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GEOMORPHOLOGY OF THE NORTH FLANK OF THE UINTA MOUNTAINS

BY

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Shorter contributions to general geology, 1934–35

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By WILMOT H. BRADLEY

ABSTRACT

The Uinta Mountains, whose northern margin is almost coincident with the southern boundary of Wyoming, extend from the Wasatch Range eastward across the northern part of Utah into northwestern Colorado. They were carved out of a large, simple anticlinal fold of sedimentary rocks arched up into essentially their present attitude at the end of the Cretaceous period. The Uinta Mountain group (†Uinta quartzite of previous reports),[1] a series of brick-red to purplish-red quartzite and sandstone beds of pre-Cambrian age, aggregating more than 12,000 feet in thickness, makes up the central mass of the range. Flanking the quartzite core and sharing its anticlinal structure are beds of limestone, sandstone, and shale ranging in age from Upper or Middle Cambrian to Upper Cretaceous. These rocks, which have a total thickness of about 15,000 feet, have been eroded from the higher part of the range, so the upturned edges of the harder beds now form hogbacks ranked along the sides of the fold. In places large faults, approximating the regional strike, cut these steeply inclined beds. Gently warped Tertiary sediments, mostly of Eocene age, fill the large Green River Basin, which lies north of the range, to a depth of several thousand feet and lap up on the flanks of the mountains, from which they were chiefly derived.

Long, narrow remnants of four old erosion surfaces slope gently northward from the north flank of the Uinta Range and truncate the upturned edges of hard and soft beds. The Gilbert Peak erosion surface, which is the highest and oldest of these surfaces, once extended from the crest of the range at an altitude of about 13,000 feet to the center of the Green River Basin. Because undisturbed remnants of this surface have gradients ranging from about 400 feet to the mile near the crest of the range to 55 feet to the mile 35 miles out in the basin, because island mounts[2] of limestone rise rather abruptly from it, and because it apparently never had a soil mantle but is covered in most places by conglomerate, this surface is interpreted as a pediment formed in a semiarid or arid climate. At the time the Gilbert Peak surface was cut the Green River Basin was filled to a greater depth than now with Eocene sedimentary rocks. The Gilbert Peak erosion surface truncated these rocks at very low angles and extended northward across them as a continuous plain. On this plain the master stream of the basin apparently flowed eastward to join the ancestral Platte or some similar river that drained into the Gulf of Mexico.

The Bishop conglomerate, which covers much of the Gilbert Peak surface, is coarse-grained and very poorly sorted and fills the deepest concavity in the profile of the pediment, where it is about 200 feet thick. The same streams that cut the Gilbert Peak pediment deposited the Bishop conglomerate, because their transporting capacity changed in response to a climatic shift toward still greater aridity. This climatic change, though critical, probably was not great.

No fossils have been found in the Bishop conglomerate, but the Gilbert Peak surface truncates the latest Eocene rocks and yet it is distinctly older than the Browns Park formation (late Miocene or early Pliocene). Hence the Gilbert Peak surface and the Bishop conglomerate are either Miocene or Oligocene. I believe that the Gilbert Peak surface is probably correlative with Blackwelder's Wind River peneplain, near the top of the Wind River Range.

About 400 to 500 feet below the remnants of the Gilbert Peak surface these same streams later cut the less extensive Bear Mountain erosion surface. The characteristics of the Bear Mountain surface are so nearly identical with those of the Gilbert Peak surface that it is regarded as a pediment formed under arid conditions probably closely similar to those which prevailed while the Gilbert Peak surface was being cut. Correlated with the Bear Mountain surface are two large, rather smooth-floored valleys, the Browns Park Valley and Summit Valley. These valleys are in the eastern part of the Uinta Range and are each roughly parallel to the range axis. The floor of the Browns Park Valley descends eastward and passes beneath the Browns Park formation, which is of upper Miocene or lower Pliocene age. As there is no indication that the deposition of the Browns Park formation did not follow immediately the completion of the Bear Mountain surface, that surface is probably also of essentially this geologic age. The Bear Mountain surface may possibly correlate with Westgate and Branson's surface no. 3 at the south end of the Wind River Range.

After the deposition of the Browns Park formation the east end of the Uinta Mountain arch collapsed. This movement may have caused the uptilting of the adjacent Miller Mountain block, on which a large remnant of the Gilbert Peak surface now has an average gradient of 102 feet to the mile, whereas an undisturbed portion of the Gilbert Peak surface farther west has a gradient of only 69 feet to the mile.

When the east end of the Uinta Range collapsed, by block faulting, it apparently lowered the stream flowing along the ancient Browns Park Valley (on the depositional surface of the Browns Park formation) enough for one of its tributaries, which had already cut through the divide on the north side of the valley, to be rejuvenated and thus to extend its course headward so far northward in the soft Tertiary rocks that it finally captured the ancient master stream of the Green River Basin. When this river, the new Green River, first entered the Browns Park Valley it flowed on the uppermost beds of the Browns Park formation, following the ancient Browns Park stream eastward beyond

[1] A dagger (†) preceding a geologic name indicates that the name has been abandoned or rejected for use in classification in publications of the U. S. Geological Survey. Quotation marks, formerly used to indicate abandoned or rejected names, are now used only in the ordinary sense.

[2] See footnote 29, p. 176.

the east end of the range. But soon thereafter it was captured by Lodore Branch, a tributary to the ancestral Cascade Creek, which drained Summit Valley, and so came to flow along the present site of Lodore Canyon. The steps in this diversion are shown diagrammatically in plate 42. The course of the Green River through Lodore Canyon was formerly regarded as perhaps having been established by superimposition from the Browns Park formation rather than by piracy.

Along Blacks and Smith Forks of the Green River are remnants of two Pleistocene erosion surfaces. The older of these, the Tipperary surface, is about 150 feet below the Bear Mountain surface, and the younger, the Lyman surface, is 50 to 75 feet below the Tipperary. Both, however, merge upstream with the present flood plains, and each has a series of treads at its north end, which are explained as partial flood plains abandoned one after another as the stream was captured at successive short intervals upstream by the tributaries of larger streams in adjacent strike valleys.

The process by which certain gravel-capped badland escarpments migrate and behead small, asymmetric, gravel-capped alluvial cones is described and illustrated.

Only those moraines that gave promise of clarifying the relations between the erosional history and the glacial history were studied. Bulky terminal moraines on remnants of the Bear Mountain surface in two or three localities north of the Utah-Wyoming boundary line seem to indicate rather clearly a third glacial stage older than the two heretofore recognized in the Uinta Mountains. The three glacial stages—Little Dry (oldest), Blacks Fork, and Smith Fork—appear to be the respective equivalents of Blackwelder's Buffalo, Bull Lake, and Pinedale stages in the Wind River Range.

The possible causes of the erosion interval between the Gilbert Peak and Bear Mountain surfaces are examined, but the evidence is inconclusive.

The erosion intervals between the Bear Mountain surface and Tipperary surface and between the Tipperary and Lyman surfaces are probably to be linked with the full, strong streams that existed during or just after the corresponding glacial stages. The two youngest surfaces themselves were probably cut by lateral planation of the streams during the somewhat more arid interglacial stages.

INTRODUCTION

The geologic record of the Tertiary period in the Green River Basin of southwestern Wyoming consists, in a broad way, of two quite different parts. The history of the first part, lasting through the Eocene epoch and perhaps on into the early Oligocene, was recorded in a thick series of sedimentary rocks of fluviatile and lacustrine origin. The history of the second part was recorded chiefly by successive stages of stream planation and stream trenching, but also in part by fluviatile sedimentation and, in certain localities, by glacial deposits. The first part of the record is virtually continuous, though its interpretation is by no means simple and obvious. The second part of the record is distinctly fragmentary, and the evidence the fragments provide is difficult to evaluate and to integrate.

The interpretation of the Eocene sedimentary formations (Wasatch, Green River, and Bridger) in the Green River Basin, in Wyoming, north of the Uinta Mountains, and in the Uinta Basin of Utah and Colorado, south of the Uinta Mountains (fig. 11) has occupied the greater part of my time since 1923. While mapping these formations in the Green River Basin in 1928 I was struck with the great extent and excellent preservation of the remnants of several erosion surfaces that extend northward from the flank of the Uinta Mountains far out into the basin.

It became evident at that time that the highest of these surfaces if projected through its basinward remnants would approximately coincide with the uppermost Eocene beds. Therefore it appeared desirable to study these surfaces and see whether the earlier sedimentary record and the later erosional history of the Green River Basin could be connected. Such a connection would yield a more or less continuous sequence of events reaching from early Eocene to the Quaternary. This project was also desirable as a supplement to the study of the relations between the Bishop conglomerate and the Browns Park formation around the east end of the Uinta Range made by Sears[3] in 1921 and 1922. In the area studied by Sears the erosion surfaces are faulted and warped, so that their relations are complicated and in part obscure.

In 1930 I had the opportunity to undertake the desired project and was able to trace certain of the higher erosion surfaces eastward from the western and central part of the Uinta Range, where they bear normal relations to one another, and of correlating them with the deformed and dislocated erosional features near the east end of the range.

LOCATION AND EXTENT OF THE AREA

The Uinta Mountains trend eastward across the northeastern part of Utah and extend into northwestern Colorado. The northern margin of the range is almost coincident with the southern boundary of Wyoming. Many of the high terraces that abut the north flank of the range and slope gently northward from it extend out as long fingers into the southern part of the Green River Basin of Wyoming. The portions of the Uinta Mountains and the Green River Basin described in this report are shown in figure 11.

PREVIOUS GEOLOGIC WORK AND BIBLIOGRAPHY

Since the time of the early Territorial surveys in the Rocky Mountain region many geologists have visited the north flank and the east end of the Uinta Mountains and in their writings have commented on the high conglomerate-covered benches or tablelands. Their interest was also aroused by the unusual courses of the Green River and some of its tributaries, which are so discordant with the structure and topography

[3] Sears, J. D., Relations of the Browns Park formation and the Bishop conglomerate and their role in the origin of Green and Yampa Rivers: Geol. Soc. America Bull., vol. 35, pp. 279–304, 1924.

of the region. Of these geologists, Rich,[4] Hancock,[5] and Sears[6] have analyzed fully the geomorphologic problems of the east end of the Uinta Range and adjoining region. The three papers by these men are summarized on pages 167–169.

region are listed below. Because the references in these are so scattered no attempt is made to summarize them.

1872. Hayden, F. V., U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1870, pp. 41–70.

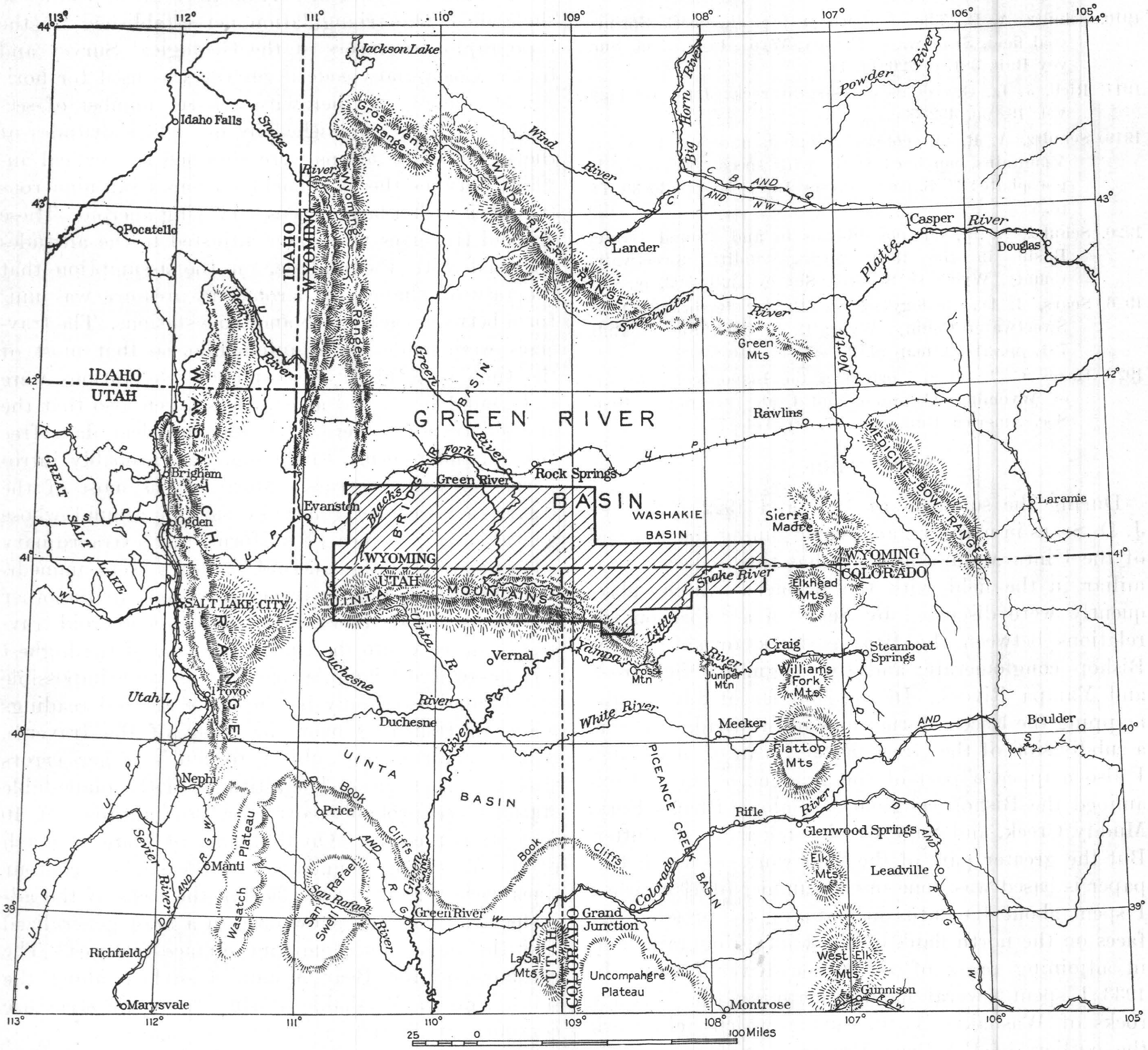

FIGURE 11.—Index map showing the area discussed in this report and its relation to the Uinta Mountains, the Green River Basin of Wyoming and its subdivisions, and adjacent parts of Colorado.

Other papers which contain references to the erosional features, drainage courses, and remnants of the later Tertiary deposits in the Uinta Mountain

[4] Rich, J. L., The physiography of the Bishop conglomerate, southwestern Wyoming: Jour. Geology, vol. 18, pp. 601–632, 1910.

[5] Hancock, E. T., The history of a portion of Yampa River, Colo., and its possible bearing on that of Green River: U. S. Geol. Survey Prof. Paper 90, pp. 183–189, 1915.

[6] Sears, J. D., Relations of the Browns Park formation and the Bishop conglomerate, and their role in the origin of Green and Yampa Rivers: Geol. Soc. America Bull., vol. 35, pp. 279–304, 1924.

1875. Powell, J. W., Exploration of the Colorado River of the west and its tributaries, pp. 150–166.

1876. Powell, J. W., Report on the geology of the eastern portion of the Uinta Mountains, U. S. Geol. and Geog. Survey Terr.

1877. Emmons, S. F., U. S. Geol. Expl. 40th Par. Rept., vol. 2, pp. 191–206, 222–250, 254–282.

1878. King, Clarence, U. S. Geol. Expl. 40th Par. Rept., vol. 1, p. 402.

1889. White, C. A., On the geology and physiography of a portion of northwestern Colorado and adjacent parts of Utah and Wyoming: U. S. Geol. Survey 9th Ann. Rept., pp. 683–712.

1907. Weeks, F. B., Stratigraphy and structure of the Uinta Range: Geol. Soc. America Bull., vol. 18, pp. 427–448.

1909. Atwood, W. W., Glaciation of the Uinta and Wasatch Mountains: U. S. Geol. Survey Prof. Paper 61, pp. 7–12, 27–39, 65–71.

1910. Schultz, A. R., The southern part of the Rock Springs coal field, Sweetwater County, Wyo.: U. S. Geol. Survey Bull. 381, p. 226, pl. 14.

1911. Rich, J. L., Gravel as a resistant rock: Jour. Geology, vol. 19, pp. 492–506.

1919. Schultz, A. R., A geologic reconnaissance of the Uinta Mountains, northern Utah, with special reference to phosphate: U. S. Geol. Survey Bull. 690, pp. 36–39, 74, pl. 5.

1920. Schultz, A. R., Oil possibilities in and around Baxter Basin, in the Rock Springs uplift, Sweetwater County, Wyo.: U. S. Geol. Survey Bull. 702, pl. 1.

1926. Sears, J. D., Geology of the Baxter Basin gas field, Sweetwater County, Wyo.: U. S. Geol. Survey Bull. 781, pp. 21–22, map pl. 2.

1926. Hares, C. J., Glacial origin of the Bishop conglomerate of Wyoming, Colorado, and Utah [abstract]: Geol. Soc. America Bull., vol. 37, pp. 174–175.

FIELD WORK

During the summers of 1921 and 1922 I assisted J. D. Sears in mapping an area adjoining the east end of the Uinta Mountains. At that time I became familiar in the field with the problems which subsequently were discussed by Sears in a paper on the relations between the Browns Park formation, the Bishop conglomerate, and the origin of the Green and Yampa Rivers. In the summer of 1928, while mapping the Eocene formations in the Bridger Basin, a subdivision of the Green River Basin of Wyoming, I also mapped a part of the Bridger bench and examined the Bishop conglomerate along Blacks Fork, Muddy Creek, and Sage Creek, and at Twin Buttes. But the greater part of the field work on which this paper is based was done in the summer of 1930, when I spent about 4 months in mapping the erosion surfaces on the north flank of the Uinta Mountains and in adjoining parts of the Green River Basin. In 1933 I spent several months mapping the Tertiary rocks of Washakie Basin, during which field work the outliers of the Bear Mountain surface and the Browns Park formation were mapped in the vicinity of Powder Wash and along the south side of Washakie Basin. This mapping was done with a plane table on the scale of 4 miles to the inch. Frank S. Parker, of the United States Geological Survey, assisted me in the field in 1933. The Marsh Peak, Gilbert Peak, and Hayden Peak topographic maps, published by the United States Geological Survey, provided excellent base maps for that part of the area in Utah. The topography shown on the Utah portion of plate 34 was taken from these maps, except a small portion east of meridian 109°30′, which was modified from Powell's topography [7] so as to fit the drainage shown on more recent maps. In Wyoming no adequate base maps were available, and I did the mapping by plane table and telescopic alidade, mostly on a scale of 8 miles to the inch, but in part on the scale of 4 miles to the inch. The triangulation net established by the topographic engineers of the Geological Survey and by the Coast and Geodetic Survey was used for horizontal control, together with a lesser number of secondary stations established by me. The altitudes of the instrument stations were obtained by vertical angles. Between the instrument stations I ran numerous traverses with a large Tycos surveying aneroid. These aneroid traverses were later adjusted to the altitudes obtained with the alidade, on the assumption that the rate of change of barometric pressure was uniform between each two plane-table stations. The traverses were made in an automobile, so that most of the time intervals between plane-table stations were less than 1 hour, and as care was taken also that the aneroid traverses were made only on clear days free from thunderstorms, this assumption probably introduced no serious errors. Moreover, as most of the traverses were over relatively smooth ground whose gentle slope was nearly uniform, any extraordinary irregularities in the aneroid readings were immediately apparent, and the traverse was repeated another day or discarded. However, a few longer aneroid traverses run back into the timber on some of the highest terraces where triangulation stations were impossible could be adjusted only by duplicate aneroid readings made in returning over the route of the traverse. These traverses are subject to much larger errors than the short ones. The altitudes of the plane-table stations are probably correct within a range of 10 feet plus or minus. On that part of plate 34 north of the Wyoming boundary line the surface contour lines were drawn in the office on the basis of the adjusted traverses and show only in a most generalized way the slopes and dominant surface features. The contours on the Bear Mountain surface along the south side of Washakie Basin are really structure contours on the deformed erosion surface.

