STRUCTURE AND PHYSIOGRAPHY OF THE JACKSON HOLE REGION, WYO.

BY

LYNN J. DE PREE

The Grand Teton Mountains as seen from the floor of Jackson Hole

Pl I

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ILLUSTRATIONS

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CONTENTS

INTRODUCTION

Location and Physiographic Provinces

The Jackson Hole region is located in northwestern Wyoming. Its northern boundary is the Northern Plateau of Yellowstone National Park. From this plateau the region extends south to the Snake River and Hoback ranges (Plate II). Moran, at the north, and Jackson in the southern part, are the two chief localities within the region. The nearest railroad is at Victor, Idaho which is in the Teton Basin on the western side of the Teton range. The chief means of transportation into the area is by U.S Highway 287 from the east and U.S, Highway 189 from the south. Wyoming State Highway 22 joins Jackson with Idaho Falls on the west side of the Teton range.

The Jackson Hole region is comprised of several distinct physiographic divisions, most prominent of which are Jackson Hole in the central portion, the rugged precipitous Grand Tetons to the west of the basin, the Gros Ventre Mountains to the east, the Hoback and Snake River ranges to the south, and the Nothern or Pitchstone Plateau to the north(PlateII).

Jackson Hole : The intermontane basin known as Jackson Hole begins eight miles south of the southern boundary of Yellowstone National Park and extends southward for forty

PLATE II

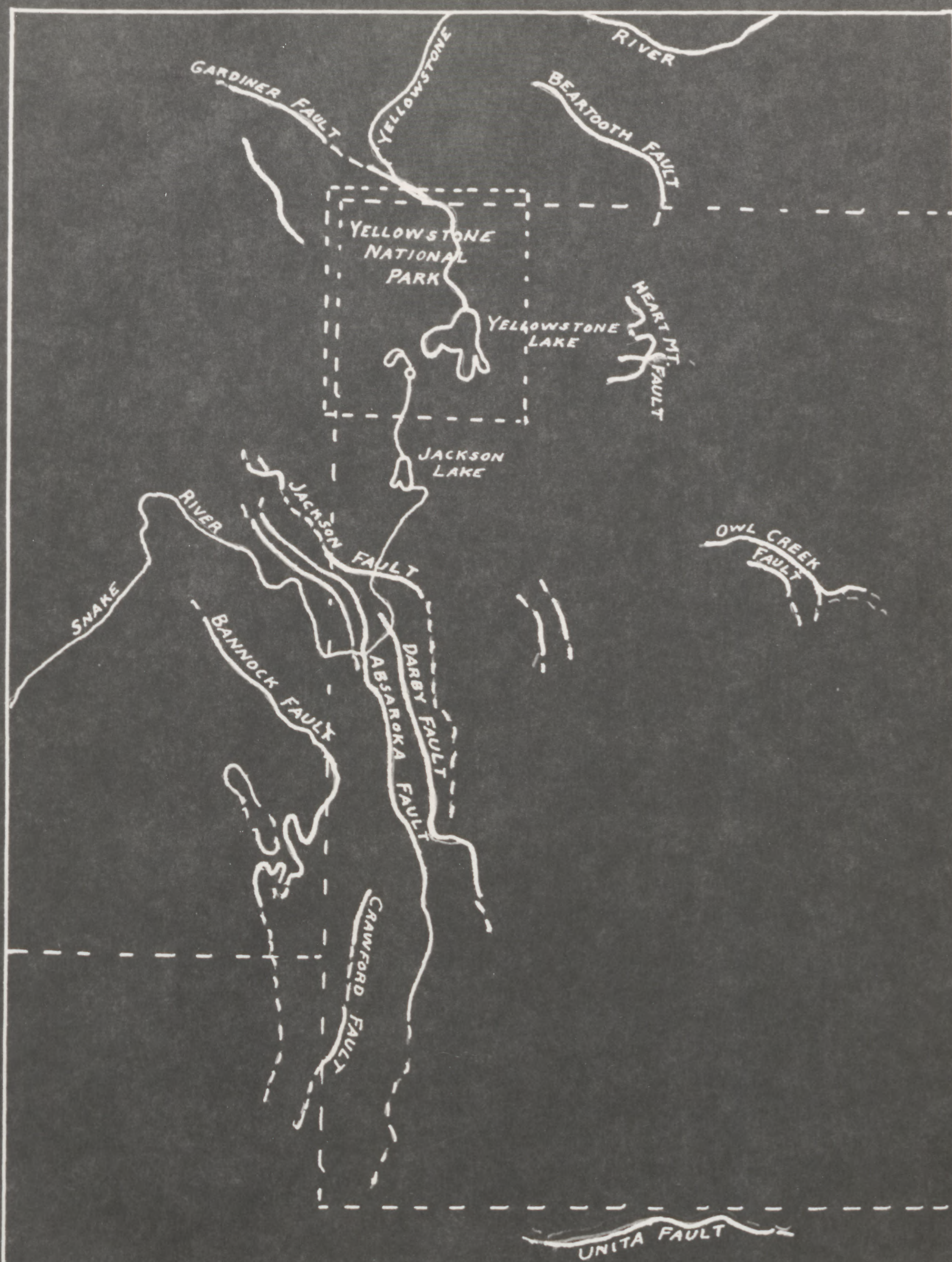
Index Map of chief physiographic regions of northwestern Wyoming. (Redrawn from Horberg, L., Structural Geology and Phyiography of the Teton Pass Area, Wyoming.)

eight miles. For the most part, its width ranges from six to eight miles. The floor of the basin ranges in altitude from 6000 to 7000 feet. The mountains on all sides of Jackson Hole rise precipitously from 2000 to 7000 feet above the floor of the basin (Plate I).

Jackson Hole is situated on the west side of the Continental Divide and is drained by the Snake River. The important tributaries from the surrounding highlands are the Buffalo, the Fork, and the Gros Ventre rivers. The floor of the basin is made up of two extensive sagebrush-covered terraces, but several "buttes" rise 500 to 1300 feet above the general floor. These are Blacktail Butte, located in the central part of the basin; Signal Mountain, in the north near the city of Moran; and East and West Gros Ventre Buttes, near the city of Jackson at the south of the basin. The alluvial terraces rise gradually toward the mountains on either side of the basin where they merge inconspicuously in places into the alluvial fans. Other important physiographic features found in the basin are the moraines which enclose Jackson and Jenny lakes along the north and west margin.

