Plate 1) and on around the west side of the bench where it surrounds a section

of the same terrace which is cut off by a wind gap. The wind gap probably represents a former ice marginal stream channel. The deposit extends at least two miles farther south than the map area, but its termination is not known. The deposit on the slopes of Bole Bench and Teton Ridge contains angular to rounded fragments of granite and schist up to eighteen inches in diameter mixed with quartzite and argillite. A subdued ridge running east-west (probably representing a recessional moraine), containing an abundance of granite and schist, angular to subangular, and up to eight inches in maximum diameter, was traced just north of the Bole Bench in SE  $\frac{1}{2}$ , sec. 28, T. 24 N., R. 3 W. (Plate 1). The ridge also contains well-rounded pink, red, and white quartzite, and sandstone up to ten inches across. The quartzite and sandstone may have come from Number Two Terrace to the north over which the continental ice flowed. The ice undoubtedly incorporated the material capping the terrace into its own ground moraine.

Angular pieces of pink granite were found in the basal units of the cutbank described earlier in relation to Bull Lake mountain ice. The granite is angular to subangular and up to three inches in maximum diameter and is found in association with reddish, yellowish, and white quartzite and some coal fragments mixed with a great deal of sand, silt, and clay, all of which is relatively unsorted. It is thought that the

continental Bull Lake ice may once have gone as far west as the bluffs just west of Choteau, one of which is called Burd Hill. If the mountain and continental ice met, their moraines would have been mechanically mixed by the ice sheets overriding one another.

One granite erratic was found just west of the Choteau Municipal Airport, and is about three feet in diameter. It may have been man-deposited or it may have been ice-rafted during Pinedale time. This would suggest that the later lake had a considerable depth in order to allow ice rafting of boulders weighing several tons. Granite and gneiss erratics up to six feet in diameter, which are sub-rounded to sub-angular were observed along with numerous angular to rounded fragments from one to four inches across. The granite content is about twenty-five percent, and is mixed in with well-rounded to sub-angular reddish, yellowish, and white quartzite, limestone, and sandstone. This description applies to deposits about one to four miles east and north of the airport and extending eastward toward the sharp, fresh-appearing continental moraine. The common frequency of the large erratics suggests that Bull Lake continental ice did extend at least as far west as Choteau. This same type of deposit was observed from three miles east of Choteau on Highway 221 to near Choteau (Plate 1). The continental ice also picked up material from the gravel-capped terraces it passed over to the north and incorporated it into its morainal material.

These, then, are the evidences for the farthest extension of Bull Lake continental ice.

Summary. The evidence for Bull Lake mountain ice is very scant. What evidence there is indicates that the mountain ice probably extended eastward to Choteau, where the apparently reworked till of continental and mountain ice together is found at the bottom of the exposure at Station 184. It has an upper irregular surface which may be erosional. Below this deposit lies a layer of silt of unknown extent which may represent a lake deposit of early Bull Lake age which became smaller and smaller as the continental and mountain ice gradually merged (Plate 3). An alternate theory would be that the deposit containing pebbles is not reworked till at all, but rests directly on late Bull Lake deposits and is only outwash from both continental and mountain ice. From other evidence found in the area it is thought that the former explanation is correct.

The evidence for the Bull Lake Continental ice is much clearer, and it is found to extend nearly to the top of Teton Ridge (Flaxville Terrace) to an elevation of 3980 feet. Angular granite and schist cobbles and erratics up to two feet across found south of Teton Ridge and the Bole Bench indicate it went south of these surfaces an unknown distance. Its westward extent may have been to the bluffs west of Choteau, according to