The areal distribution of the Bishop conglomerate east of Green River was taken, with minor modifications by me, from the published maps of Schultz [8] and Sears,[9] but the topography was based on the same sort of plane-table and aneroid traverses as in the western part of the area.

[7] Powell, J. W., Geology of the eastern portion of the Uinta Mountains, atlas, map A, U. S. Geol. and Geog. Survey Terr., 1876.

[8] Schultz, A. R., Oil possibilities in and around Baxter Basin, in the Rock Springs uplift, Sweetwater County, Wyo.: U. S. Geol. Survey Bull. 702, pl. 1, 1920.

[9] Sears, J. D., Geology of the Baxter Basin gas field, Sweetwater County, Wyo.: U. S. Geol. Survey Bull. 781, pl. 2, 1926.

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REGIONAL GEOLOGIC SETTING

The Uinta Mountains were carved out of a large, simple anticlinal fold of sedimentary rocks arched up into essentially their present attitude at the end of the Cretaceous period. On the crest of the fold the rocks are only gently inclined, but along the flanks they dip steeply and in places are cut by large faults, whose trends approximate the strike of the beds. Locally along the fault zones the rocks are considerably crushed. The Uinta Mountain group († Uinta quartzite of previous reports) a series of brick-red to purplish-red quartzite and sandstone beds aggregating more than 12,000 feet in thickness, makes up the central mass of the range. This quartzite series is unfossiliferous but is now classified by the United States Geological Survey as of pre-Cambrian age. Closely folded and steeply inclined paragonite and hornblende schists of pre-Cambrian age crop out in a small area near Red Creek, in the extreme northeastern part of Utah. These metamorphic rocks are known as the "Red Creek quartzite" and make up a part of Goslin and Wheeler Mountains. Flanking the quartzite mountain core and sharing its anticlinal structure are beds of limestone, sandstone, and shale ranging in age from Upper or Middle Cambrian to Upper Cretaceous. These rocks, which have a total thickness of about 15,000 feet, have been eroded from the higher part of the range, so that the upturned edges of the harder beds now form hogbacks ranked along the sides of the fold. Although the Uinta Range as a conspicuous topographic feature ends near Cross Mountain, in Colorado, the anticlinal fold continues southeastward for many miles and is known as the "Axial Basin" anticline. Rocks of Upper Cretaceous age are exposed along both flanks of this anticline, but in Cross and Juniper Mountains, which lie on its axis, sharp local uplifts have brought up rocks as old as the Uinta Mountain group. (See fig. 11.)

Tertiary sediments, mostly of Eocene age, fill the large Green River Basin, which lies north of the Uinta Range, to a depth of several thousand feet and lap up on the flanks of the mountains, from which they were chiefly derived. In general the Tertiary beds lie nearly flat, but along the mountain flanks they are turned up more or less steeply and in most places rest against the pre-Tertiary rocks with marked discordance. Along the western margin of this basin they are also tilted up at low angles. Locally in the fault zones bordering the mountain range they are sharply flexed and cut by faults. South of the Uinta Range is another large shallow structural basin, the Uinta Basin. Like its homolog to the north, it also contains a thick series of Eocene rocks. The broader relations between these large basins and the mountain ranges which bound them are shown in figure 11.

Near the center of the Green River Basin is an elliptical uplift known as the "Rock Springs uplift." It exposes Upper Cretaceous rocks tilted at moderate angles. The Tertiary rocks that surround this uplift and rest against the Upper Cretaceous rocks with only a slight angular discordance are also tilted up but a little less steeply. East and west of the Rock Springs uplift the Tertiary rocks have been warped into large, shallow basins known respectively as the "Washakie Basin" and the "Bridger Basin." These three structural features are all subdivisions of the larger Green River Basin. Leucite lavas cap a rather large group of flat-topped mesas of Upper Cretaceous and Tertiary rocks near the north end of the Rock Springs uplift.

The Bishop conglomerate, whose exact age is unknown, mantles many of the highest flat-topped interstream divides that extend northward from the Uinta Range.

The Browns Park formation, of late Miocene or early Pliocene age, occupies a strip along the axis of the Uinta Range at its east end. From that strip it extends eastward along and north of the Axial Basin anticline as far as Craig, Colo. (See fig. 11.) Remnants of it were also found along the south side of Washakie Basin as far east as Baggs, Wyo. The regional geology is shown on plate 34.

SUMMARIES OF PRINCIPAL EARLIER STUDIES

The three papers mentioned above as giving an analysis of the geomorphic problems of the east end of the range are summarized below.

Rich described the occurrences of the Bishop conglomerate in the area east of the Green River between Little Mountain and Aspen Mountain. (See pl. 34.) He believed that the whole region was reduced to a gently undulating plain of advanced old age, with a relief of 700 to 800 feet in a distance of 25 or 30 miles, so that the surface, on which the Bishop conglomerate was deposited, extended southward to the Uinta Mountains, far to the west and east of the area here described, and probably also northward to the Wind River Range. This surface, he thought, was the result of long-continued subaerial denudation under conditions of moist climate. Rich concluded that the deposition of the Bishop conglomerate, which he regarded as possibly of late Miocene or early Pliocene age, was due to a decided uplift of the Uinta Range and a change from a moist to an arid climate. He observed that the surface from Little Mountain north to Aspen Mountain slopes more steeply than a peneplain might be expected to and correlated this apparent northward tilting with the uplift of the Uinta Range that preceded the deposition of the Bishop conglomerate. The leucite lavas north of Rock Springs, he thought, were probably extruded, at least in part, on this same surface. The terraces at lower levels along the present streams in the vicinity of the Rock Springs uplift represent, he believed, alternate stages of humid and dry climate which may possibly be correlated with the changes in size of the Pleistocene lakes of the Great Basin.

Hancock studied the relations of the Yampa River to the Browns Park formation east of the east end of the Uinta Mountains and concluded that the course of the Yampa had been established by superimposition through the Browns Park formation. By this means it came to cut its deep, narrow canyons in the hard rocks of Cross and Juniper Mountains, which are dome-shaped mountains that rise as isolated masses above the general level of the country.

Sears analyzed the interrelations of the Bishop conglomerate, the Browns Park formation, and the origin of the drainage courses around the east end of the Uinta Mountains. These interrelations are so intimately connected with the phases of the erosional history discussed in this report that it seems desirable to summarize them rather fully.

According to Sears the Uinta Mountain arch was uplifted a moderate amount after the cessation of Eocene deposition. This uplift was followed by a long interval of erosion, during which the eastern part of the range was eroded to mature topography with a relief probably not exceeding 3,000 feet. From the Uinta Range and from its eastern extension, the Axial Basin anticline, a broad peneplain extended northward, truncating the Eocene and older rocks and perhaps merging with the peneplain on the southern flank of the Wind River Mountains described by Blackwelder.[10] Because the crest of the Uinta Range stood above the surrounding country it was subject to more rapid erosion, and in its east end a large valley was cut roughly parallel to the axis. The lower part of this valley is now known as "Browns Park." This valley opened eastward and merged with the northward-sloping peneplain from which it was separated farther west by a low range of hills. High on the south flank of the arch was a similar but smaller valley called by Powell[11] "Summit Valley." This valley drained eastward and probably turned southeastward along the line of the present Lodore Canyon.

Sears thought that in response to climatic changes or more probably to regional uplift the streams were rejuvenated, thus deepening the Browns Park Valley and distributing a large quantity of red quartzite boulders—the Bishop conglomerate, which he believed was equivalent to the basal conglomerate of the Browns Park formation. This material was laid down on the broad peneplain and extended for many miles eastward and northeastward from the east end of the Uinta Range. He thought that later these streams became less efficient transporting agents and deposited a great thickness of white sand (the Browns Park formation), which covered the conglomerate and spread up the valley by headward overlap beyond the deposits of conglomerate. This sand also encroached upon the neighboring hills and mountains, until in all the eastern part of the Uinta Range only the highest remnants of the older rocks protruded above it. After the Browns Park formation was deposited the east end of the Uinta Mountain arch collapsed, forming a great graben, which was bounded on the south by a single large fault, on the north by flexures and distributive faults, and on the east by tilted beds and some faults. As a result of this movement, which Sears discussed fully, the Browns Park formation for many miles east of the range was given a westward tilt. Guided by this westward-sloping surface on the top of the Browns Park formation, the drainage along the Axial Basin anticline naturally formed a westward-flowing master stream, the Yampa River. Its course over the covered portions of Cross and Juniper Mountains was fortuitous. Also as a result of this graben movement a vigorous young stream, the ancestral Green River, began its eastward course approximately above the old Browns Park Valley. This stream could not turn northward because of the fault scarps on the north side of the graben, and it may have continued southeastward to the end of the range and there turned southward to join the Yampa River. If the ancestral Green River followed this course, "Lodore Canyon may be due to headward erosion and piracy by a stream that ran southward in the slight depression left after filling the lower portion of Summit Valley" (with white sand of the Browns Park formation). On the other hand, Sears argued, if the Browns Park formation was thick enough to cover the site of Lodore Canyon the Green River may have origi-

[10] Blackwelder, Eliot, Post-Cretaceous history of the mountains of central-western Wyoming: Jour. Geology, vol. 18, pp. 193–207, 1915.

[11] Powell, J. W., Report on the geology of the eastern portion of the Uinta Mountains and a region of country adjacent thereto, atlas, map A, U. S. Geol. and Geog. Survey Terr., 1876.

nally turned southward along this line, being thus diverted by the westward or mountainward tilt of that part of the Browns Park formation which lay east of the range. The thickness of sandstone needed to cover Lodore Canyon seemed to him to argue against the second possibility, but he noted that the entrenched meanders of Lodore Canyon and the topography in its vicinity point to superposition rather than to headward erosion.

Because the streams flowing northward from the mountains on the surface of the Browns Park formation had a gentle gradient, portions of their drainage basins were probably captured by the new tributaries to the Green River, which had steep gradients into the graben. Sears thought that by the rapid headward erosion of one of these tributaries the early Green River drainage may have grown northward out into the basin and ultimately captured the major stream of the Green River Basin and thus diverted it southward through Browns Park and Lodore Canyon. This hypothesis, he pointed out, is supported by the present courses of Red, Sage, and Salt Wells Creeks, which flow northward and westward before joining the Green River. Such courses suggest that these streams were originally tributaries of a river that did not flow southward to the Uinta Mountains. He thought also that meanders in the Green and Yampa Rivers that are now deeply entrenched may have developed during a period of temporary baselevel, caused perhaps when the Green River cut through the overlying Browns Park formation and encountered hard rocks downstream from Lodore Canyon. With the courses of the rivers once firmly established in the beds of the Browns Park formation, only time was needed to carve out their deep, narrow canyons.

GENERAL RELATIONS AND NAMES OF THE EROSIONAL FEATURES

Because Green River, the master stream of the area, has been obliged to cut a series of deep canyons in the hard rocks of the Uinta Range, which lies athwart its course, the removal of the softer Tertiary rocks in the Green River Basin has been greatly retarded. In consequence the present surface of the greater part of the Tertiary rocks filling the Green River Basin stands nearly 1,000 feet higher than large areas of comparable Tertiary rocks in the Wind River Basin, to the north, and in the Uinta Basin, to the south. This general retardation of erosion has also spared comparatively large remnants of ancient erosion surfaces in the Green River Basin. Moreover, the remnants extending out from the north flank of the Uinta Mountains are particularly well situated to be protected from erosion, as they lie along the upper reaches of long and comparatively weak tributaries of the Green River.

Four surfaces were distinguished and studied. All were apparently formed by the lateral planation of graded streams, in the manner described by Gilbert,[12] Johnson,[13] and others. The areal extent of this planation was successively less with each surface in descending order. Thus the oldest and highest surface was one of remarkable perfection and great regional extent. The lowest and youngest surface mapped in this area is really a long level-topped terrace on an interstream divide. These surfaces are not simple; rather there are four groups of surfaces whose remnants are at nearly accordant altitudes. As each group was probably formed by the combined lateral planation of several streams, the remnants within each group differ somewhat in altitude from one stream province to another, though there is no discernible difference in the perfection of the planation. The remnants comprising each group of surfaces are, however, so nearly accordant and are separated so distinctly from the next group above or below that it seems safe to infer that these four groups represent four stages in the erosional history of the region, during each of which the earth's crust and the climate were stable enough to permit the streams to wander widely and thus plane off considerable areas. Some of these stages may also be distinguished by deposits of fluviatile or glacial material on their surface remnants.

The oldest and highest of these erosion surfaces will be referred to in this report as the "Gilbert Peak erosion surface." It takes its name from the large remnant of the surface which slopes westward and northward from the west base of Gilbert Peak. The peak itself, which is one of the highest in the range, rises about 600 feet above the erosion surface. Portions of the Gilbert Peak surface in the western part of the area extend far northward from the crest of the range, and the most remote remnants are more than 30 miles out in the Green River Basin. In that part of the area north of the Uinta fault and the Uinta flexure the Gilbert Peak erosion surface is covered by the Bishop conglomerate. Along the crest of the Uinta Mountains the surface reaches a maximum altitude of 13,000 feet. Its lowest point, which is in the eastern part of the area about 10 miles southwest of Aspen Mountain, has an altitude of about 7,300 feet.

The next younger and next lower surface is called the "Bear Mountain erosion surface", from one of its more conspicuous remnants, the nearly level top of Bear Mountain, which is in the big bend of the Green River a few miles south of Flaming Gorge (pl. 34). Eastward from Bear Mountain the surface descends

[12] Gilbert, G. K., Geology of the Henry Mountains, pp. 126–133, U. S. Geol. and Geog. Survey Terr., 1877.

[13] Johnson, Douglas, Planes of lateral corrasion: Science, vol. 73, pp. 174–177, 1931.

gradually, and in Browns Park and around the east end of the Uinta Range it is covered with the Browns Park formation. Westward from Bear Mountain it rises until in the vicinity of Henrys Fork, a few miles north of Gilbert Peak, it nearly reaches the level of the Gilbert Peak surface. (See pl. 35.) Along the north flank of the Uinta Range in the northwestern part of the area the Bear Mountain surface is represented by a group of elongate remnants, the largest of which is the Bridger bench, which extends for many miles along the west rim of the Bridger Basin. Bridger Butte, a well-known landmark in the vicinity of Fort Bridger, Wyo., is shown on plate 34 as a part of the Bear Mountain surface, though its top stands about 75 feet above that surface as represented by the adjacent Bridger bench. Strictly, Bridger Butte probably belongs to an erosion surface of unknown extent which was formed just before the Bear Mountain surface but which was almost completely destroyed during the long epoch of planation that produced the Bear Mountain surface. In general the Bear Mountain surface is 400 to 500 feet lower than the Gilbert Peak surface.

The two surfaces below the Bear Mountain surface were studied only in the area west of the Green River and north of the Utah-Wyoming boundary line, to which virtually all their remnants are restricted. The older of these lower surfaces is represented by three comparatively small remnants and will be referred to in this report as the "Tipperary erosion surface", after the largest remnant, the Tipperary bench, which lies between Smith Fork and Little Dry Creek. (See pl. 34.) These remnants are really only broad terraces rather than remnants of a once extensive plain like the Bear Mountain and Gilbert Peak surfaces. The Tipperary surface is about 150 feet lower than the Bear Mountain surface. At least one remnant of it—that between the Bridger bench and Blacks Fork—merges upstream with the present flood plain of Blacks Fork and its tributary Spring Creek.

The lowest and hence the youngest surface studied in this area is the Lyman surface. It is so named from the town of Lyman, which is built upon its northern edge above Blacks Fork. Near Mountainview it lies about 50 feet below the Tipperary surface but merges upstream with the present flood plain of Blacks Fork.

FORM AND RELATIONS OF THE GILBERT PEAK EROSION SURFACE

CORRELATION OF REMNANTS

Though the Gilbert Peak surface is the oldest and highest surface in the region, it is represented by the most numerous and by far the largest remnants. This is due partly to its having been cut on the hard rocks that make the core and high flanks of the Uinta Mountains and partly to its thick resistant capping, the Bishop conglomerate, which protects those portions cut on soft, easily erodible beds. The distribution of these remnants is shown on plate 34.

Along the crest of the Uinta Range these remnants are nearly continuous and hence easily correlated. The summits of Goslin Mountain, Cold Spring Mountain, and the intervening mountains, have the same general characteristics as the long remnants of the Gilbert Peak surface farther west. (See pl. 36, *A*.) Cold Spring Mountain, however, is now somewhat lower than it was originally, having been dropped to its present position by faulting that accompanied the collapse of the east end of the Uinta Mountain arch. The relations between the structure of the east end of the Uinta Range and the erosional features are considered more fully under the heading "Collapse of the east end of the Uinta Mountain arch," on page 185.

The basinward remnants of the Gilbert Peak surface were correlated because they are accordant in altitude and have a capping of Bishop conglomerate. The great thickness and characteristically poor sorting of the material in this conglomerate made the correlation of these remnants relatively easy. That part of the Gilbert Peak surface east of the Green River has a distinctly steeper northward slope than the part west of the river. This discordance of slope may be partly accounted for by a regional uplift and northward tilt given to that portion of the area at the time the east end of the Uinta Mountain arch collapsed, but its steeper slope may also be in part original. A fuller discussion of the interpretation of this steeper slope is given on pages 185–187.

CHARACTERISTICS OF THE GILBERT PEAK SURFACE

The Gilbert Peak surface immediately before the deposition of the Bishop conglomerate consisted of a broad, generally smooth plain that extended for great distances out from the Uinta Mountains on all sides. (See pl. 36, *B*.) All the remnants of the Gilbert Peak surface in the Wyoming part of the area here considered and rather extensive portions of them in Utah are concealed beneath the Bishop conglomerate. However, in a broad way the conglomerate is merely a veneer that does not hide the form of the underlying surface but only the insignificant irregularities. On the other hand, erosion of the conglomerate has produced local irregularities probably quite as large as those the conglomerate conceals in the surface below. Virtually all the Gilbert Peak surface where it is covered with the Bishop conglomerate is remarkably smooth. (See pl. 36, *B*.) The undulations are so gentle as to be barely perceptible. Nevertheless, in places residual hills of the older rocks project through the veneer and rise rather abruptly from the plain. The most notable of these is Aspen Mountain, in the northeast corner of the area. Its summit, which consists of partly silicified sandstone of the Upper Cretaceous Blair formation, rises about 1,000 feet above the Gilbert Peak surface. Aspen Mountain has a debris apron of its own, which merges with the Bishop conglomerate around the base. Several similar but much smaller residual hills of the Upper Cretaceous rocks also rise above the surface of the Bishop conglomerate a few miles south and west of Aspen Mountain.