<u>The Grand Tetons</u>: Along the western border of Jackson Hole, the Grand Tetons rise abruptly from the floor of this intermontane basin and presents one of the most imposing

PLATE III



Map of the major overthrusts in western Wyoming and adjacent areas. (Redrawn from Horberg, L., Structural Geology and Physiography of The Teton Pass Area, Wyoming, Figure7, page30).

fronts of all the mountains in the United States (Frontispiece) The Grand Tetons extend southward from Yellowstone National Park for a distance of forty miles to the Teton Pass.

The highest elevations and the most rugged portions of the range are in the vicinity of Jenny Lake where the mountains rise with wall-like abruptness to elevations ranging from 12,000 to 15,000 feet, thus bringing the highest peaks 8000 feet above the floor of Jackson Hole. Within this area are a group of rugged peaks, the more famous of which are Grand Teton (13,766 feet), Mount Moran (12,922 feet), Middle Teton (12,793 feet), and South Teton (12,505 feet) (Horberg, L., p. 4-5).

The Snake River Range: The mountains south of the Teton Pass are named the Snake River Range. They are not as lofty as the Grand Tetons and are composed of a series of parallel ridges with elevations from 8000 to 10,000 feet. The Pass is at an elevation of 8431 feet and is the site of the only highway between Jackson Hole of the east and the Teton Basin on the west. The major stream is the Snake river which flows southwest through the Snake River Canyon into Grand and Swan valleys in Idaho. South of this river the range continues as the Salt River Range (Plate II).

Hoback Range: The mountains forming the southeastern boundary of Jackson Hole are composed of a series of parallel ridges similar in appearance and structure to the Snake River Range. These mountains are known as the Hoback Range (Plate II). The Hoback River forms the southern boundary, and Cache Creek terminates the northern extension of the range.

<u>Gros Ventre Mountains</u>: The eastern extension of Jackson Hole ends sharply at its juncture with the Gros Ventre Mountains. The average elevation of these mountains ranges from 8000 to 10,000 feet. The Gros Ventres extend from Cache Creek on the south to the Mt. Leidy Highlands on the north (Plate II). They are dissected by many small streams and rivers, most important of which are Nolan Creek, Flat Creek, and the Gros Ventre River. The smaller streams flow from the mountains and terminate in Jackson Hole, while the larger rivers join with the Snake River and form a part of the major drainage of the basin. Although the Gros Ventre Mountains are less conspicuous than the Grand Tetons on the opposite side of Jackson Hole, they do, nevertheless, present an imposing sight when viewed from the floor of the basin.

<u>Northern Plateau</u>: The northern boundary of Jackson Hole is essentially a broad, elevated, volcanic plateau between 7000 and 8500 feet above sea level and with an av-

erage elevation of 8000 feet. Surrounding this plateau are mountain peaks rising 2000 to 4000 feet above the general level of the plateau itself. The Absarokas form the eastern boundary (Plate II) and, geologically, are closely related to the Wind River Mountains and the Gros Ventre Mountains of the Teton Area. The Absarokas for more than 80 miles form an unbroken barrier dominated by peaks 10,000 to 11,000 feet high.

STRATIGRAPHY

The rocks exposed in the Jackson Hole region range from the gneisses and schists of the Pre-Cambrian to the river alluvium of Recent time and many geologic periods are represented. The formations and their characteristics are given below.

TABLE I

STRATIGRAPHY OF THE JACKSON HOLE REGION, WYOMING

PERIOD	FORMATION	APPROX. THICKNESS	LITHOLOGY
Recent	Alluvium		Alluvium and Piedmont deposits
Pleistocene	Till and outwash		Morainic material, outwash, and loess
Tertiary	Volcanics flows and tuffs		Rhyolites, andesites white clays, and fresh water limestones
	Almy	1500 ft	Coarse conglomerates and sandy clays
Cretaceous	Frontier	1000 ft.	Shale. Gray and buff sandstones with coal beds

(continues on page 7)

TABLE I (continued)

PERIOD	FORMATION	APPROX. THICKNESS	LITHOLOGY
Cretaceous	Aspen	590 ft.	Gray and black shaly sandstone. Coal beds. Speckled gray green porcelainite
	Bear River	970 ft	Black carbonaceous shale. Two prominent "salt and pepper" sandstones
	Gannett	250 ft.	Red shales and sandstones. Nodular limestones
Jurassic	Stump	250 ft	Garyish green ccalcareous limestone
	Twin Creek	675 ft.	Dense gray limestone some beds oolitic
	Nugget	100 ft.	Quartzitic sandstones, buff to red
Triassic	Ankareh	100 ft.	Brownish red shales and thin bedded red sandstones with dense gray limestones
	Dinwoody	250 ft	Thin bedded, gray, calcareous sandstone. weathers brown. Contains some calcareous shales. Massive limestones
Permian	Phosphoria	50 - 150 ft.	Cherty(Rex) limestone at top overlying brown fossiliferous sandstone. Oolitic phosphortite at bottom
Pennsylvanian	Wells	300 ft	Quartzitic sandstone white to pink. Includes beds of massive gray limestone. Gypsum in lower part

TABLE I (continued)

PERIOD	FORMATION	ARRPOX THICKNESS	LITHOLOGY
Mississippian	Brazier	200 ft.	Fine crystalline to dense limestone with chert nodules
	Madison	930 ft.	Gray limestone, cherty in lower part
Devonian	Darby	260 ft	Dark brown cherty limestone
Ordovician	Bighorn	385 ft.	Dolomite: lower half massive, light gray. Upper half thin bedded Pitted surface on weathering
Cambrian	Boysen	90 ft.	Bluish gray, mottled limestone. Oolitic in places.
	DePass (Grand Canyon	240 ft	Limestone thick bedded to massive. Small oolites. Weathers into irregular bands of light to dark gray
	DePass (GrosVentre)	600 ft	Fine grained, dark gray limestone. Upper portion fossiliferous. Feruginous sandstone and green micaceous shale in lower part
	Flathead	215ft.	Quartzite., light gray to buff. Lower portion conglomerate with quartz pebbles
Pre-Cambrian			Gneiss and schists intruded by pegmatites and granites

STRUCTURE

Divisions: Two distinct types of structures are represented in the Jackson Hole Region. They are the folds and thrust faults of the Snake River and Hoback ranges to the south of the Teton Pass, which Horberg refers to as the Laramide structure of the western belt, and the asymmetrical folds of the