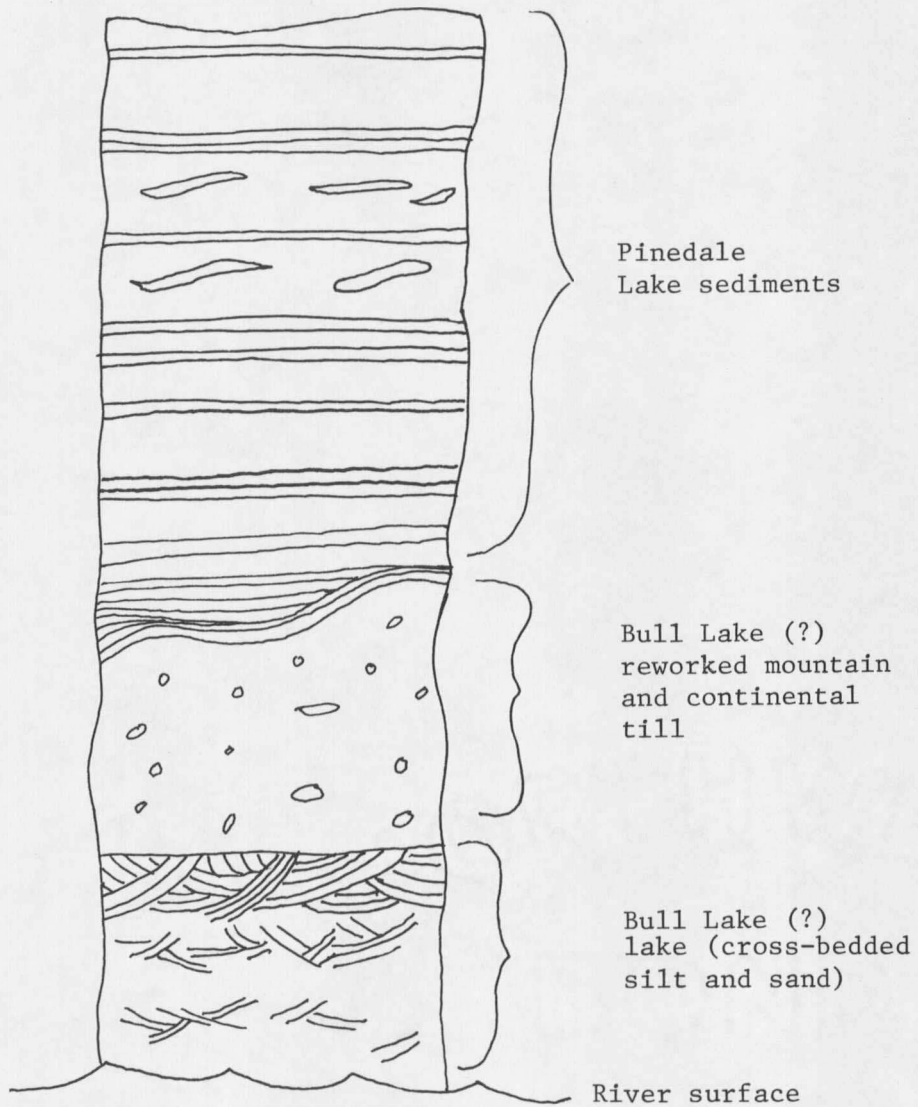


Plate 3. Diagrammatic columnar section of Pinedale Lake sediments and Bull Lake (?) deposits.

topographic correlations, although in that area the continental and mountain ice apparently met.

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## CHAPTER V

### PINEDALE GLACIATION

Mountain. The easternmost extent of the Pinedale mountain ice is very sharply defined. Its moraines rise abruptly above an otherwise flat plain near the mouth of Teton Canyon. The terminal moraine rises approximately eighty feet above the Pinedale outwash plain.

The lateral moraine near the mountain front on the south side rises 120 feet above the Pinedale outwash plain extending from it. Although the elevation of the equivalent moraine on the north side is accordant, it is only eighty feet higher than the adjacent Bull Lake (?) outwash (since the latter is inherently higher than the Pinedale outwash).

In the South Fork of the Teton River Canyon in SE  $\frac{1}{4}$ , sec. 5, T. 24 N., R. 8 W., the Pinedale lateral moraine lies at an elevation of <sup>5840</sup>5940 feet above sea level. The ice then was at least 840 feet deep in the canyon, which is 240 feet thicker than the 600 feet (Alden, 1932) stated, as evidenced by the lateral moraine being 240 feet higher than the elevation given by Alden. The moraine at this point lies 840 feet above the river bed below and large limestone erratics which are fairly angular and up to six feet across are scattered on the slopes of the canyon walls. Erratics one foot across or smaller are well rounded and show good



solution etching. Therefore it may be that some of the smaller cobbles are reworked from Bull Lake till.

To the west of the moraine just described is a rather precipitous limestone cliff which is one of the numerous sources for the limestone in the moraine. This cliff is nearly two miles west of the moraine being discussed and rises over three hundred feet at its highest point above the shoulder below it. Deeper in the mountains, peaks on the skyline have cirques, which appear to have been the source for the ice producing the prominent lateral moraine (Figure 10). At an elevation of 1000 feet or more higher than that of the lateral moraine, are flat bench remnants projecting from the sides of the gullies which may represent other stages of glaciation.

To the north, on the river slopes below, limestone boulders are perched here and there. Farther north and across the two forks of the river, in the gullies high on the mountainside, are the flat bench remnants just previously described. Also a breached anticline is observed and forms part of a prominent shoulder running along the front of the mountains at an elevation of about 5800 feet (Figure 5, page 20). This feature looks like a shoulder which has a rounded, smooth, or polished-off appearance that may have been caused by glaciation at an earlier time. To the east an arcuate ridge extends away from the mountains (Figures 11 and 12). It is covered by a growth of jack pines, which do not appear



Figure 10. View west up the two forks of the Teton River showing the source area for the mountain ice. Note the limestone cliffs on the mountain front with the ice polished shoulder just below them. Typical Pinedale morainal topography is seen in the foreground.



Figure 11. View of the north side of the Pinedale moraine looking north-east. The farthest east extent is indicated by the line of trees. The Teton River narrowly breaches the terminal moraine in the upper right horizon. Note the characteristic morainal topography. The outwash plain is beyond the moraine near the horizon.



Figure 12. South side of Pinedale moraine looking southwest. The farthest east extent is marked by the humpy topography. Pine Butte (Number Two Terrace) is seen on the upper left horizon. The outwash plain is just to the south of Pine Butte.

to grow anywhere else. This marks the eastward extension of the Pinedale ice. The hummocky terrain contains an abundance of lakes and swamps near the mountains, which farther east give way to intermittant lakes, containing water only during rainy periods.

The Pinedale moraine east of the mountains drops more than two hundred feet in less than half a mile in sec. 5, T. 24 N., R. 8 W. It parallels a lower moraine trending south, and then swings sharply to the east appearing to join the moraine being traced eastward (Plate 1). The moraine swings toward the south and gradually decreases in elevation, losing forty feet per half mile until it reaches the North Fork of Willow Creek, where it sharply descends nearly 160 feet to the river bottom, then rises upon a ridge to over eighty feet above the river and descends once again at over 100 feet per half mile. There it drops into a slightly swampy meadowland lying at an elevation of about 4780 feet. An ice marginal channel one quarter of a mile long is west of the Bowman Ranch. East of the Bowman Ranch the moraine is absent for about one quarter of a mile, and there is an outwash plain to the west, W  $\frac{1}{2}$  sec. 10, T. 24 N., R. 8 W. (Plate 1). Then the moraine climbs northeast and finally attains an elevation of about 5270 feet. In the SW  $\frac{1}{4}$  SE  $\frac{1}{4}$  sec. 3, T. 24 N., R. 8 W., (Plate 1), a small outwash plain was mapped. To the west numerous inner moraines or recessional moraines are seen which show the pattern of small advances, and then recession of ice. To the east



the same phenomena are observed. The two terminal moraines of the Pinedale ice corresponding to the laterals which have just been described make an arc east of the mountains. The terminal moraine is a little more than four miles from the mountain front. This outermost moraine is at least one-half mile wide. An outwash plain nearly a mile wide separates the latter moraine from the inner moraine. This inner moraine is about one-half mile wide. West of it is another outwash plain. These two moraines are the oldest and farthest from the source area of the three formed by Pinedale glaciation. The third and youngest moraine, according to Richmond, 1965, if present, is within the canyon itself. The presence of this youngest Pinedale moraine was not investigated at this time. The age of the outer moraine is less than 25,000 to about 20,000 YBP, ca., and the inner moraine is less than 18,000 to 12,000 YBP, ca. (Richmond, 1965).