As the Gilbert Peak surface rises toward the crest of the Uinta Range in the western part of the area the veneer of conglomerate thins and then disappears. Above that the surface is bare rock or is covered with sharply angular fragments loosened but not far removed from their source.

About at the place where the conglomerate stops there is a conspicuous though discontinuous strike ridge. This is formed by the hard siliceous limestone beds of Carboniferous age, which are steeply upturned along the main Uinta flexure. The finest remnant of this ridge rises from the Gilbert Peak surface just east of the East Fork of Blacks Fork in secs. 18 and 19, T. 2 N., R. 13 E., Summit County, Utah. That remnant rises abruptly more than 300 feet above the plain, but it is evident that the plain is continuous around its east end. Hayden[14] and Emmons[15] both commented on this strike ridge of Carboniferous rocks in the vicinity of Blacks Fork. Other remnants along this same hogback in sec. 25 and secs. 27 and 32, T. 2 N., R. 11 E., also rise abruptly above the Gilbert Peak surface. (See pl. 34.) On other stream divides, notably between Henrys Fork and the East Fork of Smith Fork, the ancient streams that planed off this surface apparently leveled off the projecting nubbins of this hogback.

The truncation of both hard and soft rocks is a characteristic feature of the smoother parts of the Gilbert Peak surface. Along the divide between Henrys Fork and the East Fork of Smith Fork the surface is particularly smooth, and yet it cuts across a great thickness of beds of the Uinta Mountain group, whose dips increase northward until in the vicinity of the Uinta flexure they are nearly vertical. Furthermore, no break in this surface is discernible where it crosses from the hard quartzite and limestone on the south side of the Uinta flexure to the soft Tertiary mudstone on the north whose beds it truncates at low angles (fig. 12).

The form of the Gilbert Peak surface changes as it rises toward the crest of the range. As the flattened divides now representing the surface become narrower the slopes become more varied and steeper (pl. 37, *C*). Residual hills become more numerous, and the differentiation into plain and residual hill is progressively less until along the crest the topography is that of a hilly post-mature surface. Locally, however, smooth portions of the Gilbert Peak surface cross the range and slope southward, being the headward remnants of that surface which once flanked the south side of the range. (See pl. 34.) In places cliffs and ledges whose angles have become somewhat rounded and softened break the continuity of the gentle slopes. Many of the hills of this old topography have smoothly rounded though steep slopes and rise 1,000 feet or more above the remnants of the Gilbert Peak surface. One of the largest of these hills is the great dome about 2 miles north of North Burro Peak. Similar topographic features are found farther east on the north slope of Leidy Peak. Indeed, the whole crest line of the Uinta Range from South Burro Peak for many miles eastward is a well-preserved portion of this ancient topography.

The form of this old topography is the more striking in view of the fact that it was modeled out of the same hard, brittle rocks that make the great crags and bold cliffs in the cirques at the heads of the deep canyons which the glaciers cut back into this range, nearly or in places quite up to the axial divide. (See pl. 37, *B*.)

The essential features of the topography during the formation of the Gilbert Peak surface, then, are still to be seen in the western part of the area, where not only large portions of the remarkably smooth plain are preserved but also the narrower remnants running back up into the ancient hills whence came the streams that performed the work of lateral planation. As these ancient hills have been exposed to weathering and erosion since the Gilbert Peak surface was formed, they probably have been reduced in height and have become more rounded. On the other hand, the narrow flattened remnants of the surface that run up into the high mountains and merge with this hilly postmature region seem to have undergone no perceptible change beyond the loosening of angular fragments on their surfaces and the development of a moderate amount of sandy soil. The Pleistocene glaciers working headward and enlarging their cirques evidently destroyed much more of the landscape of the Gilbert Peak erosion cycle in the mountains than was removed during a long interval of subaerial erosion before them.

As the Gilbert Peak surface merges imperceptibly with the postmature hilly topography along the crest of the Uinta Range, it is difficult to separate what should properly be regarded as the Gilbert Peak erosion surface from the residual hills whose upper parts may represent portions of a surface belonging to a still more ancient erosion cycle. These residual hills,

[14] Hayden, F. V., U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1870, p. 44, 1872.

[15] Emmons, S. F., U. S. Geol. Expl. 40th Par. Rept., vol. 2, p. 256, 1877.

however, are not numerous enough nor are their summits nearly enough accordant to give any idea of the configuration of this hypothetical ancient surface.

On the basis of the remnants of various parts of the Gilbert Peak surface the diagram in plate 38, *A*, was constructed to show the probable topography of the north side of the Uinta Range and the adjacent plain to the north when the Gilbert Peak surface had just been completed. This great plain that extended northward from the Uinta Range was almost certainly continuous around the east end of the range and merged with a similar plain that extended southward from the south side of the range. Indeed, Powell[16] and Schultz[17] both show a considerable number of remnants of the Bishop conglomerate from the vicinity of Lodore Canyon westward along the south flank of the Uinta Range.

BISHOP CONGLOMERATE

The Bishop conglomerate was named by Powell[18] from its occurrence on Bishop Mountain, now known only as "Pine Mountain", in the eastern part of this area. His original name was †"Bishop Mountain conglomerate", but this was later simplified to the present name. This mountain has become widely known, not only because it is a conspicuous geographic feature but also because it is an excellent hunting ground for deer. Because of the present widely accepted usage of the name, the mountain will be referred to in this report as "Pine Mountain." (See pl. 34.) Emmons,[19] who was exploring that part of the country at about the same time as Powell, called this conglomerate the †"Wyoming conglomerate." There can be no doubt that both names refer to the same lithologic unit. Powell's name, which has never been confused with other conglomerates remote from this area and which antedates Emmons' name, has been adopted by later writers.

The distribution of the Bishop conglomerate is shown on plate 34. According to my measurements the conglomerate is about 140 feet thick on the south end of Sage Creek Butte and also on the south end of Cedar Mountain. On Twin Buttes it is about 100 feet thick, and in most places on Little Mountain and Miller Mountain it does not exceed 75 feet. Rich,[20] however, says that near the south side of Aspen Mountain it is more than 200 feet in thickness, and Hayden[21] reports nearly horizontal beds of conglomerate 200 feet thick on the east side of Elizabeth Mountain, which is in the western part of T. 3 N., R. 11 E., Summit County, Utah. Though no more actual measurements of the Bishop conglomerate are available, I feel rather sure, from having examined it in numerous places, that in a regional way the Bishop conglomerate reaches its maximum thickness in the vicinity of the Utah-Wyoming boundary line. Southward the surface rises and the conglomerate thins to an irregular edge. Northward it thins very gradually and before dissection of the Gilbert Peak surface presumably extended far out into the basin.

Phil Pico Mountain (Mount Corson of the early territorial surveys), just south of the Wyoming line in T. 3 N., R. 18 E., Summit County, Utah, is not capped with Bishop conglomerate as shown on most maps, but instead the whole mass of the mountain consists of a conglomeratic facies of the Bridger formation. This conglomerate is composed predominantly of pebbles and cobbles of limestone with a lesser proportion of black and red chert and white quartzite. The Bridger is similarly conglomeratic both east and west of Phil Pico Mountain for several miles along the flank of the Uinta Range.

The Bishop conglomerate consists predominantly of reddish boulders and gravel derived from the Uinta Mountain group, which makes up the great bulk of the Uinta Mountains. Mixed with the red quartzite and sandstone is a moderate quantity of gray cherty limestone and white and greenish-gray quartzite from the hogbacks of Carboniferous rocks that flank the red quartzite core. Locally, as on Miller Mountain but particularly on the south end of Little Mountain and on Pine Mountain, the conglomerate contains an abundance of vein quartz, white quartz schist, and hornblende schist derived from a rather small area of pre-Cambrian metamorphic rocks about 10 miles to the south known as the Red Creek quartzite. At other places, as on the west end of the bench just east of the Green River and north of Sage Creek, it contains an abundance of angular shale and mudstone fragments evidently scoured from local sources by the streams that formed the conglomerate.

A characteristic feature of the Bishop conglomerate is the poor sorting of its constituents. Commonly medium- to coarse-grained sand is mixed with gravel, cobbles, and boulders as much as 2 feet in maximum diameter. (See pl. 39, *B*.) Boulders ranging from 6 inches to about 1 foot in maximum dimension are plentiful in the greater part of the area, and in general they are rather well rounded. Boulders 4 to 5 feet long were found near the mountain flanks, but

[16] Powell, J. W., Report on the geology of the eastern portion of the Uinta Mountains, atlas, U. S. Geol. and Geog. Survey Terr., 1876.

[17] Schultz, A. R., A geologic reconnaissance of the Uinta Mountains, northern Utah, with special reference to phosphate: U. S. Geol. Survey Bull. 690, pl. 5, 1918.

[18] Powell, J. W., Report on the geology of the eastern portion of the Uinta Mountains, p. 169, U. S. Geol. and Geog. Survey Terr., 1876.

[19] Emmons, S. F., U. S. Geol. Expl. 40th Par. Rept., vol. 2, p. 205. 1877.

[20] Rich, J. L., The physiography of the Bishop conglomerate, southwestern Wyoming: Jour. Geology, vol. 18, p. 619, 1910.

[21] Hayden, F. V., U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1870, p. 47, 1872.

they are comparatively rare. The variation in the size of the constituents narrows outward away from the mountains, so that at the north end of Cedar Mountain and in the vicinity of Aspen Mountain the material brought from the Uinta Mountains ranges from sand to moderate-sized cobbles. The commonest matrix for the cobbles and boulders is gray or white sand containing stringers and lenses of gravel. The white sand itself was probably derived from Uinta Mountain quartzite, as that rock loses its red interstitial cement on weathering and breaks down into white sand. In places, however, the matrix is cemented with white, dense, and nodular material, which was evidently deposited in the conglomerate after its formation and is in part silicified. Nearly everywhere the Bishop conglomerate is less coarse near the top where boulders are rare and the bulk of the material is coarse gravel.

The courses of ancient streams through the sand and gravel of the Bishop conglomerate are marked by irregular lines and lenses of the larger cobbles and boulders. At the south end of Cedar Mountain the Bishop conglomerate contains a huge lens of boulder conglomerate which weathers into columns. (See pl. 37, *A*.) This lens is more than half a mile wide and about 100 feet thick. Though a stream with sufficient power to move large cobbles and boulders while in flood would probably scour its channel deeply, it is very unlikely that such a stream would set in motion material to the full depth of this lens at any one time. More probably this lens represents the site of a good-sized stream that flowed northward and gradually built up its course as it wandered over a strip the width of the lens. The conglomerate on each side of this channel is in general finer-grained than that in the channel and contains an abundance of fine gravel and white or gray sand.

Both Rich [22] and Sears [23] have described the interfingering of the material in the Bishop conglomerate derived from the Uinta Mountains with that derived from Aspen Mountain at the base of its southern slope. Evidently, therefore, the debris mantle sloping away from Aspen Mountain is a part of the Bishop conglomerate and differs only because of its local source. It is unlike the greater part of the Bishop conglomerate in that its constituents are predominantly angular and consist chiefly of brown sandstone and quartzite from the Upper Cretaceous Blair formation. At the junction of these two facies of the Bishop conglomerate Sears [24] also found lenses of fresh-water limestone, one of which is 75 feet thick.

[22] Rich, J. L., op. cit., pp. 610–612.

[23] Sears, J. D., Geology of the Baxter Basin gas field, Sweetwater County, Wyo.: U. S. Geol. Survey Bull. 781, p. 21, 1926.

[24] Idem, p. 21.

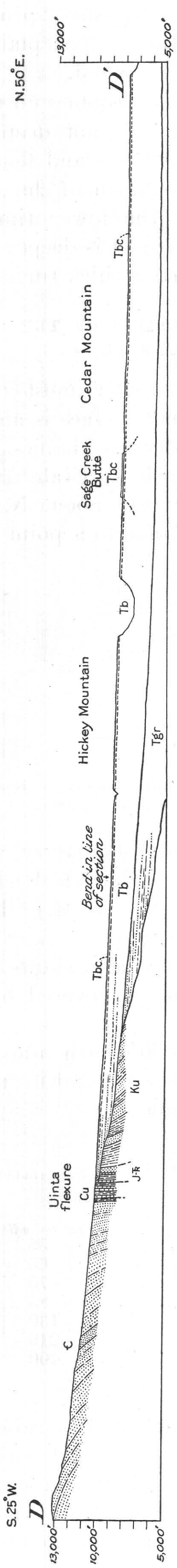


FIGURE 12.—Hickey Mountain profile, a composite profile along the line D–D′, plate 34, showing remnants of the Gilbert Peak surface projected laterally into the plane of the section. As the rocks are not exposed in the vicinity of this profile, the geology shown is generalized from sections exposed farther east and west and projected into the plane of this section so as to show the even truncation of both hard and soft rocks by certain portions of the Gilbert Peak surface. Є, Uinta Mountain group (†Uinta quartzite of previous reports); Cu, Carboniferous undifferentiated; J–Ꞧ, Jurassic and Triassic undifferentiated; Ku, Cretaceous undifferentiated; Tgr, Eocene Green River formation; Tb, Eocene Bridger formation; Tbc, Bishop conglomerate.

These he interpreted as deposits "probably formed in temporary ponds on the old peneplain upon which the conglomerate was deposited."

The quartzite pebbles and cobbles on the surface of the Bishop conglomerate are not deeply weathered, yet they are dull and lusterless and tend to flake off. A light sandy soil covers much of the surface of the Bishop remnants below the lower timber line, but within the timber belt the soil is deeper and finer and in the open parks supports a thick turf.

CHARACTERISTICS OF PROFILES OF THE GILBERT PEAK SURFACE

The longest and apparently most nearly perfect profile of the Gilbert Peak surface is along the bench that forms the divide between Henrys Fork and the East Fork of Smith Fork in Utah. (See fig. 12.) The line of this profile runs about N. 25° E. from the crest of the Uinta Range to a point about 3 miles north of the Utah-Wyoming boundary, where it turns to about N. 60° E. so as to include Hickey Mountain and Sage Creek Butte. (See pl. 34.) The surface of Cedar Mountain was projected westward into the line of the profile. This figure also shows the extent to which the erosion surface is covered by the Bishop conglomerate.

The average gradients for each 5-mile interval of the profile from the basinward end up to the crest of the range are given below:

Distance from basinward end	Average gradient
Miles	*Feet per mile*
0– 5	55
5–10	65
10–15	75
15–20	85
20–25	130
25–30	210
30–35	400

In figure 13 this profile, hereafter referred to as the Hickey Mountain profile, is plotted with the vertical scale exaggerated nearly eight times and with the little irregularities of the observed data smoothed out. On this smoothed profile also is shown the approximate thickness of the Bishop conglomerate, so that the lower smooth curve at the base of the conglomerate shows the probable configuration of the Gilbert Peak erosion surface before it was buried beneath the gravel. At the time of its formation the Gilbert Peak surface undoubtedly had a gravel veneer of moderate thickness. This original gravel veneer is now included in the Bishop conglomerate, as there is no evident way of distinguishing one from the other. The lower profile probably represents rather closely the graded condition attained by large portions of the Gilbert Peak surface and the condition toward which the remainder was approaching just before the deposition of the Bishop conglomerate. Doubtless, however, profiles along divides between the streams that cut the surface would show a somewhat more abrupt change in the curvature near the head, and likewise profiles along some of the larger streams probably would show a somewhat lesser change of curvature.

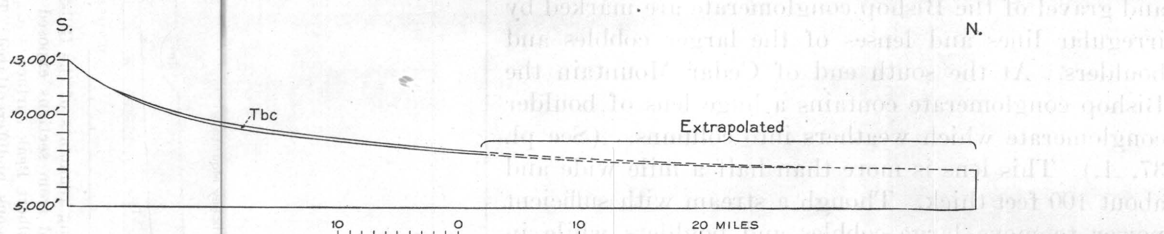
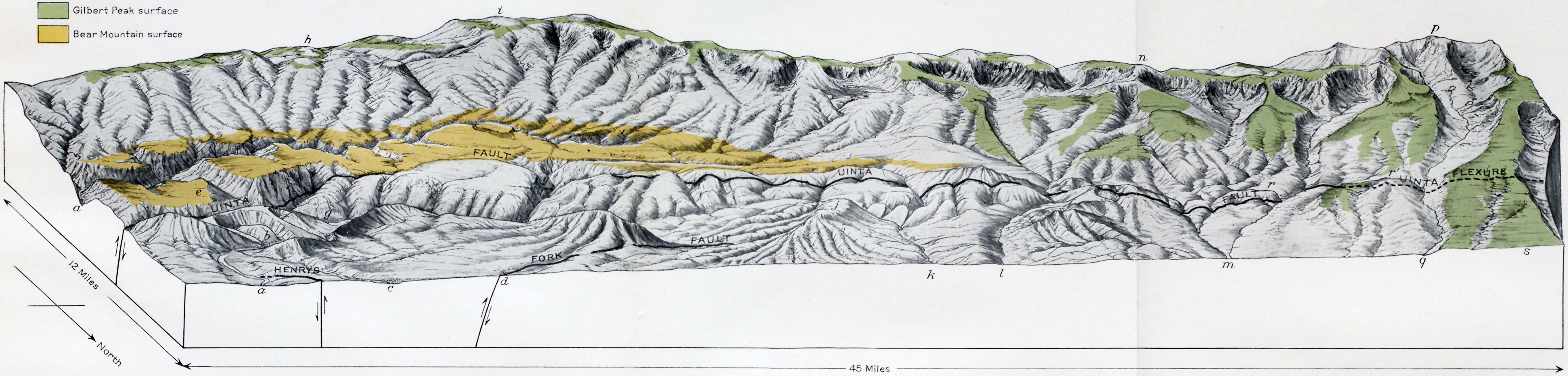


FIGURE 13.—Smoothed curve of the Hickey Mountain profile with the vertical scale much exaggerated to show how the Bishop conglomerate (Tbc) fills the most concave portion of the profile. The extrapolation was made from plots on double logarithmic paper.

Nevertheless, comparison of the profiles on the remaining remnants indicates that the flatter parts of the profiles had closely similar gradients.