PLATE IV

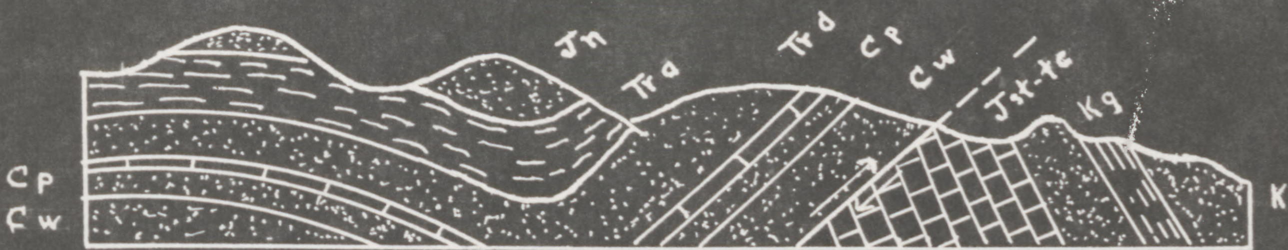


Fig. I
Darby Fault, Snake River Canyon, Snake River Range, Wyo.

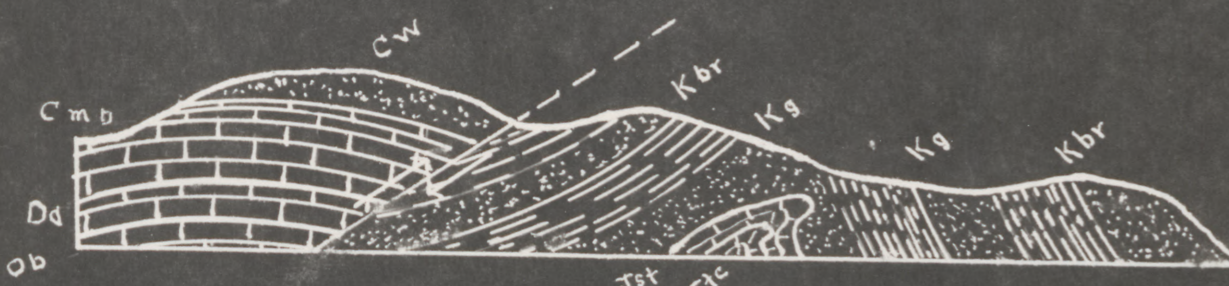


Fig. II
Absaroka Fault, Snake River Canyon, Snake River Range, Wyo.

Od, Ordovician Bighorn; Dd, Devonian Darby; Cmb, Mississippian Madison and Brazier; Cw, Pensylvanian Wells; Cp, Permian, Phosphoria; Trd, Triassic Dinwoody; Tra, Triassic Ankareh; Jn, Jurassic Nuggett; Jtc, Jurassic Twin Creek; Jst, Jurassic Stump; Kg, Cretaceous Gannett; Kbr, Cretaceous Bear River.

Grand Tetons and Gros Ventre Range, referred to by Horberg as the structures of the eastern belt (Horberg, L.,p.24).

Laramide structures of the western belt: The most characteristic features of the western belt are the closely compressed folds which are overturned to the east and associated with overthrust faults. Within the area under consideration, the Snake River Range best exemplifies the western belt structure. Within the Snake River canyon, formed where the Snake River makes a sudden turn and leaves the intermontane basin of Jackson Hole and cuts through the range, two large overthrust faults the Darby and the Absaroka, are conspicuous (Plate III).

Plate IV,Figure I shows the stratigraphic relationship between the beds on the north and south sides of the Darby fault. From the diagram of the Darby fault, it is seen that the Wells formation of the Pennsylvanian period is thrust over the Twin Creek formation of the Jurassic period. The Wells formation dips approximately 33 degrees to the west while the beds on the east side of the fault are extremely steep, having an approximate dip of 70 degrees to the east (Horberg,L.,p.34). In the north, the Darby fault terminates at the Teton Pass, but it continues southeastward into the Green River Basin of Wyoming, a distance of approximately 100 miles (Plate III). In tracing this fault. A.C. Peale has

PLATE V

Fig. I
St. John's Fault, Snake River Canyon, Snake River Range, Wyo.

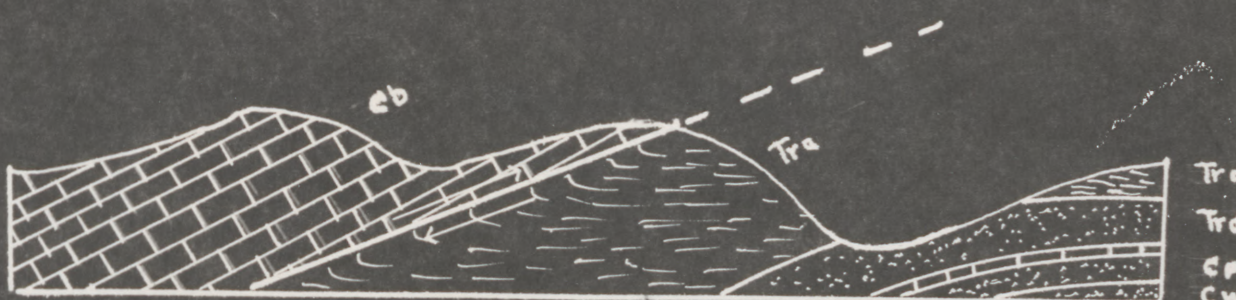


Fig. II
Game Creek Overthrust, Game Creek Canyon, Jackson Quadrangle, Jackson, Wyo.

C, Cambrian(undifferentiated); Ob, Ordovician Bighorn; Dd, Devonian Darby; Cmb, Mississippian Madison and Brazier; Cw, Pensylvanian Wells; Cp, Pensylvanian Phosphoria; Trd, Triassic Dinwoody; Tra, Triassic Ankareh.

found that at several points the Mississippian beds are thrust against the Frontier formation of the Upper Cretaceous, giving the fault a stratigraphic displacement of over 20,000 feet (Horberg,L.,p.34).

Plate IV,Figure II represents the Absaroka fault as it is seen in the Snake River canyon. From this diagram,it is seen that the Absaroka thrust sheet consists of Paleozoic formations-namely, the Wells(Pennsylvanian), the Madison and Brazier (Mississippian), the Dinwoody (Devonian), and the Bighorn (Ordovician). These are thrust over the Gannett formation of the Cretaceous. The fault continues north into Idaho and southward to the Wyoming-Colorado border(Plate II). The total length of the fault is about 200 miles and Horberg estimates the stratigraphic displacement to be over 20,000 feet (Horberg,L.,p.28).