The lateral moraine curves south, dropping 200 feet in one mile, and then turns sharply east on the east border of sec. 11, T. 24 N., R. 8 W. and the west border of sec. 12, T. 24 N., R. 8 W. (Plate 1), and drops nearly 300 feet in less than one-quarter mile to the plain below. From its curving outer margin extends an outwash plain consisting largely of limestone pebbles and cobbles, with some quartzite and some Kootenai conglomerate (Figure 13).

Where the outermost moraine is breached by the Teton River a good cross-section of the morainal material is displayed. The



Figure 13. View looking north across the southern Pinedale lateral moraine with the outwash plain beginning in the foreground. Note the limestone erratics perched on the morainal surface.

moraine is weakly cemented and contains a great deal of sand, gravel, and clay, with limestone cobbles and boulders up to two feet across which are sub-angular to sub-rounded. A few very small and fragile white invertebrate shell fragments were found. Where the river cuts through the moraine on its south side, a layer of what are apparently buffalo bones is exposed. The bones lie nearly one hundred feet below the top of the moraine. People living on the area state that the site was examined by an archaeologist. It was his opinion that it is a buffalo kill and that it was not used after the Indians began to use arrows. He found no arrowheads associated with it, but did find boulders which apparently were thrown down on the buffalo to kill them. It is not certain if G<sub>14</sub> dates from the bones would be useful or not.

The north half of the arcuate moraine extending onto the plain is much like the south half with the exception that in the SW  $\frac{1}{4}$  NW  $\frac{1}{4}$ , sec. 24, T. 25 N., R. 8 W., the moraine rises thirty feet from the level that the main part is on, onto another flat surface which apparently is the recessional outwash plain of the Bull Lake mountain ice (Figure 14).

The margin of the north lateral moraine was traced no farther west than to the west edge of sec. 23, T. 25 N., R. 8 W., because it was not permissible to go on the privately owned land into which the moraine extended. The outwash plain extends east from the moraine and shows the braided pattern one would expect in an outwash plain (Figure 15).





Figure 14. Pinedale moraine on north side where the terminal moraine changes to lateral moraine, left center. Probable Bull Lake outwash plain is the surface seen between the third and fourth telephone poles. The Pinedale moraine "climbs" onto the Bull Lake surface just beyond the first telephone pole.



Figure 15. View west with mountain ice source area in background. The outer Pinedale lateral moraine is marked by the trees with the outwash plain in the foreground exhibiting a typical braided pattern. The Pinedale ascends onto the probable Bull Lake outwash plain in right center. (Bull Lake outwash surface lower right.)

One apparent outlet for the melt water of the Pinedale ice is Ralston Gap, which also probably was an outlet for the meltwaters of the receding Bull Lake ice. East beyond the Ralston Gap is the fan-shaped deposit known as the Burton Bench, which was previously described. It has a slope of about forty feet per mile and at its western edge has an elevation of about 4040 feet above sea level, sloping eastward to about 3800 feet. Just north of the Choteau Municipal Airport is a gravel pit, dug into the outwash, which reveals small sand lenses and stream channels incising each other, suggesting the cross-section of braided stream deposits.

At its eastern edge the limestone gravel, which includes quartzite, all well-rounded, grades into an undefined edge which contains some granite fragments, from a fraction of an inch up to about three feet across in spots, along with clay and silt. In sec. 17, T. 24 N., R. 4 W. (Plate 1) at about 3880 to 3900 feet, the gravel changes rather sharply to gumbo soil containing limestone, quartzite, granite, and gneiss pebbles and cobbles with granite and gneiss boulders up to three feet in diameter, some of which are rounded to sub-angular. In the SW  $\frac{1}{4}$  SW  $\frac{1}{4}$ , sec. 27, T. 25 N., R. 4 W. (Plate 1), the gumbo-like soil is underlain by gravel ten feet below the surface. Three miles east the gravel lies about thirty feet below the surface. The gravel contains limestone, quartzite, and some granite fragments, and is apparently an extension of the gravel emitted from the Ralston Gap. The data

for depth of gravel is obtained from wells dug in the area. Thus the gumbo soil laps west up onto the gravel. The transition zone is about at Farmington and lies between about 3880 and 3900 feet.

Lake. The gumbo soil which laps up onto the gravel to the west formed in part from lake deposits, and thus the lake deposits mix with the Pinedale outwash plain at about 3900 feet, giving an approximate boundary of intermingled lake deposits. From this it may be said that the lake was probably at least at an elevation of 3900 feet. The absolute minimum elevation of lake deposits is 3820 feet.

In the NW  $\frac{1}{4}$ , sec. 36, T. 25 N., R. 4 W., (Plate 1) Station 183 (Figure 7), an ash layer was found by the writer at about one to three feet below the surface in lake clays at an elevation of about 3750 feet. The ash layer is two inches thick, and the top and bottom grade into the lake clays. The ash layer seems to be continuous in places, thinning laterally and appears to have been re-worked later by worms. Dr. Ray Wilcox of the United States Geological Survey, examined the ash and tentatively identified it, in the field, as Mount Mazama ash having an age of about 6500 YBP.