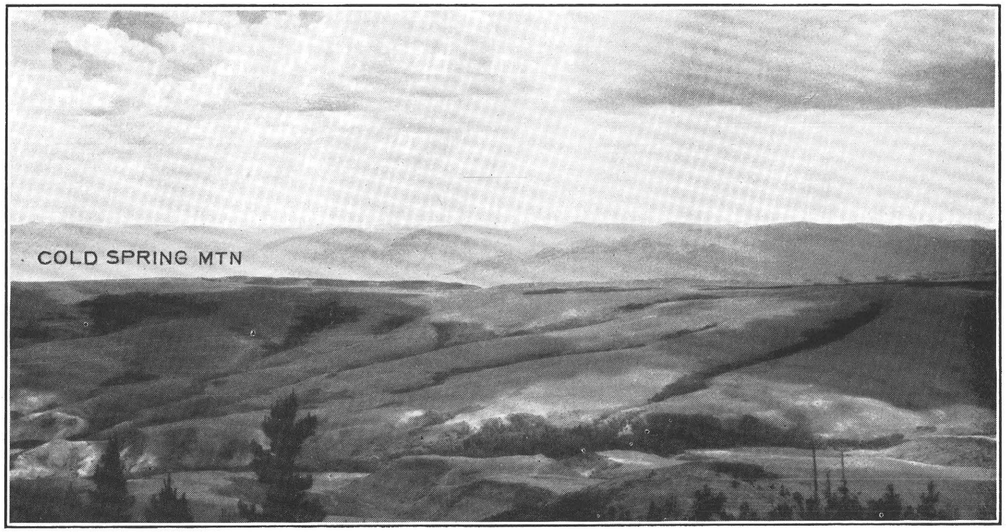
ORIGIN AND DEVELOPMENT OF THE GILBERT PEAK EROSION SURFACE

The Gilbert Peak surface is not a normal peneplain. It flanks a mountain range, away from which it slopes at gradients ranging from 400 feet to the mile in the highest part to about 55 feet to the mile in the parts most remote from the range. The rock which it cuts is apparently fresh and undecayed where it is overlain by conglomerate and only shallowly weathered and fractured where it is exposed. The residual hills, some of which are of limestone, rise rather abruptly from the erosion surface. (See figs. 14 and 15.) Furthermore, at no place does the Gilbert Peak surface have a deep soil mantle. Instead it is in most places covered with conglomerate. This conglomerate, however, is unusually thick, and a special explanation of it is given on pages 178–179. Thus the Gilbert Peak surface evidently has more characteristics in common with the plains formed under an arid climate than with those formed by the normal process of peneplanation in a humid region.



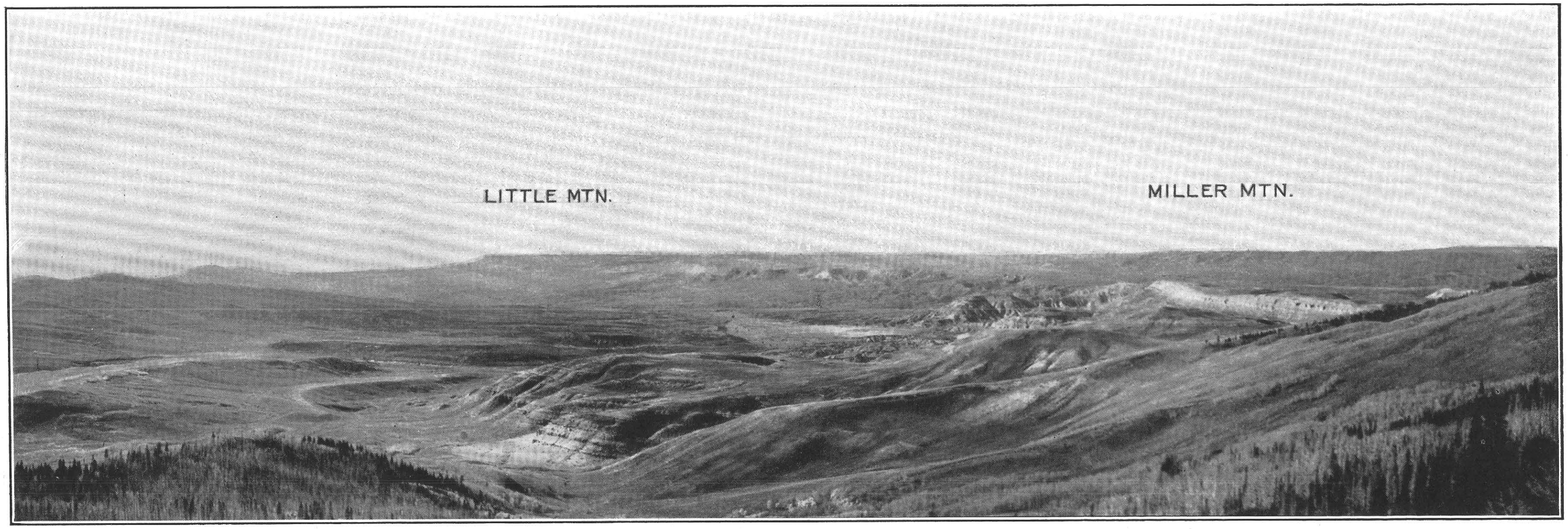
BLOCK DIAGRAM SHOWING THE PRESENT TOPOGRAPHY OF THE NORTH SLOPE OF THE UINTA RANGE, FROM THE PLACE WHERE THE GREEN RIVER ENTERS FLAMING GORGE WESTWARD TO THE HEADWATERS OF HENRYS FORK AND KINGS PEAKS.

The Green River enters the block at *a*, flows southward to Flaming Gorge (*b*), then winds around past the mouth of Sheep Creek (*g*), passes south of Bear Mountain (*e*), and emerges from the block at *a'*, whence it flows eastward into Browns Park. The trace of the Uinta fault and its westward extension, the Uinta flexure, can be followed across the diagram from Flaming Gorge to the upper part of Henrys Fork (*q*) by the hogbacks of harder rocks, which dip steeply toward the observer. Just south of the line of these hogbacks are plateaulike remnants of the floor of the ancient Browns Park Valley. This surface, which is best shown in the eastern part of the diagram, truncates beds of hard Uinta Mountain quartzite and the hard limestone beds of the Carboniferous formations. The valley narrows and rises westward until only a small remnant of it is to be found on the divide east of Henrys Fork behind the strike ridge *r*. The Gilbert Peak erosion surface is represented by the flattened interstream divides in the western part of the diagram (notably at *s*) and by the postmature hilly sarface along parts of the crest of the Uinta Range, as in the vicinity of Gilbert Peak (*o*), South Burro Peak (*n*), Leidy Peak (*i*), and Trout Peak (*h*). The diagram was constructed from the Marsh Peak, Gilbert Peak, and Hayden Peak topographic maps by means of an isometrograph. Because the projection upon which this sketch was based does not show perspective, the diagram appears to be distorted. Thus the range appears to be highest near Leidy Peak (*i*), but actually it is highest at Kings Peaks (*p*) and diminishes in altitude rather uniformly eastward. The apparent great height of Leidy Peak is due simply to the fact that the crest line of that part of the range swings several miles southward, or back from the observer. Plate 43, *B*, does not adjoin this block but shows the present topography a few miles to the east, in the vicinity of Browns Park and Lodore Canyon.



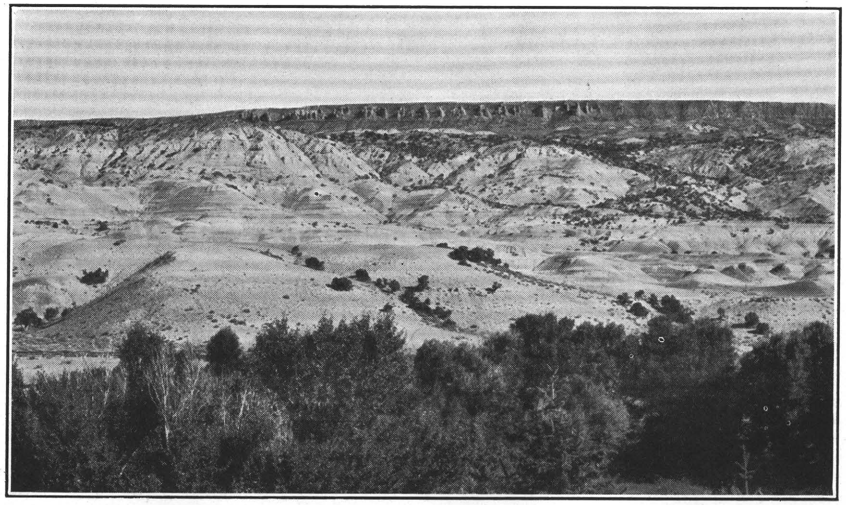
A. VIEW SOUTHWARD FROM DIAMOND PEAK, SHOWING THE NEARLY FLAT TOP OF COLD SPRING MOUNTAIN, A REMNANT OF THE GILBERT PEAK SURFACE.

Eastern portion of the Uinta Range in the background and the Browns Park formation in the valley of Talamantes Creek in the foreground. Photograph by W. C. Alden.



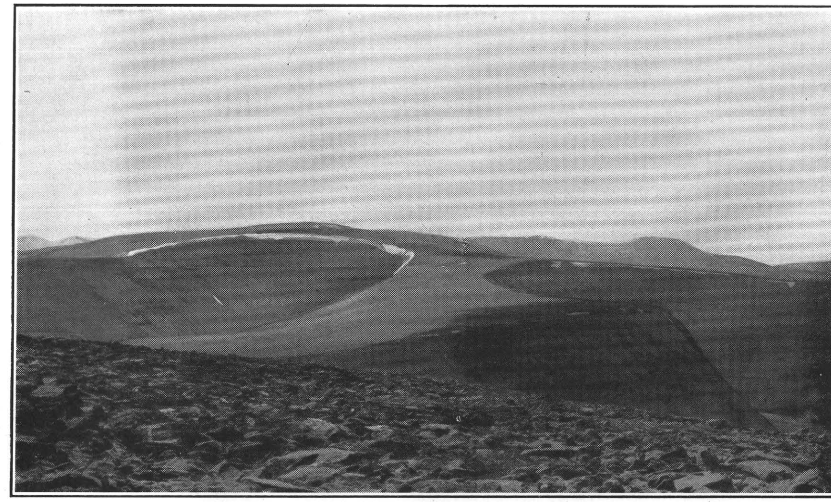
B. VIEW WEST AND NORTHWEST ACROSS THE VALLEY OF RED CREEK, SHOWING THE GILBERT PEAK SURFACE SLOPING NORTHWARD FROM THE SOUTH END OF LITTLE MOUNTAIN AND PASSING THROUGH MILLER MOUNTAIN.

The photograph was taken from Pine Mountain, whose flat top is a remnant of the Gilbert Peak surface comparable to the south end of Little Mountain.



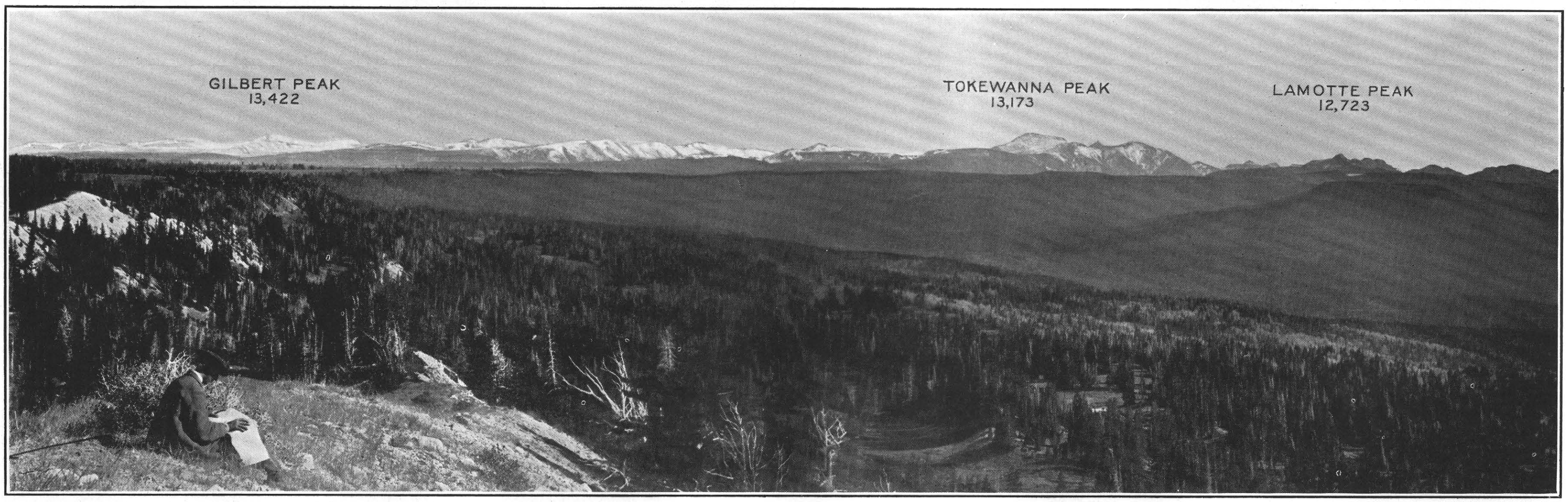
A. VIEW NORTH ACROSS HENRYS FORK, SHOWING THE SOUTH END OF CEDAR MOUNTAIN WITH ITS THICK CAPPING OF THE BISHOP CONGLOMERATE, WHICH CONTAINS A HUGE LENS OF COARSER-GRAINED MATERIAL THAT WEATHERS INTO COLUMNAR FORMS.

Below the conglomerate are tuffaceous beds of the Bridger formation.



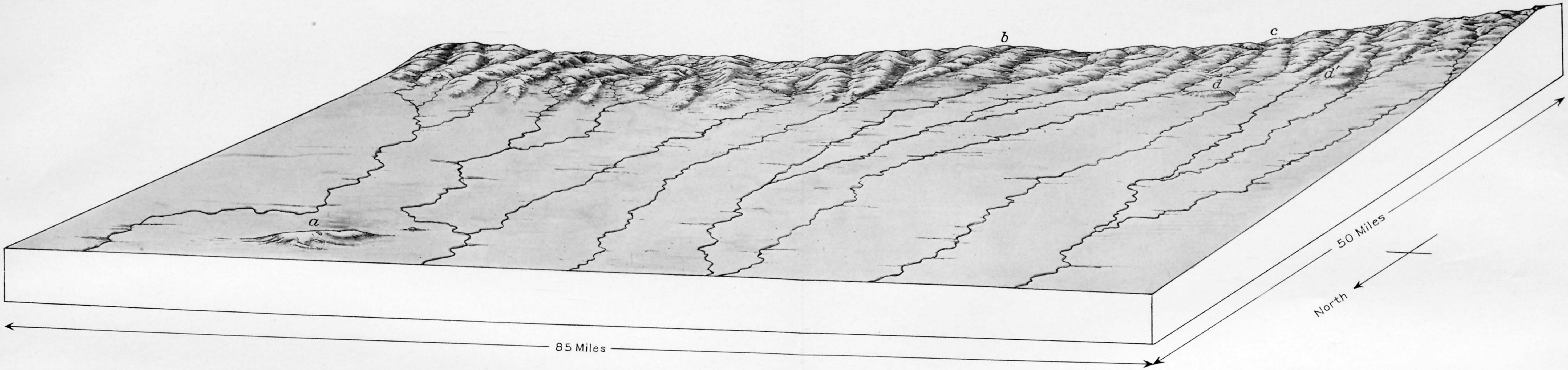
B. CREST OF THE UINTA RANGE AT THE HEAD OF THE WEST FORK OF SHEEP CREEK, SHOWING A PORTION OF THE GILBERT PEAK SURFACE WHERE IT CROSSES THE RANGE.

Photograph by W. W. Atwood.



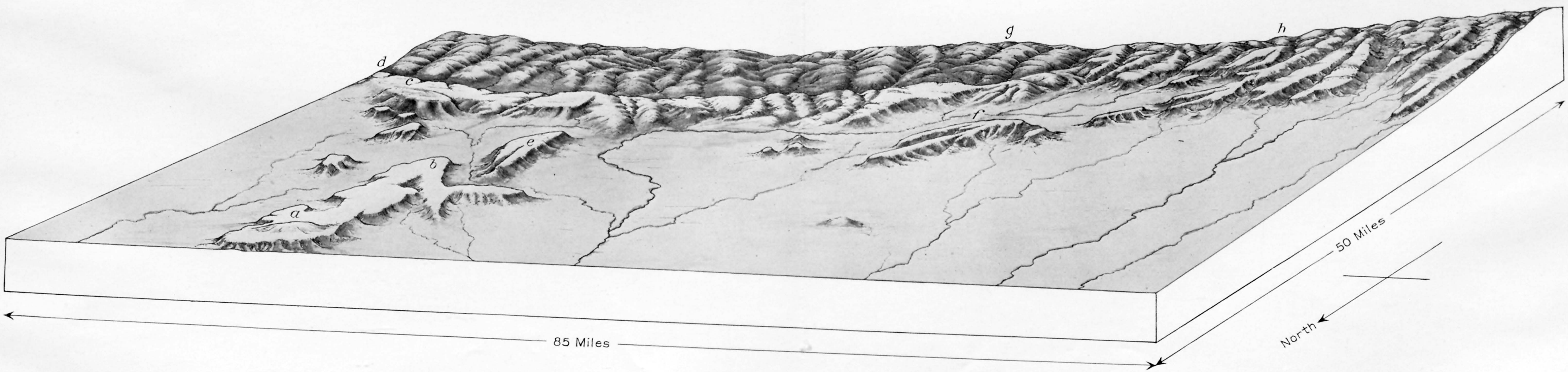
C. VIEW SOUTHEASTWARD FROM ELIZABETH MOUNTAIN, SHOWING THE GILBERT PEAK SURFACE RISING SOUTHWARD TOWARD THE CREST OF THE UINTA RANGE.

Blacks Fork Canyon heads between Lamotte and Tokewanna Peaks, and the flat-topped ridge nearest the observer is Concrete Plateau. Other similar remnants of the Gilbert Peak surface can be seen on successive interstream ridges east of Blacks Fork and notably at the foot of Gilbert Peak. Photograph by W. H. Jackson.



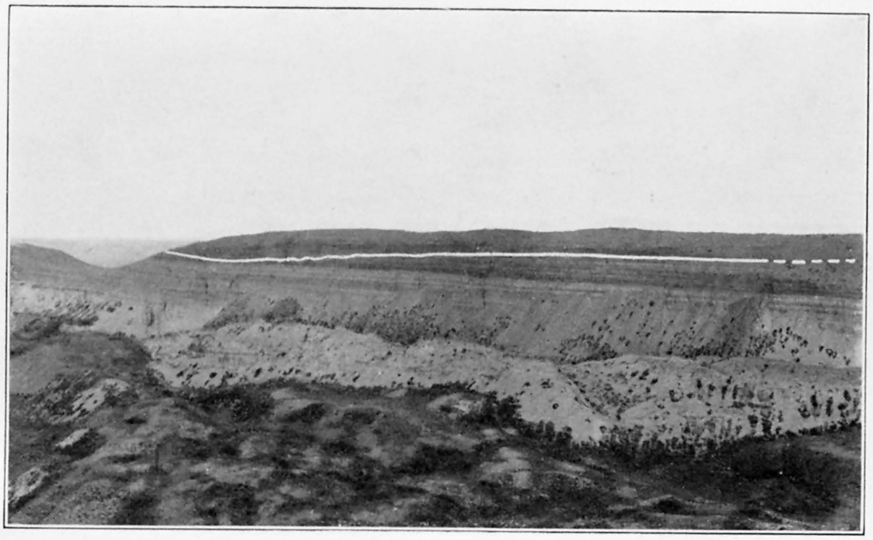
A. BLOCK DIAGRAM CONSTRUCTED TO DEPICT THE PROBABLE CONFIGURATION OF THE GILBERT PEAK SURFACE EXTENDING NORTHWARD FROM THE POSTMATURE HILLY CREST OF THE UINTA RANGE AT ABOUT THE TIME THE BISHOP CONGLOMERATE WAS DEPOSITED.