Near the outlet of the Snake River canyon is the St. John overthrust (Plate V,Fig.I), in which the Cambrian rocks are thrust over the Mississippian. A short distance east of this fault another fault is seen (Plate V,Fig.I), in which the Darby (Devonian) is thrust over the Wells(Pennsylvanian) formation. These faults, although not as long as the Darby and Absaroka faults, do, nevertheless, follow the same general trend.

PLATE VI

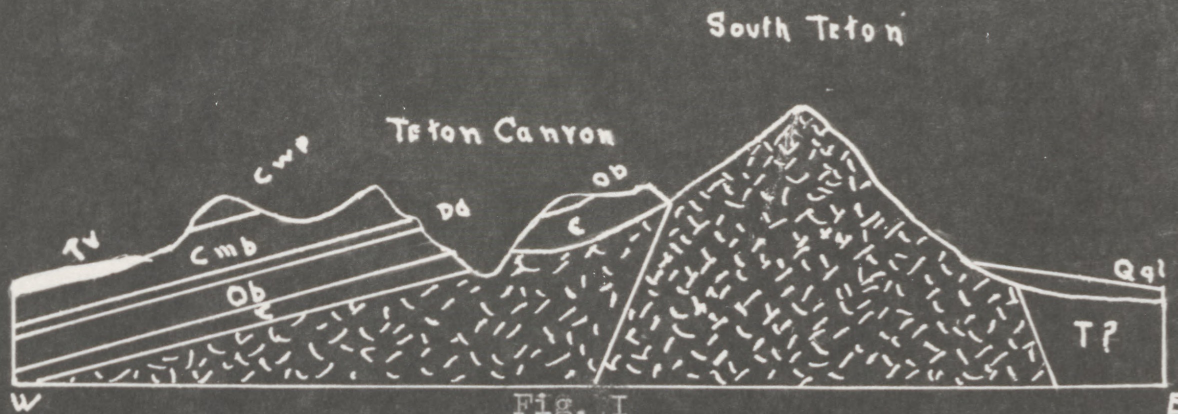


Fig. I

Structural section across the Teton Mountains. (Drawn from Horberg, L., The Structural Geology and Physiography of the Teton Pass Area, Wyo,).

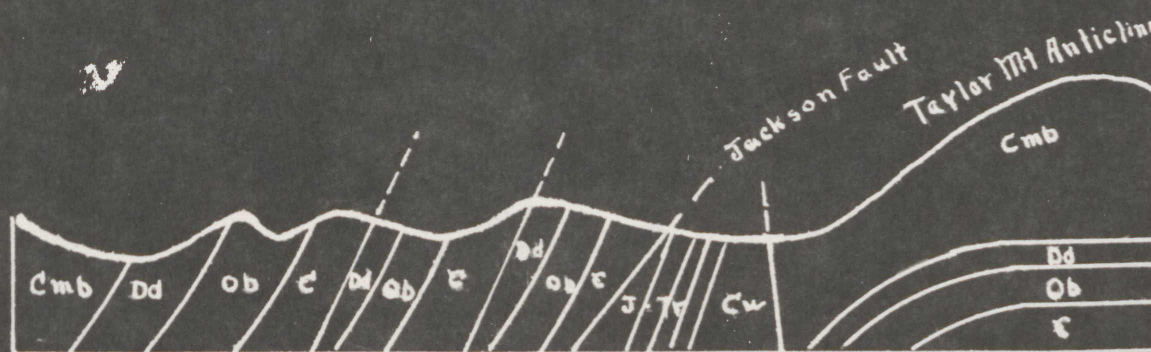


Fig. II

Taylor Mountain Anticline and Jackson Fault in the vicinity of the Teton Pass.

C, Cambrian (undifferentiated); Ob, Ordovician Bighorn; Dd, Devonian Darby; Cmb, Mississippian Madison and Brazier, Cw, Pensylvanian Wells; Cp, Pensylvanian Phosphoria; Trd, Triassic Dinwoody; Tra, Triassic Ankareh, Tv, Tertiary Volcanics; Qgl, Pleistocene glacial

Another overthrust of the western belt is found in the Hoback Range. It cuts across Game Creek canyon a short distance above the narrows and will be called the Game Creek overthrust. Plate V, Figure II is a view of this structure along the west side of the canyon.

Eastern Belt structure: In general, the Eastern Belt structure consists of broad asymmetrical folds often exposing crystalline rocks in the central portion. These flexures can best be seen on the west side of the Teton Mountains where the Paleozoic beds have not been removed by erosion and in the central part of the Gros Ventre Mountains. Plate VI, Figure I illustrates the structures in the Tetons and shows the Paleozoic beds rising steeply along the flanks of the crystalline core.

At Teton Pass the relation of the closely compressed folds of the western belt to the monoclinal folds of the eastern belt is revealed. The western belt terminates with the Jackson fault and there the formations of the western belt are thrust obliquely over the Taylor Mountain anticline (Plate VI, Fig. II) of the eastern belt. The Jackson fault has been mapped from Victor, Idaho, across the Teton Pass into Jackson Hole and into Cache Creek of the Gros Ventre Mountains (Plate III). Associated with the major fault are minor faults and folds as is shown in Plate VI, Figure II.

In addition to the Taylor Mountain anticline, there are numerous other folds which represent the eastern belt structure. Most outstanding of these are the Gros Ventre anticline, which Horberg suggests as being a probable extension of the Taylor Mountain anticline (Horberg, L., p. 35); the Moose Creek anticline, consisting of high-dipping, monoclinal folds on the south and gentle folds on the north; and the Nolan Creek anticline in the Gros Ventre Mountains, which Horberg thinks may be a continuation of the Moose Creek anticline (Horberg, L., p. 39).

Without taking local variations into consideration, a study of the above described structure reveals that the general trend of the western belt structures is North 30 degrees west and the eastern belt structures, in general, trend North 20 degrees east. This divergence in trend between the Western and Eastern belts is the most outstanding characteristic which distinguishes the two belts (Plate III).