The Mount Mazama ash has an index of refraction between 1.501 and  $1.506 \pm .002$ . Where sampled it contains perhaps 80-90 percent impurities. The index of refraction indicates a rhyolite composition of the shards (74 percent  $\text{SiO}_2$ ). The ash fragments are characteristically triangular, with some of the fragments

having very sharp points, indicating that they have been essentially undisturbed since original deposition.

It is not absolutely certain that the above ash in the lake clays is in glacial lake clays, although from the thickness of the deposit it would seem that a lake of several hundred years duration was the agent of accumulation. From well data it is known that the clays are approximately forty feet thick in this area. It is possible that a long narrow lake existed even after the continental ice receded. The remaining ground and terminal moraine lies at an elevation of 3775 to 3780 feet above sea level and may have dammed the waters of the Teton River enough to form a lake having a maximum elevation of 3775 feet and having a depth of probably ten feet. The foregoing was based on elevation comparisons of silts and predicted morainal dams. As the Teton River cut its way through the morainal material, the water found an outlet, and the lake shrank until it was absent entirely. During this process isolated lakes probably existed, being trapped in hollows as the level of the water decreased. Perhaps it was then that the ash was deposited. Isolated lakes would explain the absence of the ash layer in places.

Another possible explanation is that the particular lakes in which the ash was deposited were not glacial but were of the nature of lakes in the area today. They come into being after several weeks of precipitation. If the area was characterized by greater

amounts of precipitation just after the recession of the ice than at present, it is highly possible that shallow lakes formed in hollows and remained for an extended period of time. Even now, after a week or more of rain, lakes form, one of the major ones being found in sections 25 and 26, T. 25 N., R. 4 W. It is several miles in extent, very shallow, and may exist for several weeks. It is conceivable that a relatively warm and humid condition existed in this area after the retreat of the ice, and that lakes were constantly present in the hollows.

Two miles east and two miles south of the first-described ash layer is another ash layer found by the writer exposed in a fresh slide scarp about thirty feet high (Station 203, Figure 7) just south of the New Rockport Hutterite Colony. The slide occurred January 2, 1967, and blocked the river, forcing it to change its course (Figure 16). The ash layer, one-half inch thick, and with an indistinct lower boundary and rather sharp upper boundary, lies from three to ten feet below the surface at an elevation of about 3690 feet (Figure 17). Wilcox examined the site and, in the field, tentatively identified the ash as being from Glacier Peak. This ash has been dated from another locality found by Mudge at about 12,500 YBP (by personal communication with Wilcox, June 16, 1968).

The Glacier Peak ash has a refractive index of  $1.500 \pm .002$  and is characterized by having many very angular shards which



Figure 16. Slide along the Teton River in Pinedale lake sediments.





Figure 17. Close up of slide (Figure 15) showing the ash layer tentatively identified in the field as Glacier Peak ash by Dr. Ray Wilcox (shown by arrow).



clearly show three concave sides and sharp points. The ash is very fine and contains only 5-10 percent impurities. The index of refraction indicates a  $\text{SiO}_2$  content of about seventy-two percent (Moorehouse, 1959). This would indicate that the ash originated from a rhyolitic magma. The angularity of the shards indicates that the ash deposit has not been transported from the original position of deposition. The ash layer is overlain by about two feet of horizontal lake deposits. The deposit shows alternating dark and light layers and exhibits a typical glacial lake deposit. Above this the beds are deposited at about a thirty degree angle to the horizontal. The dipping beds are parallel to each other and are dipping westward. This sequence of parallel, dipping beds is about five feet thick. They may represent the foreset beds of a delta extending into the lake from the west. Above this lies a two-foot deposit of loess which extends to the surface (Figure 18). In the loess, about eight inches below the surface, is an Indian firepit, cut through by the landslide scarp. The firepit is eighteen inches wide and rimmed by rounded quartzite and granite cobbles. An abundance of charcoal is also present. This firepit may be of use in determining the approximate date of the end of the Pinedale and the time of the altithermal period.

Another ash layer is present in the SW  $\frac{1}{4}$  NE  $\frac{1}{4}$ , sec. 36, T. 24 N., R. 5 W. This layer, exposed in the lowest terrace of the Teton



Figure 18. Indian fireplace in loess overlying the Pinedale lake sediments. This is altithermal in age.

River at about 3795 feet above sea level is about two inches thick, has fuzzy, indistinct lower and upper contacts, and is not pure. This ash, found by Mudge, has been identified as Mount Mazama, dated at ca. 6500 years (personal communication with Wilcox, June 16, 1968).

These ash layers indicate that the lake deposit is, definitely Pinedale, as proved by the ash layers found in the upper layers of the lake sediments. Just south of the New Rockport Hutterite Colony is a lake deposit of Pinedale Number Two, whereas the deposits near Choteau and in sec. 36, T. 25 N., R. 4 W., are assigned to Pinedale Number Three.

Excellent exposures of the lake sediments are seen in the cutbanks along the Teton River (Figures 19 and 20). Stratigraphic sections are presented. A description follows, top to bottom, N to A:

Partial Measured Section of Pinedale Lake Deposits on Teton River, Choteau, at Station 184 (Figure 7, page 32).

| <u>Unit</u> | <u>Description</u>                                                                                                                                                                                                                                                                                                                                                    | <u>Feet</u> |
|-------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------|
| N.          | Finely laminated silt layer; medium brown; top layer is nine inches of dark brown richly organic, thinly laminated clay; root casts in whole layer . . . . .                                                                                                                                                                                                          | 4½          |
| M.          | Nearly black clay layer rich in organic matter; light brown silt layer two inches thick; gray brown sandy layer six inches thick with one-half inch dark brown clay layer at top; alternating silt and clay layers about one foot thick with root casts topped by a thinly bedded clay and fine silt layer, all layers finely laminated on close inspection . . . . . | 2½          |



Figure 19. Cutbank exposure of Pinedale lake sediments along the Teton River. Horizontal layers are easily seen.