The reconstruction is based on the remnants of the Gilbert Peak surface shown on plate 34. *a*, Aspen Mountain; *b*, Leidy Peak; *c*, Gilbert Peak; *d* and *d'*, strike ridges along the Uinta flexure.

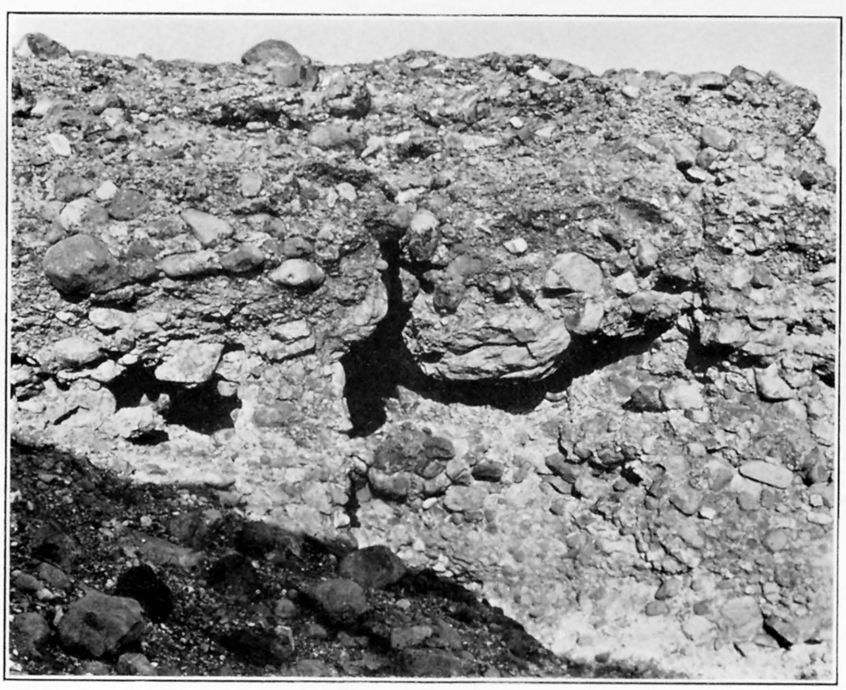


B. BLOCK DIAGRAM CONSTRUCTED TO DEPICT THE PROBABLE TOPOGRAPHY OF THE NORTH FLANK OF THE UINTA MOUNTAINS AT THE TIME THE BEAR MOUNTAIN SURFACE WAS COMPLETED.

The reconstruction is based on remnants of the Gilbert Peak and Bear Mountain surfaces. Features of the present landscape are shown at *a*, Aspen Mountain; *b*, Miller Mountain; *c*, Cold Spring Mountain; *d*, Browns Park Valley; *e*, Little Mountain; *f*, Cedar Mountain; *g*, Leidy Peak; *h*, Gilbert Peak.



A. IRREGULAR CONTACT DUE TO LOCAL SCOUR AND FILL WHERE THE BISHOP CONGLOMERATE RESTS ON THE BEDS OF THE GREEN RIVER FORMATION, WHICH HERE MAKE UP THE EAST SPUR OF LITTLE MOUNTAIN.



B. DETAIL OF THE BISHOP CONGLOMERATE ON THE SOUTH END OF LITTLE MOUNTAIN.

The larger boulders are a little more than 1 foot across.

GROWTH OF PEDIMENTS IN ARID CLIMATES

Plains comparable in smoothness with the Gilbert Peak surface may be formed in arid regions by the combined action of lateral wandering and lateral planation of streams, rill erosion, and weathering. Many students [25] have discussed the process by which rocks of differing hardness and diverse structure are planed off by streams, first by widening their valleys, then by cutting through the divides between streams so that the flood plains coalesce, and finally by cutting away the remnants of the interstream divides and integrating the flood plains of all the streams into an extended plain of remarkable smoothness. Apparently, however, this process operates most effectively the minor rain rills, whose erosive work he regards as secondary only to that of the lateral planation of the streams. He wrote:

At the base of a mountain slope the fine debris washed down by rains is moved forward by little rills toward the larger streams. As the supply of debris is small, these rills are not fully loaded and are effective erosive agents, tending to reduce the height of interstream areas. The grade of the rills and of the smaller streams is steeper than that of the larger streams, because all are underloaded by about the same proportion, and therefore the larger volumes of water transport their loads on the lower gradients. As a result of this relation of stream grades, the pediment, cut and molded by these streams, has a lower slope opposite the larger canyons than opposite the smaller canyons. Also, the parts of the pediment opposite the intercanyon ridges have a steeper slope

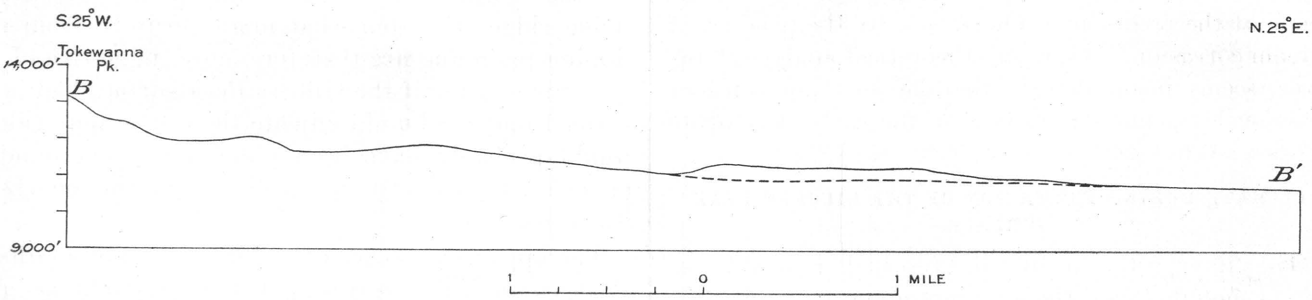


FIGURE 14.—Profile along the ridge between Middle and East Forks of Blacks Fork (B–B′, pl. 34), showing the island-mounts and the adjacent flat-bottomed saddles, which are presumably portions of abandoned channels of ancient strike-valley streams.

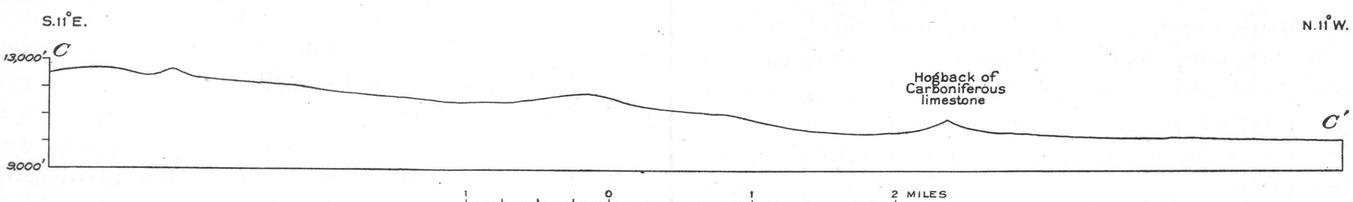


FIGURE 15.—Profile along the ridge between East Fork of Blacks Fork and Smith Fork (C–C′, pl. 34), showing the rounded island-mounts of the Uinta Mountain group at the left and the sharp strike ridge of the Carboniferous limestone beds upturned at the Uinta flexture.

in arid or semiarid regions, where the streams, even though they flow intermittently, are powerful erosive agents because they flow on steep gradients and while in flood have an abundant volume of water and a moderate yet adequate quantity of detritus to use as cutting tools.

According to Bryan's observations this relation between large volume and moderate load applies also to

away from the mountains and in addition slope toward adjacent streams.[26]

Weathering, too, plays a significant part in the growth of a pediment, as Bryan also pointed out.

When the spurs become narrow, they are cut through by slope recession on both sides, and hills are left standing as outliers on the pediment. These solitary hills are worn away with extreme slowness. Their erosion depends entirely on the gradual disaggregation of the rock which composes them and on the movement of the debris over the pediment during rains. The hills retain the same steep slopes as the original mountain but grow gradually smaller until the last remnants are masses of boulders or single rocks projecting above the general level.[27]

Johnson [28] is inclined to attribute a decidedly predominant share in the development of pediments to the lateral planation of the streams themselves. According to his interpretation the streams emerging

[25] Gilbert, G. K., Report on the geology of the Henry Mountains, pp. 126–132, U. S. Geog. and Geol. Survey Rocky Mtn. Region, 1877. McGee, W J, Sheet-flood erosion; Geol. Soc. America Bull., vol. 8, pp. 107–111, 1897. Johnson, W. D., The High Plains and their utilization: U. S. Geol. Survey 21st Ann. Rept., pt. 4, p. 624, 1901. Ogilvie, I. G., The high-altitude conoplain; a topographic form illustrated in the Ortiz Mountains: Am. Geologist, vol. 36, pp. 31–34, 1905. Paige, Sidney, Rock-cut surfaces in the desert ranges: Jour. Geology, vol. 20, pp. 449–450, 1912. Lawson, A. C., The epigene profiles of the desert: California Univ. Dept. Geology Bull., vol. 9, pp. 28–45, 1915. Bryan, Kirk, The Papago country, Arizona: U. S. Geol. Survey Water-Supply Paper 499, pp. 93–101, 1925. Davis, W. M., Rock floors in arid and humid climates: Jour. Geology, vol. 38, pp. 5–12, 14–20, 145–148, 150–158, 1930. Blackwelder, Eliot, Desert plains: Jour. Geology, vol. 39, pp. 133–140, 1931. Johnson, Douglas, Planes of lateral corrasion: Science, vol. 73, pp. 174–177, 1931; Rock fans of arid regions: Am. Jour. Sci., 5th ser., vol. 23, pp. 389–413, 1932.

[26] Bryan, Kirk, op. cit., p. 96.

[27] Idem, p. 96.

[28] Johnson, Douglas, Rock fans of arid regions: Am. Jour. Sci., 5th ser., vol. 23, pp. 392–394, 407–408, 1932.

from the mountain front cut rock fans whose apexes are at the canyon mouths. The streams are relatively fixed at the canyon mouths and shift through progressively greater arcs from those points outward, like the shifting streams on normal alluvial cones. Hence, as the streams come intermittently to flow along the contacts between the sides of the fans and the mountain front they cut back the mountain front. Consequently, in development of this sort the pediment steepens toward the canyon mouths and is lower along the interstream divides, so that close to the mountain front it is, in a broad way, shallowly fluted normal to the mountain front. Johnson regards the slope of the receding mountain front as the product of weathering and rill erosion, whereas the comparatively gentle slope of the pediment is almost wholly the product of stream corrasion. Johnson's theoretical analysis, however, seems incomplete in that he does not consider the development of rock fans in the early part of an erosion cycle.

CLIMATE DURING FORMATION OF THE GILBERT PEAK SURFACE

The interpretation of the residual remnants or island-mounts [29] and the apparent absence of soil may, however, be considered more fully. The island-mounts do not rise as abruptly from the pediment as many of those formed in extremely arid regions. Their rounded forms and smooth curves at the base seem to ally them with the features of a humid region. Their rather gentle slopes are probably accounted for in part by the tendency of the quartzite of the Uinta Mountain group to disintegrate into sand grains by weakening of the red cement. This factor is more or less independent of climate and according to Lawson's generalization [30] that "the hard-rock slopes of desert ranges which shed large spalls are steep, while those which shed small fragments have a low angle," may be operative even in a distinctly arid climate. But these island-mounts are today more rounded and smoothed than when they were first carved, for they have been continuously exposed to weathering under the varied climates of later Tertiary and Pleistocene time. Moreover, during a part and perhaps all of that time they have been in a high-altitude zone whose climate is subhumid, and during the Pleistocene they underwent the rigors of at least three glacial stages, though they were not overridden by the ice. Through this long interval of time their contours were further softened by the accumulation around their bases of waste from their disintegrating summits after the streams had entrenched themselves below the level of the erosion surface and consequently become unable to remove this waste. They have undoubtedly been modified more by weathering than the remnants of the pediment from which they rise, because the pediment has much flatter slopes and is therefore less vulnerable. Hence it seems to me that the form of the quartzite island-mounts is of little significance in reaching an understanding of the climate under which the Gilbert Peak surface was formed. It is more significant that they rise from a sloping plain that has the characteristics of a pediment. The limestone strike ridges rise somewhat more abruptly from the sloping plain and are therefore more suggestive of an arid climate, for if the Gilbert Peak surface had been formed under a humid climate these limestone ridges would probably have been reduced to low rounded mounds of distinctly less relief than the quartzite island-mounts.

The apparent absence of a soil cover on the Gilbert Peak surface also agrees with the other characteristics which suggest that it was formed under the influence of an arid or semiarid climate. Nevertheless, a soil cover may possibly have formed and then have been stripped off, as suggested by Rich.[31] According to Rich's interpretation the Gilbert Peak surface was produced by the normal processes of peneplanation under a humid climate. Later the peneplain was tilted and the climate changed from humid to arid, so that if a soil once mantled the surface it must have been removed during the arid cycle. These conclusions of Rich's were based on a study of the Gilbert Peak surface only in that part of the area east of the Green River, where there is reason to believe that the surface has been tilted. The present study, however, has shown that much of the Gilbert Peak surface west of the Green River has a considerable regional inclination that seems to be a part of its original form. Therefore, as no soil was found below the Bishop conglomerate in that area either, and as the absence of soil seems to agree far better with the other characteristics of the Gilbert Peak surface, which seem to suggest that it was formed predominantly by the lateral corrasion of streams under an arid or semiarid climate, it seems reasonable to conclude that the Gilbert Peak surface probably never was mantled with soil.

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[29] Davis, W. M., op. cit., p. 151. The term "island-mounts" (Inselberge) is used by Davis to designate erosion remnants which rise from a pediment and which he differentiates from "residual mounds" that rise from peneplains formed in humid regions.

[30] Lawson, A. C., The epigene profiles of the desert: California Univ. Dept. Geology Bull., vol. 9, p. 29, 1915.

[31] Rich, J. L., The physiography of the Bishop conglomerate, southwestern Wyoming: Jour. Geology, vol. 18, pp. 614-618, 1910.

REGIMEN [52] OF THE ANCIENT STREAMS

In order for the streams flowing northward from the Uinta Mountains to have cut so extensive a plain they must have been controlled by a local baselevel common to them all. But, as basinward beyond the present remnants of the plain virtually all traces of the drainage of that time have been destroyed, we can only surmise what may have been the controlling baselevel. The Gilbert Peak surface was formed at a time when the Tertiary sediments in the Green River Basin had not been dissected and so filled the basin to a higher level than they do today. Slightly eroded remnants of these Tertiary sediments (beneath the remnants of the Bishop conglomerate) indicate that they once lapped up high against the flank of the Uinta Range. The altitude of these highest remnants suggests, moreover, that the upper part of the Bridger formation probably lapped up against the east end of the range and was continuous with contemporaneous Tertiary beds filling the basin to the south. Apparently, this Bridger cycle of Tertiary sedimentation was followed by a long interval of time, during which the streams of the region flowed on this great plain of aggradation. During this interval the climate seems to have grown progressively more arid, and the great depositional plain was gently warped, so that the structure of the Bridger Basin and the Rock Springs uplift were mildly accentuated.

After the warping and later adjustment of the drainage the streams began to cut laterally, either because the master stream, enfeebled by the dry climate, found hard rocks athwart its course which it was able to lower only with extreme slowness or because the climate was just arid enough so that the master stream was held in a graded condition by receiving from its branches only sufficient water to move its load but not enough to cut progressively deeper into the Tertiary rocks.

This ancient stream apparently must have flowed eastward or northeastward out of the Green River Basin and perhaps connected with the ancestral Platte River or some similar stream that flowed to the Mississippi. Northward-sloping remnants of the Bishop conglomerate east of the area described in this report—namely, at the north end of the Sierra Madre—preclude the possibility of drainage southward around the east end of the Uinta Range. (See fig. 11.)

[52] W. W. Rubey (Geology of the Hardin and Brussels quadrangles, Illinois: Illinois Geol. Survey Bull. in preparation) defines regimen as "the habits or characteristics of individual streams—their particular reactions to the general laws of stream work—whether or not the streams have attained the condition of equilibrium. When we say that one river has a very different regimen from another, we then mean that the two streams have responded differently to the same fundamental laws. Their velocities of flow, the slope of their water surfaces, the shape of their channels, or their habits of cutting, filling, or of stability may differ because the conditions of run-off, load, or bank resistance are not the same in the two drainage basins."

Whatever the explanation of the temporary baselevel for the streams that cut the Gilbert Peak surface, they flowed northward and northeastward from the Uinta Range and must have been prevented from cutting downward, or at least from cutting downward rapidly, by a common cause which acted on them at a considerable distance out from the range.

Because these streams were held up at some place in their lower courses they adjusted their long middle courses to a gradient just adequate to transport the load delivered to them from the upper reaches of the streams—that is, they reached a balanced or graded condition. These streams meandered, probably while they worked down to grade as well as thereafter, and the meander belts wandered. In detail the streams scoured and filled their channels, but their principal work was to cut laterally by the meandering and the wandering of meander belts. (See pl. 39, *A*.) They widened their valleys and cut away the interstream divides so that finally the ever-widening flood plains merged into a great flood plain common to them all. By such lateral cutting the streams on the Gilbert Peak surface were able to work up close to the base of the island-mounts, to remove the weathered and loose material, and to keep the slopes relatively steep. This is a habit of stream cutting and planation more characteristic of arid than of humid regions. Indeed, it might be stated as a generalization that only powerful torrential streams with a moderate load of rock debris which are graded with respect to steep bed slopes are competent to perform the vigorous lateral corrasion necessary to cut away stream divides and carve out from a diversified terrane the rather steeply sloping, smooth plains known as "pediments." Because such streams are typical of arid and semiarid regions they are generally intermittent and, though powerful through their middle courses, are likely to be feeble in their lower reaches, where their volume is greatly depleted through loss of water to the alluvium, evaporation losses, and the like.

The Gilbert Peak surface was extensive and probably the gradients in different portions of it differed a little according to the regimen of the different streams, the lowest gradients being associated with the largest streams. Nevertheless, in a broad way, the surface ultimately developed was probably monotonously similar from place to place. In profile it was slightly concave upward and had a distinctly perceptible gradient basinward. (See figs. 12 and 20.)