Stages of Deformation

In the above discussion it has been emphasized that the Laramide structures of the Teton area are made up of two distinct types, namely, the folds and thrust faults of the east and west belts respectively. Horberg has suggested that the Laramide disturbance consisted of two stages of deformation (Horberg, L.,p.49).

The first stage resulted in the formation of the asymmetrical folds of the eastern belt. Following this period of folding, thrust faulting took place which gave rise to the structure of the western belt. This contention is given weight by the sharp termination of the western belt structure at places where it contacts the eastern belt as, for example, along the Jackson fault at the Teton Pass. Horberg contends that the folds of the eastern belt acted as a buttress for the later deformation resulting in the thrusts of the western belt. Furtherr evidence for two stages in the Laramide disturbance is found in the divergent trend of the two belts (Horberg, L.,p.49).

The Laramide did not end abruptly after the period of thrust faulting, but, in the nearby Absároka Range, continued as a series of pulsations into the Tertiary and perhaps into the Pleistocene (Love, J.D.,p.116-117).

The two types of structures in the Teton area can be better understood if their location in respect to the Rocky Mountain geosyncline is known. The thickest beds of the geosycline are found in eastern Idaho. The sediments thin out to the east and are only 12,000 feet thick in the Teton area as contrasted to 46,000 feet in the deepest portion of the trough. The structure of the western belt is the fold and thrusts of the sediments of the geosyncline, and are similar to those found in the Appalachian region of eastern United States. Tightly compressed folds and low angle faults are common throughout this belt. Horberg concludes that the forces giving rise to these folds were "shallow in origin and resulted in horizontal compression"(Horberg, L.,p.55). The eastern belt is one of thin sedimentary veneer on a crystalline complex, and monclines resulted from stresses of deep-seated origin in which the "vertical component is of importance"(Horberg, L.,p.54).

Correlation with Structures of Adjacent Areas

In addition to the Jackson Hole region, the structures discussed above are found in other ranges throughout the Middle Rockies. The Eastern Belt structure serves as a characteristic structural pattern in such areas as the Black Hills, the Bighorns, The Wind River, the Pryor Mountains, the Beartooth, and the Absaroka ranges. The Western Belt include the Gallatin Range of northwestern Wyoming, and the mountains along the Idaho-Wyomingborder south of the Wasatch Range. Some of the more important folds of the Western Belt that are found outside of the Jackson Hole region are the Bannock fault, the Crawford fault, and the Gardiner fault, while the Eastern Belt structure is represented by the Beartooth fault, the Heart Mountain fault, and the Owl Creek fault(Plate III).

The similarity in the structure of the Pryor Mountains of Montana and the Eastern Belt structure of the Teton area is brought out in a report by D.L.Blackstone. In this report, he states that the surface expression of the Pryor Mountain uplift is "an asymmetrical anticline, or a monocline"(Blackstone, D.L.,p.598). He recognizes three aspects of the structure,namely simple asymmetrical anticlines,asymmetrical anticlines and monoclines with high dips, and ruptured anticlines with low faults. The first of these are typical of the structures in the Teton and Gros Ventre Mountains discussed above.

Regarding the origin of this structure, Blackstone arrives at the conclusion that the Pryor Mountain uplift predated the Laramide orogeny and was "controlled by zones of weakness in the Pre-Cambrian rocks"(Blackstone,D.L.,p.612). This is the same conclusion reached by Horberg in his discussion of the origin of the asymetrical folds of the southern Teton area.

The structure of the Bighorn Mountains is similar to and is a continuation of a ring of mountains beginning with the Pryor Mountains in the northeast and continuing through the Bighorns, Bridger, Owl Creek, Absaroka to the Beartooth Mountains in southwestern Montana. Demorest, in his study of the structural features of the Bighorns, mentions the fact that their asymmetry is not constant, but divides the range into thre parts, north, central, and south (Demorest, M.,p.162). In the north and south segments, the folds are steepened on the west while in the central segment the folds are steeper on the east. In a study of the geological problems of the Beartooth and Bighorn region, Bucher divides the Bighorns into three structural units similar to the divisions made by Demorest (Bucher, W.H., Thom,W.T., and Chamberlain, R.T.,p.168). The central segment, whose southern boundary is marked by the Tensleep fault and whose northern boundary is marked by the Tongue River(Demorest, M.,p.162) has the simplest structure. Here the Paleozoic sediments on the west side form a long gentle dip slope toward the Bighorn Basin, but on the east side these sediments dip at a steep angle along the mountain front. The east front becomes less steep and drops to low angles northwest of the Tongue River(Bucher, W.H.,p.169). The Pre-Cambrian crystalline rocks, forming the axis of the anticline, are exposed along the eastern front of this central segment. Demorest concludes that the over-steepened portion of the eastern front is due to secondary overthrusting and states that if it were not for this thrusting the eastern front would not be very much steeper than the western side (Demorest, M.,p.167). Bucher states that "local overthrusting has pushed lobes of the crystalline core into the sediments of the foothills"(Bucher, W.H., p.169).

In the section of the Bighorns north of Tongue River, the structures are steep and overturned to the southwest in contrast to the structures of the central segment which are steepened and overturned to the northeast. The Paleozoic sediments on the eastern side of the northern section have a gentle slope, but drop off abruptly on the western side. Pre-Cambrian rocks are exposed along the western flank.

The structures of the southern section are essentially the same as that of the northern section. Here the Paleozoic strata forms a dip slope on the east and drops off abruptly on the west. The general trend of the mountain axis curves from a north-south to a southwest direction. In both the north and south sections, the structures are "essentially asymmetrical anticlines produced by overthrusting toward the west-southwest"(Demorest. M.,p.169).

Structually, the Beartooth Mountains are similar to the Pryor and Bighorn Mountains. There are two distinct structural patterns which correspond to the central and northern sections of the Bighorns. The southern portion of the Beartooth Range corresponds to the central segment of the Bighorns. The east front is formed by steep dipping Paleozoic sediments which have resulted from overthrusting. These overturned Paleozoic rocks form conspicuous palisades along the front. The Pre-Cambrian crystalline rocks form the mountain front where the palisades have been lowered by erosion. The west and south sides of the mountains are composed of Paleozoic sediments which dip to the southwest(Bucher, W.H.,p.172-173). The structual pattern in the northwest section of the Beartooth Range is reversed from that of the southern section. Here the Paleozoic sediments along the northwestern front form a gentle dip slope while on the southwest the overthrusting has formed a relatively steep front.