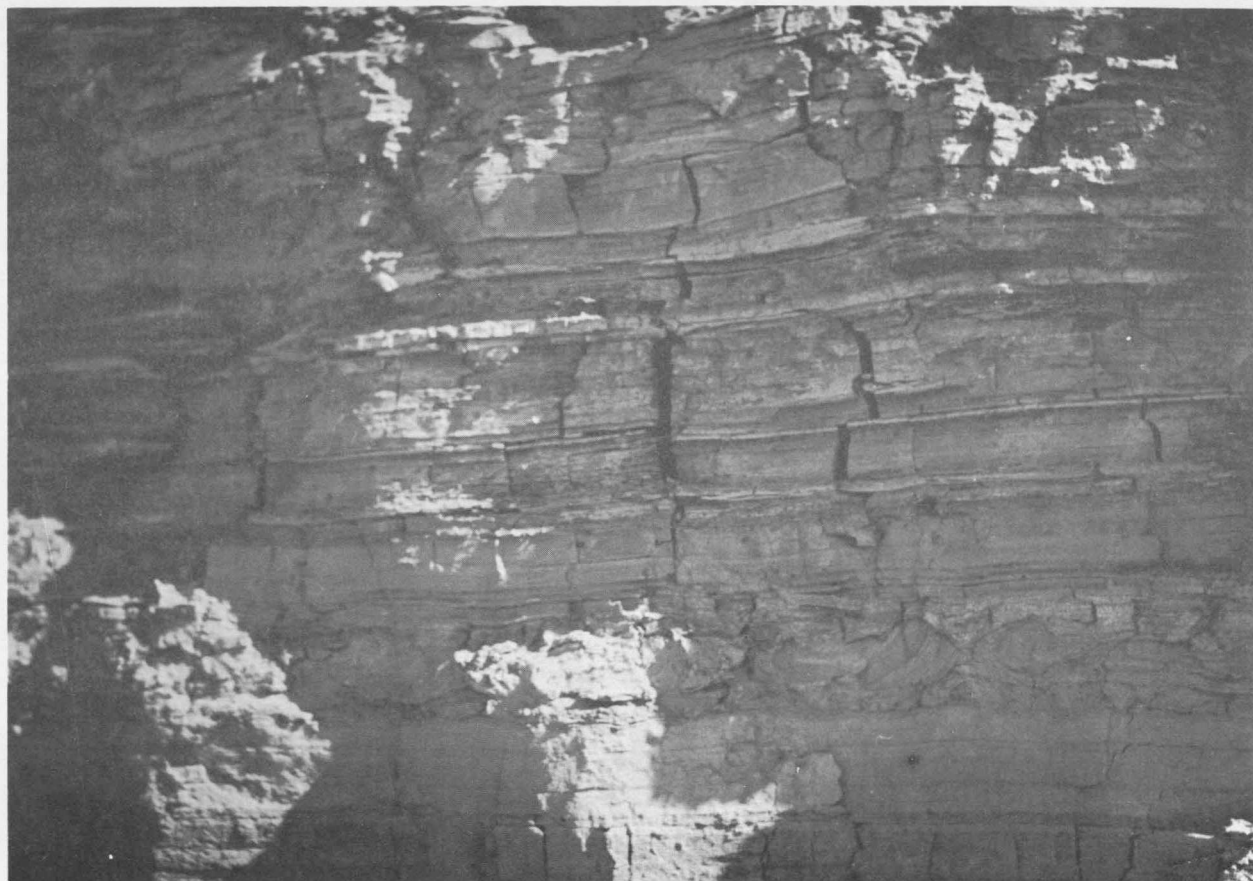


Figure 20. Close-up of Figure 18 showing the Pinedale lake sediments. The view shows approximately ten feet of sediments.

| <u>Unit</u> | <u>Description</u>                                                                                                                                                                                                                                                                                                                                                                 | <u>Feet</u> |
|-------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------|
| L.          | Alternating light brown silt and dark brown clay layers about one to three inches thick; thin laminae within major layers root casts through whole layer with limonite rings up to one and one-half inch diameter; selenite crystals in organic layers . . . . .                                                                                                                   | 2           |
| K.          | Alternating medium gray brown silt and dark brown organic rich clay layers, some of which are one inch thick to one-sixteenth inch thick; fine laminations are visible on close inspection . . . . .                                                                                                                                                                               | 2+          |
| J.          | Very dark brown to black clay layers rich in organic matter finely laminated with light brown slightly coarser layers; contains selenite crystals up to one inch in length; slight very small ripple marks of one-quarter inch amplitude present; some silt layers, light brown, intermixed near bottom of layer . . . . .                                                         | 1½          |
| I.          | Massive appearing silt layer; thin laminae upon close inspection; contains root casts and selenite crystals up to one-half inch long, light gray brown . . . . .                                                                                                                                                                                                                   | 1/2         |
| H.          | Slightly coarser layer; medium dark gray brown; contains thin laminae of clay rich in organic matter . . . . .                                                                                                                                                                                                                                                                     | 1/6         |
| G.          | Silty layer, medium brownish gray; thinly laminated on close inspection, appears massive at a distance; root casts 1/16 inch across abundant with limonite rings around them up to one inch across; selenite crystals extend down through core of root casts; single selenite crystals abundant throughout the layer . . . . .                                                     | 2½          |
| F.          | Base of silt layer three inches thick; then silt alternating with tough, leatherlike organic rich, dark brown clay layers; top layers have selenite crystals in clusters up to about three inches across in organic rich layers; root casts about one-sixteenth inch across throughout the layers; root casts have limonite rings around them up to one inch in diameter . . . . . | 3+          |