Along their upper reaches the ancient streams were actively cutting both downward and laterally, thus furnishing the detritus used for lateral planation farther downstream. Fragments of the courses of these ancient streams are still faintly revealed in the southwestern part of the area. East and west of Blacks Fork in the southern part of T. 2 N., R. 11 E., for example, strike ridges of the limestone hogback rise above the Gilbert Peak surface and make a "gate" through which the precursor of Blacks Fork probably flowed while cutting the Gilbert Peak surface. Apparently the streams working in the present drainage area of the Middle and East Forks of Blacks Fork wandered widely, for there the Carboniferous limestone hogback was effectively leveled off and makes no perceptible ridge. But just east of the East Fork it makes a high conspicuous ridge above the Gilbert Peak surface. On the upstream sides of the strike ridge of limestone and of the quartzite island-mounts the Gilbert Peak surface is generally flat. (See figs. 14 and 15.) It seems to me rather likely that these relatively wide, flat-bottomed saddles represent the courses of ancient subsequent streams. Such a stream may once have flowed along for many miles northeastward just south of the limestone hogback. A long subsequent stream of this sort seems to explain the large valley extending from the east side of Henrys Fork (at a point about 5 miles south of the Utah-Wyoming boundary line) for many miles eastward, where it broadens into the old valley in which the Browns Park formation was later deposited. (See pl. 35.)

CLIMATIC CHANGE AND THE BISHOP CONGLOMERATE

For simplicity the origin of the Gilbert Peak surface has thus far been considered wholly apart from its gravel capping. Like pediments now being formed in arid regions, however, it undoubtedly had a veneer of sand and gravel, which was being moved intermittently by the streams as they shifted their courses. The depth of this alluvial gravel depended on the vigor of the streams and must have varied from place to place. According to Bryan,[33] pediments in southern Arizona while being formed "may have a shifting mantle of alluvium from 18 inches to 5 feet thick." Whether the gravel on the Gilbert Peak surface while it was being cut was of this order of thickness is unknown, but it was certainly not as thick as the Bishop conglomerate (100 feet or more) that now covers much of the pediment. So great a thickness of conglomeratic alluvium could not have been scoured to the rock basement by streams of ordinary size like those which emerged from the Uinta Range during the Bishop epoch. Even the Colorado at flood stage scours its channel only about 40 feet below its normal depth.[34] Thus the Bishop conglomerate indicates a change in the regimen of the streams that produced the Gilbert Peak surface. For a long time they persisted in their habit of lateral wandering, neither aggrading nor degrading their beds. Then they began to deposit ever more and more of their load on the pediment, and ultimately they built up a great sheet of coarse alluvium, the Bishop conglomerate. This conglomerate presumably includes at its base the original gravel veneer of the pediment, though that was not recognized in the field as a distinct lithologic unit. The conglomerate as a whole fills in the deepest concavity in the profile of the Gilbert Peak surface. As shown in figure 13, this conglomerate filling flattens the gradients of the streams from their sources down to the point of maximum departure between the surface of the gravel and the underlying rock-cut surface, but downstream from that point it steepens the gradients of the streams through large parts of their courses where they had formerly been engaged chiefly in lateral corrasion.

These changes in the gradient by aggradation seem most reasonably interpreted as a response to a shift in the climate toward still greater aridity. Diminished rainfall would decrease the volume and hence the capacity of the streams, which, by reason of their continued tendency to maintain a balanced or graded condition, would drop some of their load and build up their gradients so as to increase the velocity and tend to compensate for the loss of volume. Other factors commonly attendant upon a change to greater aridity would also accentuate the process of aggradation. After such a change the rainstorms become less frequent but correspondingly more violent. Also they are generally restricted to relatively small areas and consequently are capable of vigorous local erosion, which further tends to overload the streams. Moreover, the flood waters from torrential storms of this sort have great power, so that the material they carry has a great range in size, and, as these floods dwindle almost as abruptly as they rise, the loads they deposit are generally ill sorted. Excessive local erosion might also be aided by the decreased vegetative cover or by the change in the type of vegetation, although in a shift from semiarid or subarid to arid climate this change would perhaps be of little significance, because the vegetation characteristic of these climates does not usually afford much protection against erosion. Loss of water from the streams by evaporation and penetration into the alluvium would also enfeeble them and cause them to aggrade.

Thus, just as the characteristics of the Gilbert Peak surface agree in indicating that it was formed under a somewhat arid climate, so the characteristics of the Bishop conglomerate—namely, the poor sorting and lenticular profile in a direction normal to the mountain flank—agree in indicating a response in the regimen of the ancient streams to a change in climate

[33] Bryan, Kirk, Erosion and sedimentation in the Papago country: U. S. Geol. Survey Bull. 730, p. 59, 1923.

[34] Davis, W. M., Rock floors in arid and humid climates: Jour. Geology, vol. 38, p. 155, 1930.

toward still greater aridity. I believe, however, that although this climatic change was decisive, it probably was not of great magnitude.

The following alternative explanation for the origin of the Bishop conglomerate depends on the assumption of a rising baselevel. For example, if the Green River Basin had had no exterior drainage and the baselevel which controlled the streams that cut the Gilbert Peak surface had been the level of an alluvial plain that was being built up in the central part of the basin, then, as the plain was slowly aggraded the baselevel would rise and the sheet of alluvium expand so as to encroach farther and farther up the slope and ultimately bury the pediment beneath a cover of increasing depth. The steps in this process by which a convex suballuvial bench is developed at the outer margin of the pediment, while the mountainward portion is cut to more and more gentle slopes until it reaches a profile of equilibrium, have been analyzed by Paige [35] and Lawson.[36] Although this continuous process of aggradation might account for the Bishop conglomerate without assuming any change from the conditions that produced the pediment, certain characteristics of the Bishop conglomerate and the pediment seem to argue against the acceptance of such an explanation. If the pediment had been buried by the Bishop conglomerate in this way the conglomerate or its basinward alluvial equivalent should thicken progressively away from the mountains, but instead it thickens to the most concave part of the pediment's profile and then thins gradually basinward, as shown in figure 13. This basinward thinning might perhaps be due to the later erosion of the basinward alluvial equivalent, which thus left only the thinner basal conglomeratic portion. However, if the basinward parts of the pediment now remaining had been exhumed in this manner, their surfaces would probably bear remnants of the former alluvial cover and accordingly be somewhat more diversified than they are. Also if the Bishop conglomerate had been formed in consequence of a rising and expanding alluvial plain, the profile of the pediment itself should become slightly convex basinward, as is indicated by Bryan [37] for some of the pediments in southern Arizona. The remnants of the Gilbert Peak surface show no tendency to become convex, but as they represent only the portion relatively near the mountains this lack of convexity is not conclusive.

[35] Paige, Sidney, Rock-cut surfaces in the desert ranges: Jour. Geology, vol. 20, pp. 449–450, 1912.

[36] Lawson, A. C., The epigene profiles of the desert: California Univ. Dept. Geology Bull., vol. 9, pp. 30–44, 1915.

[37] Bryan, Kirk, The Papago country, Arizona: U. S. Geol. Survey Water-Supply Paper 499, pp. 100–101, 1925.

From the characteristics of the Bishop conglomerate and the debris apron around the base of Aspen Mountain Rich [38] was led to the conclusion

> that the period of planation was brought to a close by a renewal of mountain uplift during which the Uintas were greatly elevated with respect to the surrounding plains; that this period of mountain making was probably followed in this region by a change from a comparatively moist to an arid climate; and that great desert fans of gravel and sand spread out from the mountains far over the plains, while at the same time smaller fans spread out in a like manner from the monadnocks of the plains and merged with the gravels from the mountains.

I agree with Rich in thinking that the climate became more arid while the Bishop conglomerate was being formed, but there is no evidence of differential uplift of the Uinta Mountains with respect to the flanking plain. In the western part of the area remnants of the Gilbert Peak surface have a smooth unbroken profile, which extends from the crest of the range far out into the basin. (See fig. 13.) Figure 13 also shows that the Bishop conglomerate merely fills in the deepest concavity of the profile and thus steepens the gradient through the middle courses of the streams where formerly they had been planing off the pediment. Although in the eastern part of the area, to which Rich's observations were restricted, the pediment probably has been tilted, that tilting as pointed out on pages 185–187, very probably occurred after the deposition of the Bishop conglomerate rather than before.

Accordingly, it seems to me unnecessary to assume either crustal movement or a large change in the climate to account for the deposition of the Bishop conglomerate. If the smooth part of the Gilbert Peak surface is correctly interpreted as a pediment, then a moderate shift in the climate toward still greater aridity would probably be adequate to bring about the deposition of a sheet of conglomeratic alluvium agreeing in its essential features with the Bishop conglomerate.

BEAR MOUNTAIN EROSION SURFACE

FORMATION AND CHARACTERISTICS

After the deposition of the Bishop conglomerate the regimen of the streams of the region underwent a decided change. Instead of aggrading, they began to cut and trenched the Gilbert Peak pediment and its conglomeratic alluvial cover. As these streams cut downward and for a long time after they reached grade they also cut laterally. Over considerable areas in the soft Tertiary rocks they widened their valleys,

[38] Rich, J. L., The physiography of the Bishop conglomerate, southwestern Wyoming: Jour. Geology, vol. 18, pp. 619–620, 1910.

cut through the interstream divides, and integrated the flood plains into a smooth surface nearly everywhere capped with gravel. Remnants of this surface, referred to in this report as the Bear Mountain surface, are plentiful in the southern part of the Bridger Basin of Wyoming between Cedar Mountain and Muddy Creek. (See pl. 34.) A little nearer the mountains, where lateral planation was less effective, narrow remnants of the Gilbert Peak surface rise rather abruptly 400 to 500 feet above the Bear Mountain surface. (See pl. 38, *B*.) In general the remnants of the Bear Mountain surface slope northward, but in some places they slope northwestward or eastward from divides or buttes protected by the Bishop conglomerate. (See pl. 34.) But on the divide between Dry Creek and Cottonwood Creek, in T. 16 N., Rs. 111 and 112 W., about 14 miles east of the town of Lyman, several remnants of this surface slope away from a shallow valley that trends northeastward. Apparently a small mound, perhaps a remnant of a butte comparable to Sage Creek Butte, occupied the position of that depression at the time the Bear Mountain surface was cut. At later stages the remnants of the Bear Mountain surface were protected by their gravel capping, whereas the low mound, having long before lost its capping of Bishop conglomerate, was worn away more rapidly.

The Bear Mountain surface, like the Gilbert Peak surface, has a readily perceptible slope, cuts undecayed rocks, and at no place has a deep soil cover but instead has a capping of stream-worn cobbles and pebbles. Also, as on the Gilbert Peak surface, islandmounts rise from it abruptly. I therefore regard the Bear Mountain surface as a pediment formed under arid conditions probably closely similar to those that prevailed while the Gilbert Peak surface was being cut.

While the basinward portion of the Gilbert Peak surface was being dissected and the Bear Mountain surface developed, two rather large valleys, each roughly parallel to the axis of the Uinta Mountain arch, were being cut out in the postmature highland along the east end of the range. The larger of these, the Browns Park Valley, extends from the east side of Henrys Fork at a point about 5 miles south of the Utah-Wyoming boundary eastward about 80 miles to the east end of the Uinta Range. (See pls. 34, 35, and 42, *A*, and fig. 16.) In its west end the position of the valley was apparently determined by an ancient subsequent stream, which flowed eastward along the south side of the strike ridge made by the Carboniferous limestone beds where they are turned up along the Uinta flexure. Fragmentary remnants of similar subsequent stream courses in that part of the area are described on page 178. The present drainage courses run almost at right angles to the western part of the ancient Browns Park Valley, but from Burnt Fork eastward Sheep and Carter Creeks and the Green River each follow the old valley for several miles and then leave it through deep, narrow canyons. The broad east end of this valley, known as "Browns Park", is partly filled with the Browns Park formation. Apparently the ancient stream that carved out the Browns Park Valley wandered rather widely, for this valley is wide and flat-bottomed, notably in the vicinity of Flaming Gorge and in Browns Park. (See pls. 35 and 42, *A*.) Also along the south side of Browns Park the ancient stream, as it deepened the valley, cut several terraces in the Uinta Mountain group. As remnants of the Browns Park formation still lie on some of these terraces, it seems likely that the terraces were cut before the deposition of the Browns Park formation, though they might conceivably have been cut by the streams that deposited the Browns Park formation.

South of the Browns Park Valley and about 1,500 feet higher is another broad, rather flat-bottomed valley comparable to the Browns Park Valley, though

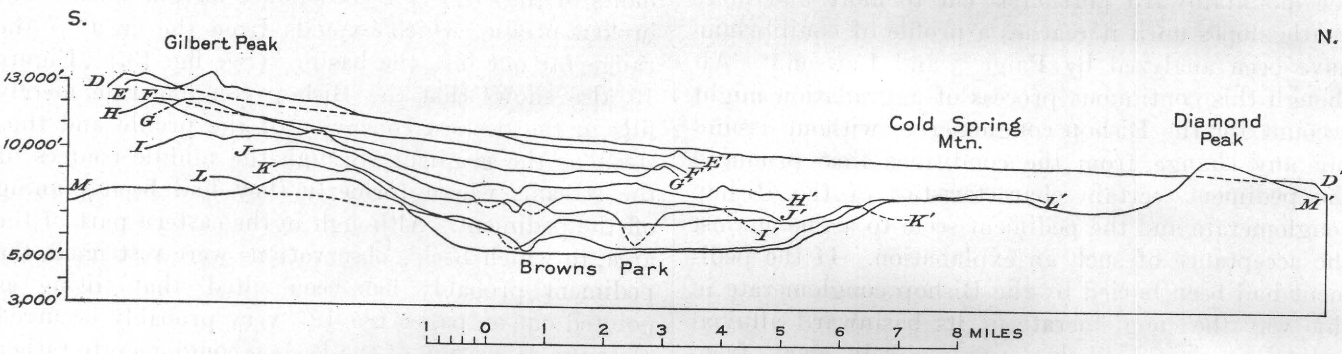


FIGURE 16.—Profiles transverse to the ancient Browns Park Valley, showing how its floor, the Bear Mountain surface, narrows and rises westward to the level of the Gilbert Peak surface along the Hickey Mountain profile which forms the back line of the diagram. The positions of the several profiles are shown on plate 34. The profile at the front of the diagram shows how the remnant of the Gilbert Peak surface on the top of Cold Spring Mountain has been faulted down and the remnant on the top of Diamond Peak has been uplifted with respect to the undeformed Gilbert Peak surface as shown in the Hickey Mountain profile. This differential movement between Cold Spring Mountain and Diamond Peak occurred by displacement along the Uinta fault, which lies between them.

smaller. Powell[39] named this "Summit Valley." It is nearly parallel to the Browns Park Valley but does not continue to the east end of the range. (See pl. 42, *A*.) Instead it turns southward along the present site of Lodore Canyon. The greater part of Summit Valley is now drained by Cascade Creek and a headwater branch, Pot Creek, though in its upper end Kettle Creek runs parallel to Pot Creek for several miles and then turns sharply northward, having been captured by Jackson Creek, which cuts through the main part of the range and joins the Green River in Browns Park. (See pl. 34.)

A surface that was comparable to the Bear Mountain surface in the western part of the area extended eastward from the mouth of the Browns Park Valley and northeastward from Cold Spring Mountain. Although this surface is at many places still buried beneath the Browns Park formation, remnants of it are exposed in the drainage basin of Powder Wash and eastward along the south side of Washakie Basin as far as Baggs, Wyo. (See pl. 34.) At the east end of Cold Spring Mountain are a few remnants which, though small, are significant in the interpretation of the erosional history. One of these remnants rises gently southward, truncates the steeply upturned Mesozoic and Paleozoic rocks, and then ends abruptly against the flank of Cold Spring Mountain in the southern part of T. 11 N., R. 101 W., Moffat County, Colo. This remnant is apparently undisturbed, and its gentle slope up to the mountain face is original. (See pl. 41, *A*.) As the surface is traced southeastward it begins to show the effect of later warping, and within a few miles, where it crosses Vermilion Creek, the surface dips 13° S. toward the Uinta Mountains. (See pl. 40.) From Vermilion Creek the Bear Mountain surface extends southeastward along and north of the Axial Basin anticline for about 63 miles, nearly to Craig, Colo. Although throughout this eastern area it is concealed beneath the Browns Park formation, it seems rather probable that, like the Browns Park formation, it has been flexed up along the margins, so that in a general way it now has the structure of a broad, shallow syncline. Along the south side of Washakie Basin the Bear Mountain surface is buried beneath the Browns Park formation. However, as the basal conglomerate which covers the Bear Mountain surface is exposed in numerous places it is evident that the Bear Mountain surface in that locality has been warped and faulted down into a broad asymmetric syncline. This structure is shown by contours on plate 34.

[39] Powell, J. W., Exploration of the Colorado River of the West, p. 161, 1875.

RELATION TO THE GILBERT PEAK SURFACE

The part of the Bear Mountain surface that extends eastward and northeastward from Cold Spring Mountain cannot be correlated by direct tracing with that part of the Bear Mountain surface along the north flank of the Uinta Mountains farther west. However, this correlation seems probable because of the analogy between the features in the two areas. The small portion of the Bear Mountain surface that flanks the east end of Cold Spring Mountain in T. 11 N., R. 101 W., lies about 500 feet below the mountain's nearly level top (which is a remnant of the Gilbert Peak surface); it ends abruptly against the mountain flank and is covered with a moderate thickness of conglomerate. Comparably, the remnants of the Bear Mountain surface in the western area lie 400 to 500 feet below the Gilbert Peak surface represented by the flat tops of buttes and narrow divides protected by the Bishop conglomerate; moreover, they are covered by a moderate thickness of conglomerate closely similar to that on the eastern remnant.

Furthermore, the Browns Park and Summit Valleys seem to be the counterparts of the long valleys which, in the central and western parts of the range, were cut below the Gilbert Peak surface and opened out onto the Bear Mountain surface where its pediment portion was extensively developed. (See pl. 38, *B*.) The similarity between these valleys and the Browns Park and Summit Valleys, however, was almost completely destroyed by the glaciers that later eroded the western valleys. Nevertheless, the uppermost portions of the sides of these old valleys on the north flank of the range are apparently preserved in a few places, as along the east side of the Middle Fork of Beaver Creek. The valley of the westernmost branch of Burnt Fork apparently was not glaciated and may also represent the form of these older valleys during the Browns Park epoch. (See pl. 34.)

In suggesting that the Bear Mountain surface is younger than the Gilbert Peak surface I differ with the interpretation offered by Sears,[40] that the Bear Mountain and Gilbert Peak (Bishop of Sears) surfaces are probably equivalent. The principal evidence upon which I base my belief is found in the small remnant of the Bear Mountain surface abutting the east end of Cold Spring Mountain in T. 11 N., R. 101 W., Moffat County, Colo., in a normal flanking relation at an altitude about 500 feet below that of the top of the mountain. But the strength of this evidence rests largely upon the identification of the

[40] Sears, J. D., Relations of the Browns Park formation and the Bishop conglomerate and their role in the origin of Green and Yampa Rivers: Geol. Soc. America Bull., vol. 35, pp. 289–298, 1924.