PHYSIOGRAPHY

Tertiary Volcanic Activity

Volcanic activity,which followed the Laramide disturbance of Cretaceous time, resulted in the pouring out of lavas over much of the surface. Horberg contends that these lava flows may have covered the Grand Tetons, which by this time had been reduced to an area of low relief, and probably extended as an unbroken flow from the Teton Basin on the west to Jackson Hole on the east(Horberg, L.,p.50). The lavas were deposited on rocks ranging from Pre-Cambrian to Upper

Cretaceous. In the Snake River Canyon, near the vicinity of Swan Valley, the lava flows are deposited on the Pennsylvanian and Cretaceous formations. At the north end of the Grand Tetons the lavas are found on the rocks that range in age from Pre-Cambrian to Cretaceous. Scattered remnants of the flows are found on the tops of the buttes in Jackson Hole and at the entrance to Sheep Creek Canyon and Flat Creek Canyon in the Gros Ventre Range.

Erosion Surfaces

Union Pass surface: In several places along the Pre-Cambrian core of the Grand Tetons, remnants of a mature erosion surface can be seen. This surface, at an average elevation of 9,500 feet, is well displayed between Death Canyon and Cascade Canyon and along the "divides at the heads of North and South Leigh Creeks"(Horberg, L.,p.66). This surface, modified by glacial erosion, is represented by gentle sloping surfaces which truncates the structure of crystalline rocks. Horberg, in his discussion of the Union Pass surface, states that gravels have been found on this surface and explains that these gravels, consisting of limestone pebbles, must have been derived from the Paleozoic beds to the west. (Horberg, L.,p.67). Elsewhere in Wyoming Blackwelder has referred to these surfaces at 9500 feet as belonging to the Union Pass Cycle of erosion (Horberg, L.,p.67 from Blackwelder, op.cit.,p.310-312), and Horberg contends that the mature surfaces at this elevation in the Grand Tetons can be attributed to this cycle. Along the back slope of the Grand Tetons the Union Pass surface is also evident although not as conspicuous as along the eastern front. The gentle slope and uniform dip along the western side is due largely to the uncovering of a pre-volcanic, base-leveled surface. Horberg, in making a study of this surface, has found it along all of the "middle and upper portions of the interstream areas on the backslope" and has found that it rises to elevations of 9500 feet (Horberg. L.,p.68). This pre-volcanic surface is undoubtly a continuation of the Union Pass surface that Blackwelder refers to in the northern part of Wyoming.

In the Snake River Range and in the Hoback and Gros Ventre Mountains, the Union Pass surface is evident along the higher divides. In the vicinity of Camp Davis, located along the Hoback River a few miles below its juncture with the Snake River, the Union Pass surface is well preserved on the surface of Cream Puff Mountain. In this area there are two very distinct surfaces which present an interesting problem to the geologist. Approximately 2000 feet below the summit of Cream Puff Mountain there is a second surface known as the Mesa. It is the contention of some geologists that the Mesa surface represents a different cycle of erosion than that which is represented by the higher surface of Cream Puff Mountain. The geologists at Camp Davis, however, contend that both of these surfaces represent the Union Pass cycle. The lower elevation of the Mesa surface, they claim, was the result of faulting and does not represent another cycle of erosion.

Black Rock surface: Throughout the Jackson Hole region there is evidence of a mature surface at elevations ranging from 6500 to 8200 feet. Upon this surface is found scattered remnants of glacial till(Buffalo). This surface is referred to by Horberg and Blackwelder as belonging to the Black Rock cycle of erosion of pre-Buffalo time. According to Fryxell, this surface occurs as "gently sloping flats on the summits of the buttes", as "westward sloping benches and divides in the eastern highlands", and as "upper valley slopes along the Gros Ventre River and Buffalo Fork - 800 to 1200 feet above the streams" (Fryxell, E.M., p.220-221).

Along the eastern front of the Grand Tetons, there are many hanging valleys 800 to 1000 feet above the floor of Jackson Hole. The level of these valleys is at the level of the Black Rock surface and Horberg contends that these valleys were left as the result of the lowering of the floor of Jackson Hole 800 to 1000 feet by erosion of the Black Rock surface since Buffalo time (Horberg. L.,p.71). Fryxell disagrees with this contention and suggests the possibilty of Jackson Hole being lowered by faulting in place of erosion (Fryxell, E.M.,p.221). This contention is also maintained by the geolohgists at the University of Michigan station at Camp Davis.

Fryxell gives an excellent description of the conditions which existed during the Black Rock cycle by desribing the surface as follows. "....the floor of Jackson Hole was perhaps 800 to 1000 feet higher than now and the buttes were low, inconspicuous hills. On all sides except the west the basin was bounded by mature topography - broad, flat valleys and gentle slopes descending toward the basin. Farther back in the highlands were preserved areas recording a still earlier cycle (the Union Pass). On the west rose the Teton scarp, precipitous as now, though not as high, deeply dissected, but lacking its present distinctive glacial sculpturing".(Fryxell, E.M.,p.221)

In the Snake River Range, the Black Rock surface is not as conspicuous as in the Grand Tetons and the Gros Ventre Mountains. Blackwelder considers the terraces along the Snkke

River as possibly belonging to the Black Rock cycle. In the vicinity of Camp Davis, the Black Rock surface appears as a Pediment surface extending from the level of the Mesa down to and under the alluvium of the valley.

Recent: The changes which have been produced since the last glacial stage(Pinedale) are less pronounced than those which occurred during other interglacial periods. This is due, mainly, to the short interval of time which has elapsed since the last period of glaciation. The major streams have entrenched themselves in the outwash plains and moraines. The tributaries of the major streams are re-excavating their valleys and have built large alluvial fans along the margins. Wave action has steepened the inner side of the Jackson Lake moraine. Landslides are prevalent, the most notable of which is the Gros Ventre slide near Kelly, Wyoming. Weathering has been active at high levels, producing talus and rock slides. The rivers in the canyons have accomplished very little down-cutting as they are expending most of their energy in clearing away the debris on the glaciated slopes.

Block Faulting

The absence of foothills, the abruptness of the east wall, the triangular facets, and the numerous hanging valleys are clear physiographic evidences indicating that, structurally, the Teton Range is a fault block (Plate VI, Figure I).