| <u>Unit</u> | <u>Description</u>                                                                                                                                                                                                                                                                                                                                                                        | <u>Feet</u> |
|-------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------|
| E.          | Fine silt alternating with clay layers rich in organic matter; thin laminae within silt and clay layers; cuts across all previous layers, but in some places does not cover up humps of (C); thicker silt layers towards bottom, clay dark brown; silt medium brown . . . . .                                                                                                             | 1-2+        |
| D.          | Clay layer with some silt and organic rich layers; deposited at angle of forty degrees to irregular surface; upper layer is discontinuous and has irregular thickness; dark brown . . . . .                                                                                                                                                                                               | 1/48-1/2    |
| C.          | Silt layer; very thin laminae, also parallel to irregular surface; upper edge uneven and whole silt layer almost absent in some spots; in low areas layer is thicker; medium brownish gray . . .                                                                                                                                                                                          | 1/48-1/2    |
| B.          | Thinly varved clays parallel to the apparent erosion surface, medium brown . . . . .                                                                                                                                                                                                                                                                                                      | 1/12        |
| A.          | Irregular surface, varying in relief up to four feet, of what appears to be reworked till of Bull Lake (?) some shallow stream channels and sand lenses; contains angular to rounded fragments of granite, quartzite (red, yellow, and white), sandstone, and some coal up to three inches in diameter; at bottom edge of exposure is silt in one spot; medium brown (Figure 7) . . . . . | 0           |

Partial Measured Section of Pinedale Lake Deposits on Teton River, Choteau, at Station 198 (Figure 7, page 32)

| <u>Unit</u> | <u>Description</u>                                                                                                                                                                                                                                                                                   | <u>Feet</u> |
|-------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------|
| J.          | Coarse silt and sand unit which seems to lie on a slightly irregular surface, erosional (?); unit varies in thickness by nearly ten feet; slight cross-bedding apparent; layers of fine gravel present; thin layers in whole unit less than 1/32 inch thick; represents Pinedale Three (?) . . . . . | 10-20       |

| <u>Unit</u> | <u>Description</u>                                                                                                                                                                                                                                                                           | <u>Feet</u> |
|-------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------|
| I.          | Limonic stained clay with some silt, selenite crystals in the layer, eighteen inches thick; then a silt layer with disrupted layers of clay in it, probably first caused by necking and then sliding to the east (Figure 21); selenite crystals and root casts through the whole layer . . . | 8           |
| H.          | Silt layers ten to fourteen inches thick and clay layers eight to ten inches thick having thin laminae within; limonic staining in clays; clay layers are disturbed and some push up into silt layers (Figures 22 and 23) . . . . .                                                          | 3           |
| G.          | Alternating silt and clay with silt units being six to ten inches and the clay units four to six inches thick with fine laminae. This layer marks top of undisturbed layers . . . . .                                                                                                        | 10          |
| F.          | Layer of alternating organic rich clay and silt with coarse silt and pebbles near bottom; layers of clay one-sixteenth to one-half inch thick with fine laminae within; at top get silt layers three to four inches thick; light brown to dark gray. . .                                     | 10          |
| E.          | Silty sand layer with many pebbles of red, white, and yellow quartzite, sandstone, quartz; chalcedony, granite, and coal (?) or wood (?) from one-sixteenth inch to three inches diameters; shell fragments (very small); brown to dark gray . . . . .                                       | 1+          |
| D.          | Clay and silt layers alternating; from one to three inches thick with thin laminae. Silt is coarse with well-rounded pebbles of red, white, and yellow quartzite, and sandstone less than one inch in diameter. Clay layers usually thicker than silt . . .                                  | 2           |
| B.          | Silt layer; gray; finely layered; cross bedded, cross-laminae one to one and one-half inches in amplitude, probable ice rafted pebble in silt, clay layer on top lying directly on silt . . . . .                                                                                            | 3           |
| A.          | River surface . . . . .                                                                                                                                                                                                                                                                      | 0           |



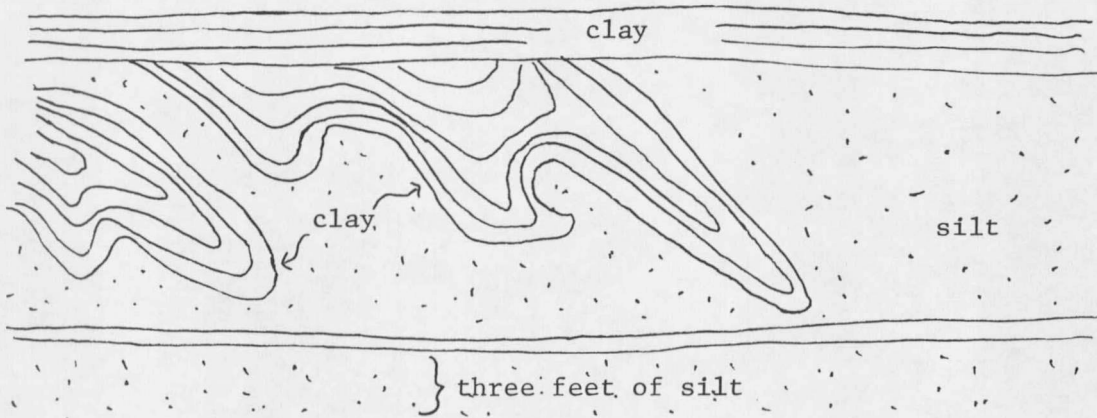


Figure 21. Disrupted clay layer in Pinedale Lake.