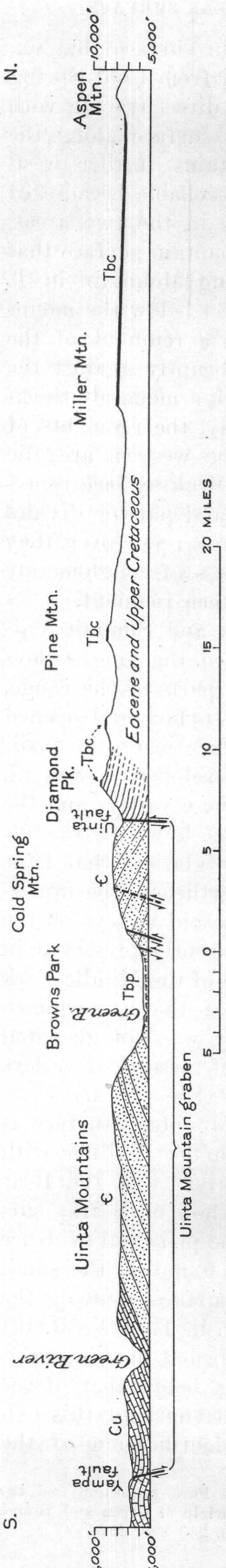


FIGURE 17.—Structure section from the Yampa fault across the east end of the Uinta Range to Aspen Mountain, showing the relation of the remnants of the Gilbert Peak surface to the down-faulted portion of the range. €, Uinta Mountain group; Cu, Carboniferous undifferentiated; Tbp, Browns Park formation; Tbc, Bishop conglomerate. (After Sears.)

nearly level top of Cold Spring Mountain as a remnant of the Gilbert Peak surface. Of this identification, however, I feel fairly confident, having traced the surface eastward from the western part of the area, where it is better preserved and not faulted. The level top of Cold Spring Mountain is believed to be the eastward extension of that part of the Gilbert Peak surface which passes through the tops of Goslin and Wheeler Mountains, though it lies somewhat lower than they do, having been dropped down into its present position by faulting. (See pl. 41, *A*, and figs. 16 and 17.)

Thus the analogy between the features around the east end of the Uinta Range and those farther west along the north flank suggests that the Bear Mountain surface was probably once continuous westward and was a part of the extensive pediment now represented by the Bridger and Cottonwood benches, which lie 400 to 500 feet below the Gilbert Peak surface and are therefore definitely younger than that surface or the Bishop conglomerate, which covers it. The Bear Mountain surface in the eastern part of the area, however, differs from the remnants in the western part in being generally buried beneath the Browns Park formation.

According to his interpretation that the Gilbert Peak and Bear Mountain surfaces are equivalent, Sears[41] indicated that the top of Cold Spring Mountain must once have stood considerably higher than Diamond Peak if the Bear Mountain surface extended northward from the flank of Cold Spring Mountain and coincided with the top of Diamond Peak. (See fig. 18.) That concept would mean that when the east end of the Uinta Range collapsed Cold Spring Mountain must have been dropped about 2,200 feet—a figure representing the present difference in altitude between the top of Cold Spring Mountain and the top of Diamond Peak (1,700 feet) plus the interval between the top of Cold Spring Mountain and the Bear Mountain surface (500 feet). (See fig. 18.) But in the light of the recent field work to the west Mr. Sears agrees with my interpretation that the top of Cold Spring Mountain and the top of Diamond Peak are both remnants of the Gilbert Peak surface, and that the Bear Mountain surface is younger and lies about 500 feet below the tops of these two mountains. Hence it follows that Cold Spring Mountain was dropped only about 1,700 feet—that is, the present difference in altitude between the top of Cold Spring Mountain and the top of Diamond Peak plus the amount that the original surface sloped northward from Cold Spring Mountain to Diamond Peak. (See fig. 18.)

BROWNS PARK FORMATION

At the base of the Browns Park formation near the east end of the Uinta Mountains is a conglomerate consisting largely of cobbles of Uinta Mountain quartzite. Overlying the conglomerate are beds of chalky white and grayish-white sandstone, tuffaceous sandstone, and beds of glass tuff that have an aggregate thickness of at least 1,200 feet.[42] Most of the sandstone has a limy cement, is soft and friable, and is rather irregularly bedded or else massive. Locally, however, as along the south side of Washakie Basin and a few miles northwest of Craig, Colo., the formation is highly cross-bedded and suggests a wind-blown deposit. At these places the false bedding planes are characterized by extreme variability both in length and direction of dip. The dip ranges from a few degrees to 32°, but dips of 25° to 32° are common. Mechanical analysis of the sand from the upper part of the Browns Park formation north of Powder Wash shows that it is exceptionally well sorted, nearly 90 percent of it being between 0.25 and 0.5 millimeter in diameter. (See fig. 19.) In degree of sorting this sample agrees with the group of sands chosen by Wentworth[43] as typical of wind-blown material. On the other hand, the skewness of the pyra-

[41] Sears, J. D., op. cit., p. 297.

[42] Sears, J. D., Relations of the Browns Park formation and the Bishop conglomerate and their role in the origin of Green and Yampa Rivers: Geol. Soc. America Bull., vol. 35, p. 286, 1924.

[43] Wentworth, C. K., Method of computing mechanical composition of types of sediments: Geol. Soc. America Bull., vol. 40, pp. 787–788, 1929.

mid diagram, figure 19, is about as divergent from the group of wind-blown sands as possible. Wentworth's

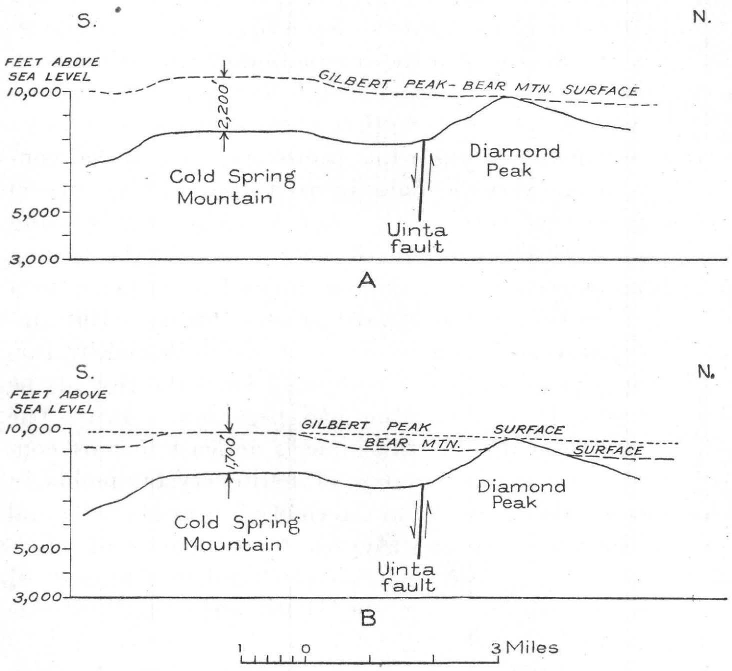


FIGURE 18.—*A*, Profile showing the difference in altitude between the present position of Cold Spring Mountain and its position before the collapse of the east end of the Uinta Mountain arch, according to the earlier view of Sears that the Gilbert Peak and Bear Mountain surfaces are equivalent. *B*, Profile showing the relative depression of Cold Spring Mountain according to the present interpretation that the Bear Mountain surface is lower and younger than the Gilbert Peak surface.

skewness coefficients for the wind-blown sands range from -1.097 to -0.957, whereas the skewness coefficient for the Browns Park sand is $+1.357$. Though the sand is remarkably uniform in size this characteristic, as Dake[44] has pointed out, is not diagnostic of wind-blown deposits; indeed, he is inclined to believe that the maximum uniformity of grain size is to be expected in marine sandstones because the depositing medium is subject to less range of velocity.

Microscopic examination of the sand shows that most of the grains are well rounded and that their surfaces are decidedly frosted and pitted. Dake[45] has also pointed out that frosting of quartz grains can be produced by wave and river action and is therefore not diagnostic of wind-blown material. He remarks, however, that the evidence seems to show that wind is probably much more efficient in producing such surfaces than any other agent we know, and "it follows, then, that these frosted grains are the best textural criterion we have of wind action on sand." Dake also states that the frosting may be produced at an earlier stage in the history of sand grains and that subsequently they may be transported and deposited from another medium. That the sand in this particular part of the Browns Park formation was not transported far from its source and may even have been frosted by the medium from which it was deposited is suggested by the fact that a small percentage of the grains have the form of short bipyramidal prisms or at least have several pyramidal crystal faces and that the crystal faces are uniformly frosted but show no mature rounding of the interfacial angles. This suggests that the sand grains were well rounded in the formations from which the Browns Park was derived and that they had been secondarily enlarged before they were reworked into the Browns Park formation.

Although none of these characteristics indicate conclusively that the Browns Park formation along the south side of Washakie Basin is a wind-blown deposit, they become somewhat more significant when taken together with the fact that several layers of wind-faceted cobbles were found just below the highly cross-bedded sandstone facies of the formation.

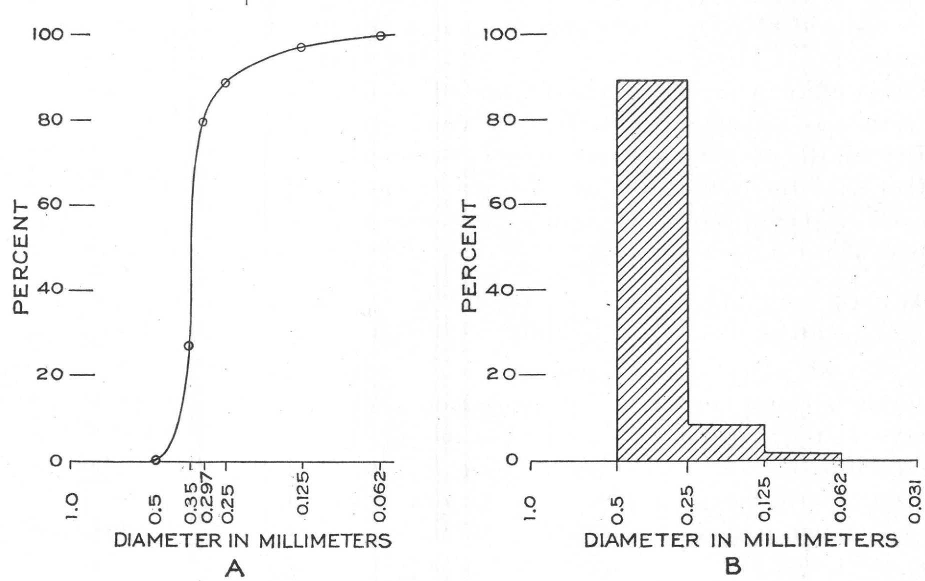


FIGURE 19.—Cumulative curve (A) and standard pyramid diagram (B) showing the distribution of grain sizes in a sample of sand from a highly cross-bedded facies of the Browns Park formation in sec. 15, T. 12 N., R. 96 W., Sweetwater County, Wyo.

The lower part of the Browns Park formation along the south side of Washakie Basin consists largely of glass tuffs. The glass in these tuffs has a refractive index ranging from a little below to a little above 1.50. With the glass is a moderate quantity of ferromag-

[44] Dake, C. L., The problem of the St. Peter sandstone: Missouri School of Mines Bull., vol. 6, no. 1, p. 167, 1921.
[45] Idem, pp. 185–186.

nesian minerals, chiefly biotite and magnetite and the accessory minerals apatite and zircon. Feldspars are rare, but grains of sanidine were found, together with plagioclase crystals that range in composition from calcic oligoclase to calcic andesine. Rounded grains of tourmaline, garnet, and other minerals not derived from tuffs indicate that these tuffs, though apparently pure, have been reworked and contain small amounts of clastic material. Likewise, many sandstone beds in the Browns Park formation in nearly all localities contain moderate admixtures of volcanic ash. Locally, the formation contains irregular beds of chert and cherty sandstone, and along the south side of Washakie Basin the cross-bedded sandstone in the uppermost part has been converted into dense quartzite.

The fact that only the part of the Bear Mountain surface in the eastern part of the area is now buried beneath the Browns Park formation is due to the collapse of the east end of the Uinta Mountain arch and its eastward extension, which, as Sears [46] has shown, let down a part of the Browns Park formation into a graben, so that it has been protected from erosion. The collapse was caused by a single large fault on the south side of the range and by distributive faulting and flexures along and near the Uinta fault on the north side. The resulting graben will be referred to hereafter as the "Uinta Mountain graben." Undoubtedly the Browns Park formation once extended over a much larger area, as is shown by its occurrence along the south side of Washakie Basin where, though it is beyond the limits of the graben, it has evidently been preserved because it occupies a structural depression. (See pl. 34.) We have no means of knowing whether it ever buried the pediment farther west along the north flank of the Uinta Range. Indeed, the only deposits resting on the conglomerate that caps those remnants are a few moraines of the earliest glacial stage. These are discussed in a later part of this report.

AGE OF THE BROWNS PARK FORMATION AND THE BEAR MOUNTAIN EROSION SURFACE

Several years ago the age of the Browns Park formation was provisionally placed by Peterson [47] between the uppermost Oligocene and middle Miocene, on the basis of a small collection of vertebrate fossils from the vicinity of Sunbeam, Colo. Additional mammalian fossils found a few years later near Greystone, Colo., however, led him to conclude [48] that the formation was somewhat younger and probably should be placed in the upper Miocene or lower Pliocene.

The Bear Mountain erosion surface is probably also of essentially this geologic age, as there is no evidence to indicate trenching or partial destruction of this surface or to indicate the lapse of a significant interval of time between the completion of the erosion surface and the deposition of the basal conglomerate of the Browns Park formation, which, in turn, is followed conformably by the white sandstone. This basal conglomerate may be only in part the shifting gravel mantle that covered the surface while it was being cut. Probably the greater part of it, like the Bishop conglomerate, was a deposit formed in response to a shift in the climate toward greater aridity. But, unlike the Bishop conglomerate, it was followed by further deposition, which continued until the rest of the Browns Park formation had been laid down. The probable aridity of this time is at least in part confirmed by the occurrence of halite crystal molds in beds of the Browns Park formation near the west end of Browns Park and also by the occurrence of wind-faceted cobbles and wind-blown sand in that part of the formation along the south side of Washakie Basin.

RELATIONS OF THE GILBERT PEAK AND BEAR MOUNTAIN EROSION SURFACES TO EROSION SURFACES IN ADJACENT DISTRICTS

I believe that at the time the Gilbert Peak surface was cut it truncated the gently warped Eocene sediments that filled the Green River Basin to a considerable depth and extended northward to the center of the basin as an unbroken plain. From the center of the basin the plain rose northward, so that it merged with the Wind River peneplain,[49] near the top of the Wind River Range. The remnants of the Wind River peneplain resemble the higher remnants of the Gilbert Peak surface, which have no conglomerate, in that they form a partly dissected bench or shoulder on each side of the Wind River Range above which rises a comparatively narrow central ridge made up of the highest peaks of the range. Similar remnants of surfaces that make flanking shoulders near the summit of other neighboring ranges, such as the Big Horn Mountains [50] and the Medicine Bow Range,[51] suggest that they also may once have been part of an extensive system of pediments cut perhaps during the same arid epoch in which the Gilbert Peak and Wind River surfaces were cut. Mansfield's Snowdrift peneplain,[52] in southeastern Idaho and extreme western

[46] Sears, J. D., op. cit., pp. 290-298.

[47] Peterson, O. A., Discovery of fossil mammals in the Browns Park formation of Moffat County, Colo.: Carnegie Mus. Annals, vol. 15, p. 300, 1924.

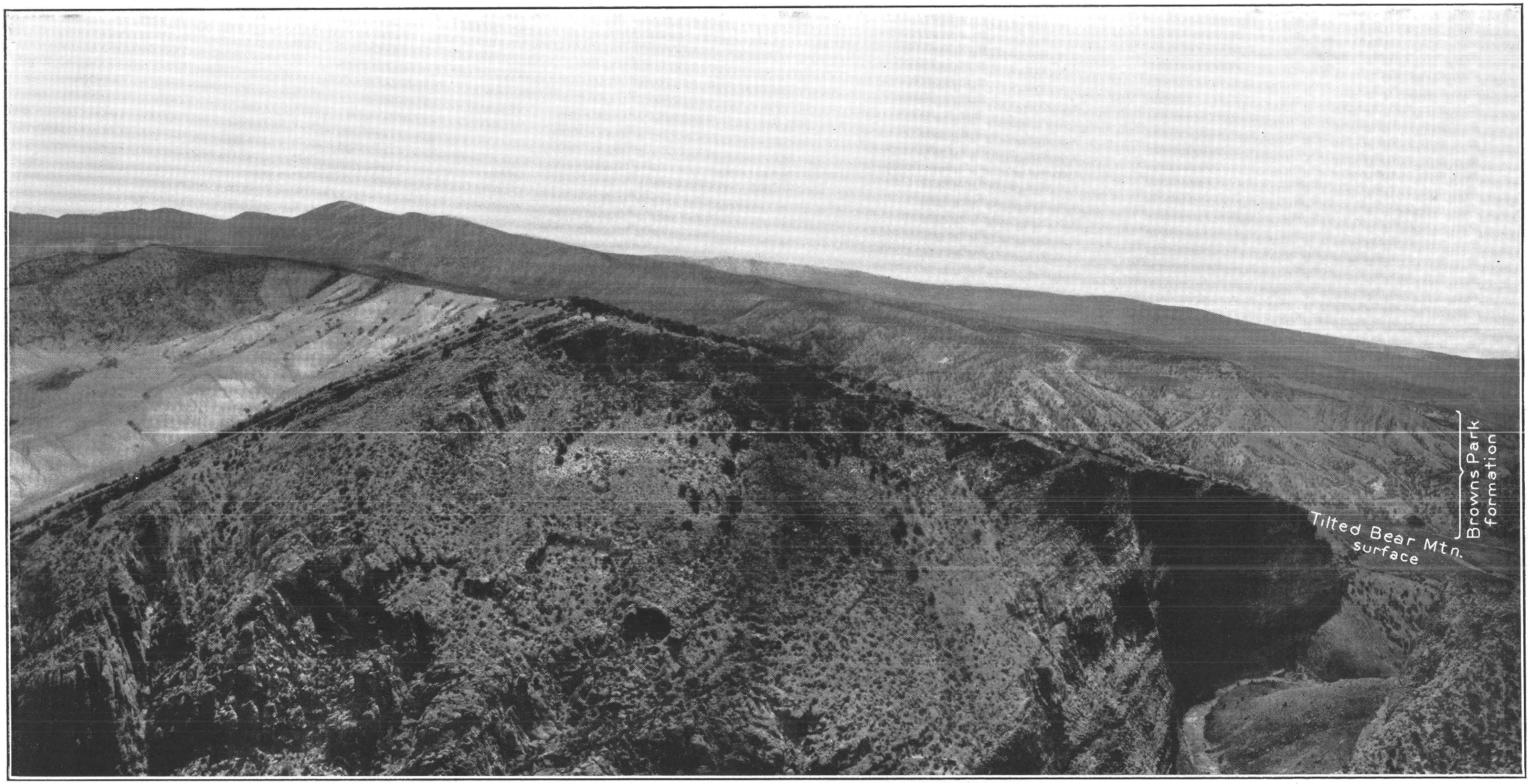
[48] Peterson, O. A., The Browns Park formation: Carnegie Mus. Mem., vol. 11, no. 2, p. 88, 1928.

[49] Blackwelder, Eliot, Post-Cretaceous history of the mountains of central western Wyoming: Jour. Geology, vol. 23, pp. 193-202, 1915.

[50] Darton, N. H., Geology of the Bighorn Mountains: U. S. Geol. Survey Prof. Paper 51, pls. 8, *A*, 27, *A*, 30, and 31, *A*, 1906.