In this block, the Pre-Cambrian crystallines and overlying sediments have been "fractured along a north-south line, uplifted, and tilted westward"(Fryxell, F.M., p.381). Horberg states that the trend of the fault is North 10 degrees West and except for a slight change at Death Canyon, the strike is uniform (Horberg, L., p.37). The exact dip is unknown, but from a study of some of the better-preserved triangular facets, Horberg concludes that the dip must be over 40 degrees.

From general observations, the range appears as a simple fault block, but detailed studies show that although the principal fault, for the most part, follows the straight east front of the range, many cross faults have broken the main block into individual segments which have varying amounts of displacement. The greatest uplift ocurred in the central portionof the range and it is here that the lofty peaks such as Mt. Owen, Grand Teton, Middle Teton, and South Teton are located. Near Jenny Lake the exposed scarp is over 7000 feet while the true displacement may be a great as 15,000 feet. This displacement decreases to the south and to the north of the main peaks.

At Phillips Canyon, the fault branches to form the Wilson ridge block(Horberg, L., p.37) and sedimentary rocks occur on the peaks. Cambrian and Ordovician rocks appear at the front of the range near the north end of Jackson Lake.

The blocks at the northern end of the range have been lifted higher than those at the south so that the relative elevation increases from south to north. Crystalline rocks are exposed as far north as Mt. Moran, while the southern blocks soon come within the area of sedimentary rocks.

The triangular facets along the east side of the Gros Ventre Buttes suggests that the structure of these buttes is due to block faulting. Blackwelder suggested this possibility after noticing the uniform dip of the strata and the repetition of the beds in the East and West Gros Ventre Buttes (Horberg, L., p. 42).

On the west edge of the town of Jackson, Karl Kent has dug a tunnel into the East Gros Ventre Butte. This tunnel penetrates the butte for a distance of about 20 feet and then turns sharply to the right for approximately 20 or 30 feet. The initial 20 feet was dug through talus. At this point, bed rock was encountered and Mr. Kent, in hopes of finding less resistance, extended the tunnel along the face of this rock for a short distance before abandoning his project. The rock encountered by Mr. Kent was the Madison limestone. The surface of this limestone, exposed in the tunnel, is polished and slickenslided and, undoubtedly, is a fault plane. The uncovering of this surface verifies the conclusions of Blackwelder and suggests that all of the buttes in Jackson

Hole are true fault blocks.

Pleistocene Glaciation

Studies by E. Blackwelder and W.S. Alden have established the existence of three glacial stages in western Wyoming. These stages and their proable relation to the stages of Pleistocene glaciation in the Middle West are shown in the following table

TABLE II*

STAGES OF PLEISTOCENE GLACIATION

	Glacial stages in Wyoming	Glacial stages in the Middle West
Recent	Post-glacial	Post-glacial
Pleistocene	Pinedale	Wisconsin
	Late inter-glacial	Peorian (?)
	Bull Lake	Iowan
	Early inter-glacial	Sangamon(?)
	Buffalo	Illinoian or Kansan
	Pre-glacial	

* Taken after Blackwelder, Journal of Geology, XXIII,1915, p. 310 from Fryxell, F.M.,p.220

Buffalo stage: The Buffalo drift, which once covered an extensive area of the Black Rock surface, is today found only in isolated patches on this surface. These patches occur on the summits of the buttes, on the benches and divides of the eastern highlands, and along the upper valley slopes of the Gros Ventre River and Buffalo Fork(Fryxell,F.,p.220).

In Jackson Hole, the Buffalo drift consists chiefly of quartzite boulders less than 8 inches in diameter. These boulders have been rounded by water transportation and, in many cases, glacial striae have been superimposed on the rounded surfaces. The boulders are found in unassorted deposits with volcanic material and crystalline rocks. The deposits of drift vary from scattered boulders and cobbles to deposits 20 or 30 feet thick. The possible source of the quartzite boulders in the Buffalo drift is the Pinyon conglomerate (Eocene) which outcrops 15 miles northwest of Jackson Hole (Fryxell,F.,p.221-222).

From a study of the composition and distribution of the Buffalo drift, Horberg and Fryxell conclude that the Buffalo stage was one of widespread plateau glaciation in which the ice moved southward from the Yellowstone Plateau into the Teton Basin and Jackson Hole (Horberg,L.,p.74). Fryxell concludes that although sufficient data is lacking it is probable that Jackson Hole was more completely covered with ice in this stage than in any of the later stages(Fryxell,F.,p.222).

<u>Earlier Interglacial stage</u>: The stage of Buffalo glaciation was followed by a period of stream erosion. Jackson Hole was excavated about 1000 feet, the valleys were deepened

to approximately their present level, and the buttes were etched in sharp relief. Truncated valley spurs, benches, and terraces located on the buttes and along the western slope of the Gros Ventre Mountains represent the level established by the close of the earlier interglacial stage and probably represents the Circle cycle of erosion mentioned by Blackwelder.

Bull Lake stage: From a study of the deposits of the Bull Lake glacier, Fryxell concludes that these features were produced by valley glaciers which entered Jackson Hole from the mountains on the east and west side, and by a large ice mass that was located in the northern portion of Jackson Hole (Fryxell, F., p. 222).

The Bull Lake drift is intermediate in age and position between the Buffalo and Pinedale. It occurs "several hundred feet below the Buffalo drift, but outside of the limits of the Pinedale" (Horberg, L., p. 76). It is found either within the canyons which border the basin or on the basin floor. The distribution of the Bull Lake deposits is more extensive in the vicinity of the Snake River Range than in the Teton Range. In Jackson Hole, the moraines are absent a short distance from the mouths of the canyons, while in the Snake River Range the Bull Lake moraines cover large areas and are found as high as 7000 feet(Horberg,L.,p.76). Bull Lake glaciation was more extensive on the eastern side of the Tetons than on the western side. Horberg contends that most of the Bull Lake stage was of the piedmont type and states,

"...where valley glaciers existed during the Pinedale stage, there were piedmont glaciers during the Bull Lake, and where only valley glaciers were present during Bull Lake time, Pinedale moraines are absent"(Horberg,L.,p.77).

The Bull Lake stage is represented by well-defined moraines and outwash which have been dissected. A characteristic feature of these deposits is the presence of a surface covering of loess which has buried most of the boulders and has given this surface a regular and less bouldery appearance than the deposits of the Pinedale glacier.