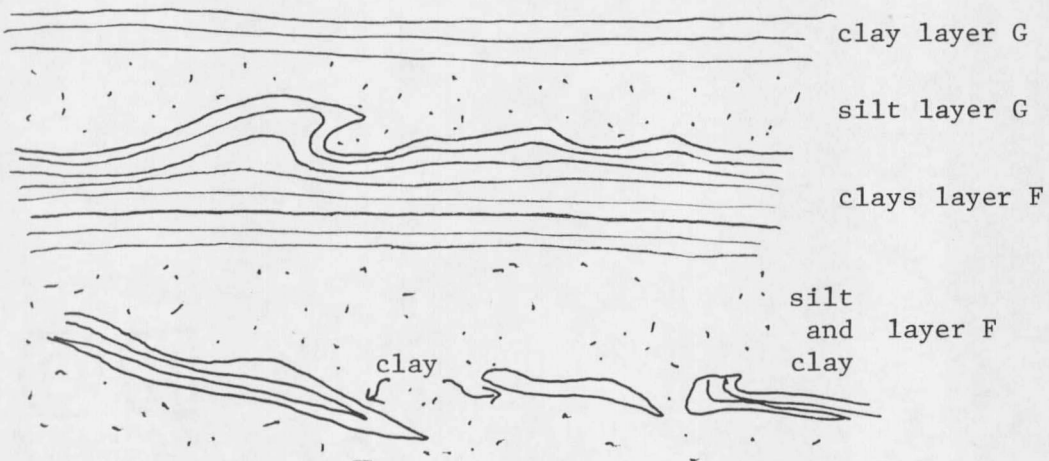


Figure 22. Disrupted clay and silt layers in Pinedale Lake.

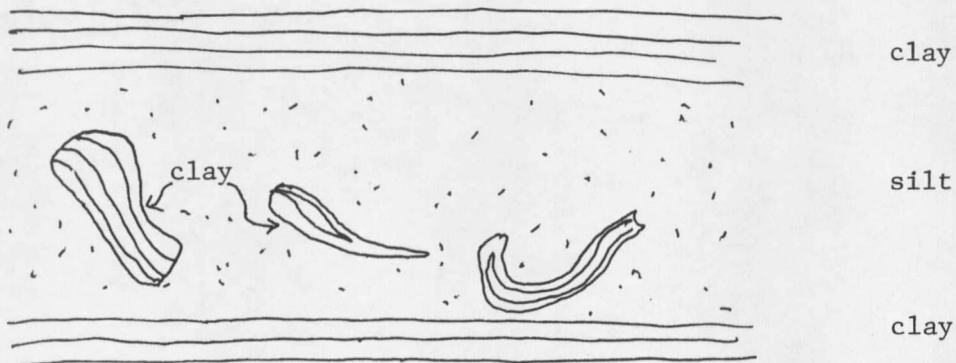


Figure 23. Disrupted layers in Pinedale Lake.

Partial Measured Section of Pinedale Lake Deposits on the Teton River, Choteau, at Station 199 (Figure 7, page 32)

| <u>Unit</u> | <u>Description</u>                                                                                                                                                                                                                                                                                                                                                                                    | <u>Feet</u> |
|-------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------|
| D.          | Top of section, not described in detail . . . . .                                                                                                                                                                                                                                                                                                                                                     |             |
| C.          | Silt with ripple marks on top; cross laminae in some places exhibiting climbing ripple marks; thin layers of clay show ripple mark impressions on bottom layer and top layer is smooth; these layers alternate with clay layers about one inch thick and silt layers varying from one foot to three inches thick; layers not parallel, some layers pinch out; bottom silt layer is two feet thick . . | 6           |
| B.          | Clay layer; massive from a distance, finely laminated on close inspection; medium brown, slightly silty; on top of flat surface was one piece of granite . . . . .                                                                                                                                                                                                                                    | 6           |
| A.          | River surface . . . . .                                                                                                                                                                                                                                                                                                                                                                               | 0           |

The sediments are composed generally of fifty percent calcium carbonate, thirty percent quartz, ten percent selenite, five percent Colorado shale fragments, five percent biotite and coal fragments, and five percent other (granite, quartzite, chalcedony, and others). The silty layer contains more quartz than the clay layers.

(?)

It is known that the lake's absolute minimum deposition level was 3820 feet above sea level and probably was 3900 feet. It is estimated that the water may have been one hundred feet deep or deeper, which would indicate its water surface was at an elevation of at least 4000 feet and probably higher.

It is thought that all the lake deposits observed are of

Pinedale age with the possible exception of the silt below the apparently reworked Bull Lake till. An explanation would be that in early Bull Lake time a lake of unknown extent was crowded into a smaller and smaller space as Bull Lake mountain and continental ice finally coalesced. Another explanation is that the coarse, mainly unsorted material with the irregular surface is not reworked till at all, but is an outwash deposit of both the mountain and continental ice lying on top of the Bull Lake lake deposits. From other evidence such as the limestone cobbles found on Pine Butte, east of Bynum Reservoir, and in scattered places up to Choteau, the first explanation seems more plausible.

Continental. The boundaries of the Pinedale continental ice are very well defined although quite attenuated. It is believed that the greatly modified edges were "melted down" by the lake waters at the edge of the continental material. The position of lake sediments overlapping onto the continental till are shown on the map in the pocket (Plate 1), and the outer edge of the continental till is also indicated.

Exposures of the continental till are displayed in the cutbanks along Muddy Creek, which are up to thirty feet in height at Station One (Figure 7). The till is slightly cemented by calcium carbonate and is unsorted (Figure 24). It contains a clay and silt matrix with fragments of rocks ranging from a



Figure 24. Cutbank on Muddy Creek exposing Pinedale continental till at Station one.

fraction of an inch up to ten inches in diameter, in form angular to well-rounded (Figure 25). The morainal material contains granite, gneiss, schist, red, yellow and white quartzite, some carbonized wood (?) or coal (?) fragments, and some small, white, thin shell fragments. The last two constituents mentioned may be reworked Cretaceous material. Some of the granite fragments are so deeply weathered that they may be crumbled in one's hands. This suggests that the Pinedale continental ice probably contains reworked continental till which is older than Pinedale age. A gneiss erratic three feet across, is perched on top of the ground moraine material at this point.

Summary. The maximum extent of Pinedale mountain ice is very clear. The arcuate moraine of the mountain ice is very sharply defined as it rises more than one hundred feet above the surrounding flat surface. Jack pines grow thickly among its large limestone erratics. Two moraines are present, separated by an outwash plain. The north outer lateral moraine extends thirty feet up onto the older flat surface believed to be of Bull Lake age.