In Jackson Hole there are three areas where Bull Lake till is recognized. These are Burned Ridge, located south of Jackson Lake; Timbered Island, on the southeast side of Jenny Lake; and patches of till south of the Gros Ventre Buttes. The deposits in the northern portion of the basin are larger and Horberg contends that these deposits resulted from the ice which came from the Yellowstone Plateau and the valley of Buffalo Fork (Horberg,L.,p.77). In contrast to this view, Fryxell contends that Burned Ridge probably resulted from piedmont glaciers which were fed chiefly from the vallgy glaciers from the northern canyons of the Teton Mountains (Fryxell, F.,p.223). The ridge is not over 100 feet high and extends transversely across Jackson Hole for approximately 6 miles. Near the east end, the Snake River has cut a notch through the ridge which locally is known as the Narrows.

Later Interglacial stage: After the retreat of the Bull Lake glaciers, streams began to clear away the moraine and outwash deposits from the floor of the basin and from the mouth of the canyons. The moraines, if not entirely removed, were dissected and the lakes enclosed by these moraines were drained. Flood plains developed along the major valleys and the moraines were cut back to the sides of the mountains.

Two large interglacial streams were in existence during this stage. The Snake(?) flowed southward along the western border of Jackson Hole. At a point northwest of Blacktail Butte this stream joined with a second stream, the Buffalo Fork(?) and cut across Burned Ridge, forming the large trench now occupied by the Snake River(Fryxell,F.,p.224). The piedmont moraine north of Taggart Lake was removed at this time and only Timbered Island, a remnant of this moraine, remains today.

The loess deposits were formed during the early part of this interglacial period and reached a maximum depth of

30 feet. These deposits were dissected along with the mo-rainic and outwash material.

Pinedale stage: The Pinedale glaciers on the east slope of the Grand Teton Mountains were relatively short and had high gradients. They ranged from cliff glaciers to valley glaciers 10 miles long(Fryxell, F.,p.225). These larger glaciers extended beyond the outlets of the canyons into the basin for a mile or more. Here they expanded and spread laterally. forming, according to Hobb's classification, the typical "expanded foot" type of glacier.

Crescentric moraines developed along the terminus of these glaciers and gave rise to the many beautiful piedmont lakes such as Jackson Lake, Jenny Lake, Taggart Lake and Bradley Lake. The largest of these moraines was formed by the Jackson Lake glacier. This moraine has considerable areal extent but is not as high as the moraines around Jenny Lake, Bradley Lake, and Taggart Lake. Jackson Lake glacier moved from the north or northwest. In its movement it was obstructed by the buttes east of Moran. The glacier divided into several lobes; moved around the buttes, and pushed up the slopes of the mountains, leaving moraines at altitudes as high as 400 feet above Jackson Lake(Fryxell, F.,p.225). Horberg believes the Jackson Lake glacier to be of the piedmont type, possibly related to the ice mass in the Yellowstone region (Horberg,L.,p.80) while Fryxell contends that this glacier probably resulted from a "coalition of Teton Valley glaciers"(Fryxell,F.,p.226).

With the possible exception of the Jackson Lake glacier, all of the other Pinedale glaciers were fed by the snow fields in the cirques at the head of the canyons. Pinedale glaciers were also in existence in the canyons on the east side of Jackson Hole, but they did not move out of the canyons to enter the basin.

The Pinedale moraines are characterized by their fresh appearance and by their position "upstream from the Bull Lake deposits"(Fryxell,F.,p.225). The moraines are bouldery and contain many undrained basins as well as the morainal lakes mentioned above. The Pinedale moraines in Jackson Hole are limited in extent to the area north of Phillip's Canyon. The outwash plains associated with these moraines have many pitted surfaces and abandoned glacial stream channels. A broad outwash plain extends out from the Jackson Lake moraine as far as Burned Ridge. Benches bordering the Snake River channel appear at levels corresponding to this plain. These benches continue beyond Blactail Butte and gradually widen into swampy flats to the south of Jackson Lake(Fryxell,F.,p.226).

The rugged topography and the "alpine features" for which the Grand Tetons are famous are, to a large extent, the result of the erosion which took place during the Pinedale stage.

Postglacial interval: Due to the short interval of time, the changes which have taken place since the retreat of the Pinedale glaciers are less pronounced than those which occurred during the previous interglacial stage. The major streams have entrenched themselves in the Pinedale outwash. This entrenchment is greatest in the upper portion of the stream channels and, in some cases, is practically negligible in the lower portion. The tributaries have built conspicuous alluvial fans along the margin of the basin. There has been a negligible amount of downcutting in the canyons since Pinedale time, while erosion has been especially active at higher levels. These higher areas are characterized by large accumulations of talus which produced recent rock slides and land slides.

Comparative Chronology of the Teton Area

There is a difference of opinion among geologists as to the sequence of events which took place following the Laramide revolution. For the purpose of comparative study, an outline of two different views is given below.

Horberg's chronology: The sequence of events in this chronology was obtained from a study of Horberg's publication on the "Structural Geology and Physiography of the Teton Pass Area". The outline of Horberg's study is as follows

1. Erosion following the Laramide revolution forming the Union Pass surface at 9500 feet

2. Rejuvenation as a result of regional uplift

3. Erosion forming the Black Rock surface at 7500-8000 feet

4. Block Faulting: Teton block raised from the level of the Cascade Canyon to its present level.

5. Buffalo glaciation

6. Rejuvenation and erosion (Circle cycle)

   a. 1300 feet of erosion resulted in the deepening of Jackson Hole

   b. Buttes left as remnants of "circum-denudation"

7. Bull Lake glaciation

8. Erosion - Lenore cycle

9. Pinedale glaciation

10. Recent

Camp Davis chronology: The sequence of events outlined by geologists of the University of Michigan, at Camp Davis, Wyoming, differs in some respects from Horberg's study. Their conception of the sequence of events is given in the outline below.

1. Erosion following the Laramide revolution formed the Union Pass surface at 9500 feet.

2. Period of erosion

3. Black Rock surface formed at 6500 to 8200 feet

a. Pediment surface which extends below the valley alluvium.

b. Tetons similar to present Bighorns and not a peneplane surface

4. Buffalo glaciation

5. Block faulting

a. Valley floor dropped below the level of the Cascade Canyon

b. Union Pass block broken into two surfaces. (In the vicinity of Camp Davis these surfaces can be identified as (1) Cream Puff Mountain (2) the Mesa.)

6. Period of alluviation of the downthrown block in Jackson Hole

a. Bull Lake glaciation

b. Erosion

c. Pinedale glaciation

d. Recent

The End

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