One outlet for the outwash from the mountain ice was Ralston Gap, where a fan-shaped, braided deposit is found to the east, grading gradually into lake deposits at about 3880 to 3900 feet above sea level. This gives an approximate minimum level of



Figure 25. Close-up of ground moraine shown in Figure 23. The black spot above the rock to the left of the badger hole and shovel is where a piece of carbonized wood(?) was found.

deposition for the Pinedale lake. The lake itself probably was at least one hundred feet deep or deeper, thus giving an elevation for the lake surface of at least 4000 feet above sea level. The lake is Pinedale in age as evidenced by the ash layers incorporated in the lake sediments found in the NW  $\frac{1}{4}$ , sec. 36, T. 25 N., R. 4 W. (Plate 1), and just south of the New Rockport Hutterite Colony.

The border of the Pinedale continental moraine has an attenuated edge. It lies in an arc in the northeast corner of the mapped area and was the boundary for the eastern side of the lake.

## CHAPTER VI

### CONCLUSIONS

The evidence found tends to support the hypothesis that the Bull Lake ice in the Teton River drainage extended farther east onto the plains than did the Pinedale ice and that the continental ice extended farther west and south than previously described.

Other conclusions are listed below:

1. With the exception of the magnetite-bearing, sandstone capped, flat-topped hills and Pine Butte, all the high ridges extending toward the mountain front are capped with pre-Bull Lake glacial till.
2. The Flaxville Terrace is represented by the upper flat surface of Teton Ridge.
3. Number Two Terrace is represented by Pine Butte Terrace and the flat, gravel-capped hills straight east of Pine Butte, by the magnetite-bearing, sandstone-capped hills west and northwest of Choteau, by Bole Bench east of Choteau, and the flat surface 204 feet lower than and adjacent to the Flaxville Terrace (Teton Ridge).
4. Number Three Terrace is the lower terrace and has Wisconsin age ice and lake deposits on it.



5. The Bull Lake continental ice nearly reached the top of the Flaxville Terrace and attained an elevation of 3980 feet above sea level.
6. Bull Lake mountain and continental ice eventually met near Choteau, gradually crowding out the lake trapped between them.
7. Pinedale mountain ice extended in an arc to about four miles east of the mountain front.
8. Pinedale outwash on the Burton Bench is overlapped by lake deposits at about 3880 to 3900 feet above sea level, giving a minimum approximate deposition level for the lake at the aforementioned elevation. The lake was probably at least one hundred feet deep, giving a water surface elevation of at least 4000 feet. The lake is ascertained to be Pinedale due to the Glacier Peak and Mount Mazama ash layers within the lake sediments of 12,500 and ca. 6,500 YBP, respectively.
9. The Pinedale continental ice came into the northeast corner of the mapped area and has an attenuated edge because it was sapped by the lake bordering it.

These are the conclusions drawn from this study. Further expansion of the area at a later date would yield much more information. It is left to others to determine the solutions to yet unanswered questions.

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## APPENDIX A

The writer theorizes, from meteorological principles gained, that the growth of the ice on the continents may possibly be attributed, in part, to the fact that the continent was cold and that the prevailing wind was westerly, giving rise to winds coming off a comparatively warm ocean. Relatively warm, moist air was forced to rise over a chain of mountains along the west coast which may have been approximately 1000 to 2000 feet lower than at present (Antevs, 1934) but which were sufficiently high to cause orographic lifting. The warm air then collided with colder continental air. The air contained moisture, but was not saturated, thus the lapse rate followed was nearly dry-adiabatic until the condensation level was reached, after which it cooled at a slower rate, which is the moist adiabat. The height of the condensation level depends on the initial temperature and humidity of the air which is being forced to rise, and evidently the mountains then, even though assumed to be lower, were sufficiently high to cause the air to rise, consequently causing cooling and expansion and condensation. Assuming the foregoing to be true, one may conclude that much of the moisture was lost on the windward side, leaving a drier air to come eastward onto the cold plains, which were in all probability snow covered; this may especially be assumed to be true in the winter. The sudden cooling of the still relatively warm but now fairly dry air resulted in a temperature inversion immediately above the surface. A net flow of heat downward from the inversion

layer to the snow field was absorbed by the snow field and radiated back. Part of the radiated heat simply was lost to space by going through the transparent bands, which take in the energy being emitted from eight to thirteen  $\mu$ , which is the wave length for the optimum emissivity of a body having the temperature of the earth. Thus, energy emitted at these wave lengths can travel nearly freely through the atmosphere and into outer space. The ultimate result was that the warmer air just above the inversion layer was constantly losing heat to the snow covered surface, because it was not receiving the same amount in return that it was radiating downward. So, by means of the foregoing process, the air over the cold continental area gradually became cooled up to high altitudes. As a result, cold core highs probably developed over the snow fields which were rather stable in maintaining their position. The development of these anticyclones had a rather profound effect on the atmospheric circulation of the world and related climate. The air must still have been fairly moist, for it was not "wrung dry" by the mountains. The formation of the large anticyclones over the continent evidently forced the oceanic lows farther south, thus bringing warmer, moist air north to clash with the cold air, and creating stormy weather of long duration, since in all probability cyclone after cyclone broke away from the main oceanic low. This is probable, for cyclones go in families.

Therefore a source of precipitation was present to give sustenance to the emerging ice field, giving rise to growth outward and resulting expansion of the area covered. The oceanic lows were at their southernmost position during the culmination of the Wisconsin stage of glaciation (Antevs, 1934). Perhaps due to another change in the world's air circulation, the great ice sheet waned; so did, perhaps, the anticyclones over it, thus allowing the oceanic cyclones to move north to their present position.

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Quaternary Glacial and Geomorphic Map  
of the  
Teton River Drainage, Montana  
by  
Ann L. Chalmers,  
1968

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