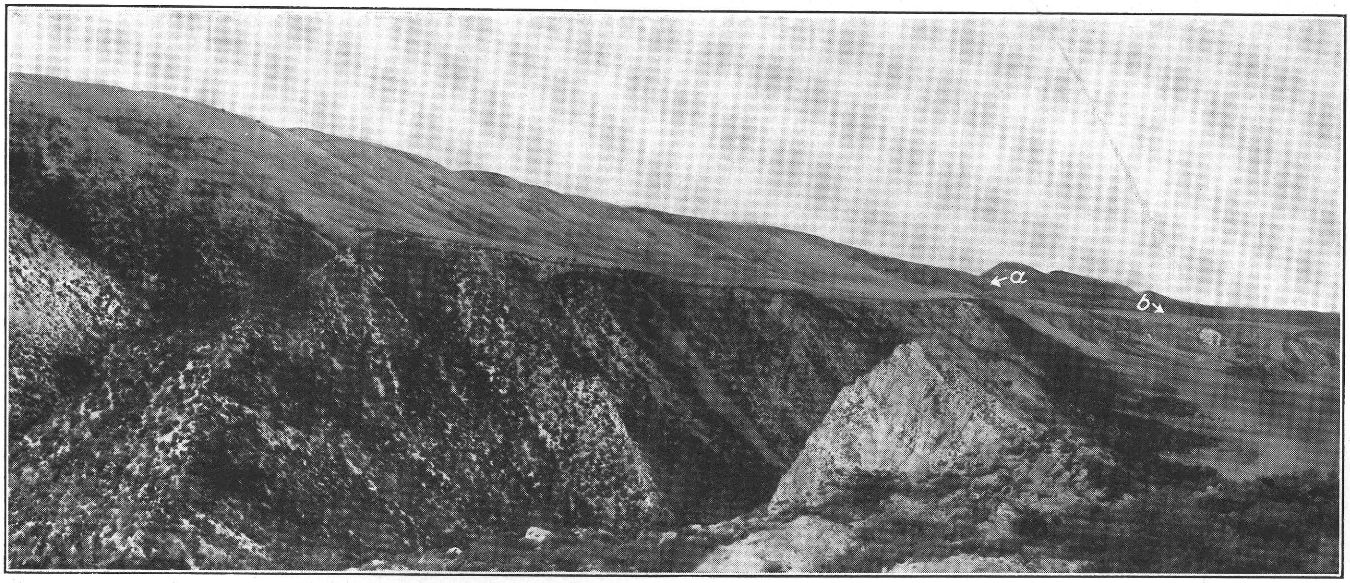
[51] Blackwelder, Eliot, Cenozoic history of the Laramie region: Jour. Geology, vol. 17, pp. 431-432, 1909.

[52] Mansfield, G. R., Geography, geology, and mineral resources of part of southeastern Idaho: U. S. Geol. Survey Prof. Paper 152, pp. 14-15, 112, 1927.



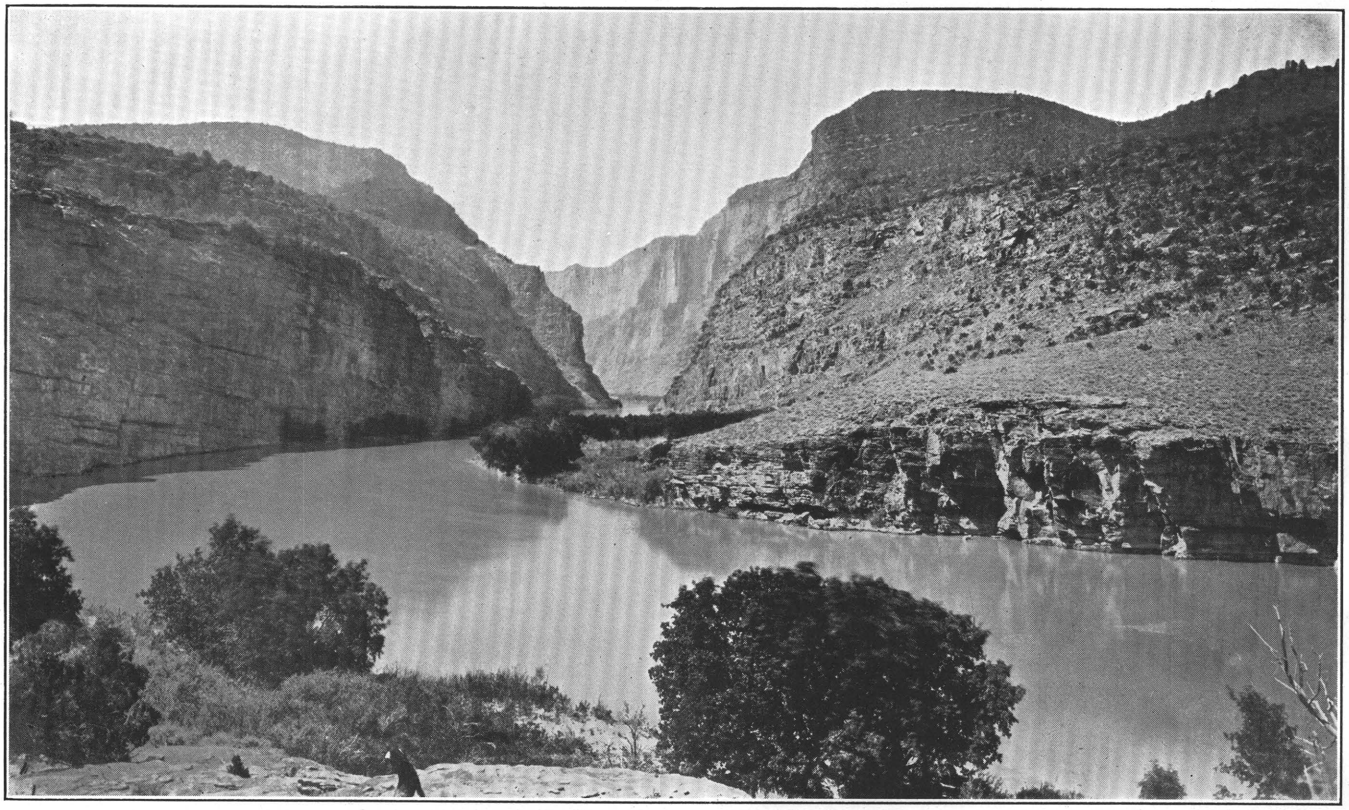
VIEW EASTWARD AND SOUTHEASTWARD ACROSS VERMILION CREEK, IN SEC. 36, T. 10 N., R. 101 W., MOFFAT COUNTY, COLO., SHOWING THE BEAR MOUNTAIN SURFACE TILTED ABOUT 13° SW. AND TRUNCATING THE MESOZOIC AND PALEOZOIC ROCKS, WHICH DIP STEEPLY NORTHEASTWARD.

At the canyon of Vermilion Creek the Bear Mountain surface has no conglomerate or other covering, but a little way to the east and to the south it passes beneath the Browns Park formation and its basal conglomerate. The dip of the beds in the Browns Park formation coincides closely with the inclination of the erosion surface. Photograph by J. D. Sears.



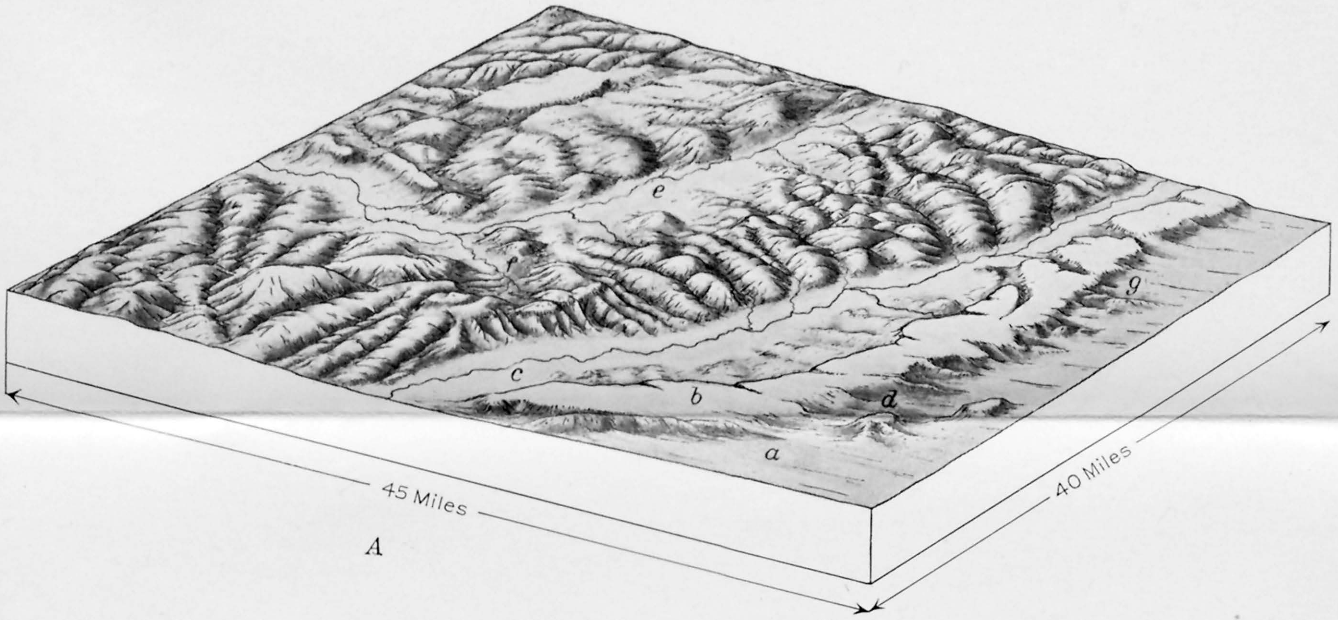
A. VIEW NORTHWESTWARD ACROSS THE NORTH END OF IRISH CANYON, SHOWING A SMALL UNDISTURBED REMNANT OF THE BEAR MOUNTAIN SURFACE TRUNCATING THE UPTURNED MESOZOIC AND PALEOZOIC ROCKS AND ABUTTING THE NORTH SIDE OF COLD SPRING MOUNTAIN, IN SEC. 33, T. 11 N., R. 101 W., MOFFAT COUNTY, COLO.

The skyline in the left half of the view marks the top of Cold Spring Mountain, a remnant of the Gilbert Peak surface. At *a* the Weber quartzite makes small monadnocks or island-mounts that rise above the Bear Mountain surface; at *b* the surface passes beneath beds of the Browns Park formation.



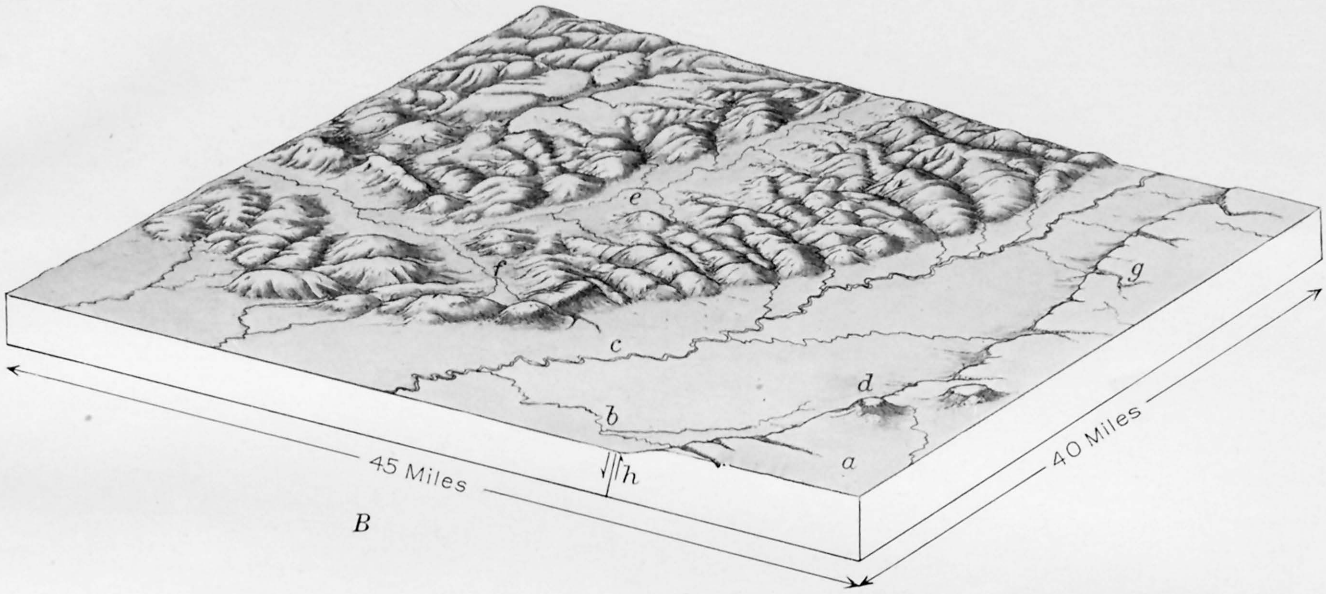
B. THE GREEN RIVER ENTERING THE UINTA RANGE AT THE GATE OF LODORE.

Shows the massive wall of the Uinta Mountain group (†Uinta quartzite of previous reports) as it rises from the river level along the south side of Browns Park. The quartzite beds dip gently southward on the south limb of the main Uinta Mountain arch. Photograph by J. K. Hillers.



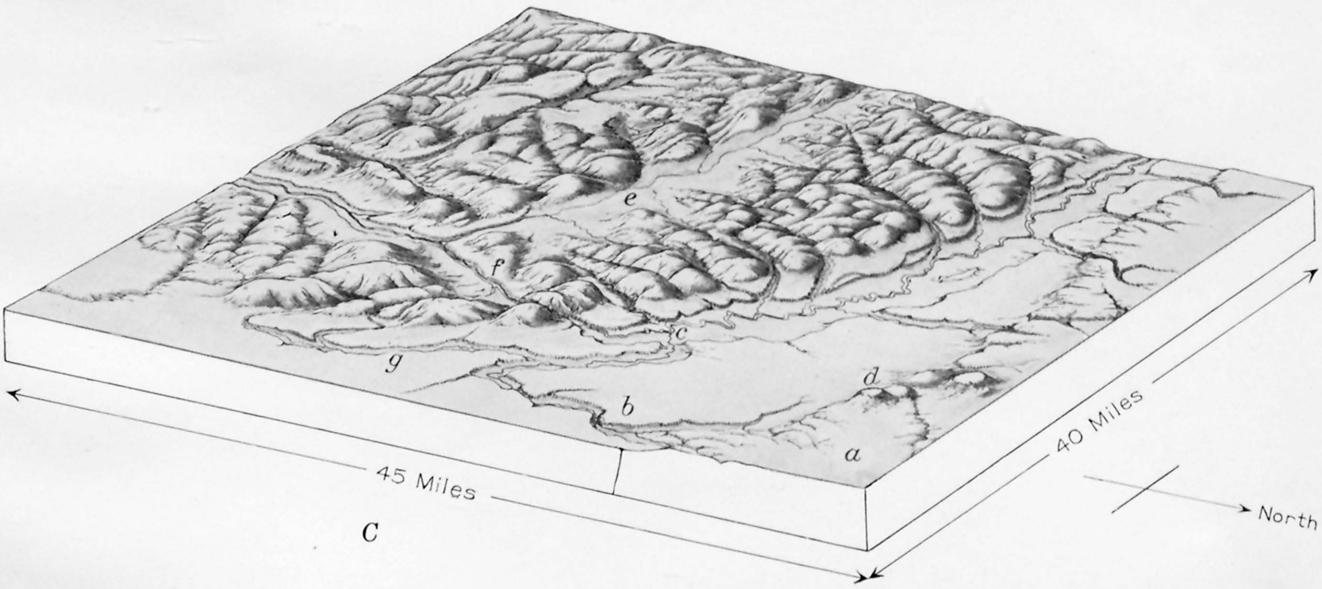
A. BLOCK DIAGRAM SHOWING THE PROBABLE TOPOGRAPHY OF THE EAST END OF THE UINTA RANGE AFTER THE EROSION OF THE BEAR MOUNTAIN SURFACE (*a*) AND THE BROWNS PARK VALLEY (*c*) BUT BEFORE THE DEPOSITION OF THE BROWNS PARK FORMATION.

The diagram also shows Cold Spring Mountain (*b*), Diamond Peak (*d*), Cascade Creek and Summit Valley (*e*), Lodore Branch of Cascade Creek and site of Lodore Canyon (*f*), and Red Creek (*g*).



B. BLOCK DIAGRAM SHOWING THE EAST END OF THE UINTA RANGE AFTER THE BROWNS PARK VALLEY HAD BEEN FILLED WITH THE BROWNS PARK FORMATION AND AFTER THE EAST END OF THE RANGE HAD COLLAPSED TO FORM THE UINTA MOUNTAIN GRABEN AND THE GREEN RIVER (*c*) HAD BEEN DIVERTED INTO THE BROWNS PARK VALLEY.

In the foreground the trace of the Uinta fault (*h*) is shown by the southward-facing escarpment. Lodore Branch of Cascade Creek (*f*) is shown about to capture the Green River (near *c*) and divert it southward along its own course. Cold Spring Mountain is buried beneath the Browns Park formation, and Vermilion Creek has established its course across the east end of this mountain near *b*. The diagram also shows the Bear Mountain surface (*a*), Diamond Peak (*d*), Cascade Creek and Summit Valley (*e*), and Red Creek (*g*).



C. BLOCK DIAGRAM SHOWING THE EAST END OF THE UINTA RANGE AFTER THE GREEN RIVER (*c*) HAD BEEN DIVERTED SOUTHWARD BY CAPTURE SO AS TO OCCUPY THE OLD VALLEY OF LODORE BRANCH OF CASCADE CREEK (*f*) AND CASCADE CREEK.

The river has entrenched itself in the soft beds of the Browns Park formation and thus accelerated the dissection of the adjacent region. Vermilion Creek at *b* has discovered Cold Spring Mountain, through which it has begun to cut Irish Canyon. Both Vermilion Creek and Cottonwood Creek (*g*) have changed their courses in response to the diversion of the Green River. In this diagram also are shown the partly dissected Bear Mountain surface (*a*), Diamond Peak (*d*), and Cascade Creek in Summit Valley (*e*).

Wyoming, may also belong with this group of surfaces, though its remnants do not flank a range whose central peaks rise above it.

The possible contemporaneity of these several subsummit surfaces seems rather likely. All except the Snowdrift peneplain apparently reached about the same stage in the geographic cycle, as is shown by the general similarity of topography along and near the crests of the ranges, despite the diversity of rock types and structure in the different ranges. Moreover, if, as I believe, the large basins between these ranges were at that time filled to a considerable depth with early Tertiary deposits, it seems that the long arid epoch and the long-continued conditions of stability necessary for the development of so extensive a surface as the Gilbert Peak surface would be rather likely to have a regional effect, so that the streams of other neighboring ranges would produce similar surfaces near the crests of the ranges.

No fossils have yet been reported from the Bishop conglomerate, but the evidence now available indicates that the Gilbert Peak surface is either Oligocene or Miocene in age. It truncates the latest Eocene rocks, which are gently deformed, and yet it is distinctly older than the Bear Mountain surface, which is probably either late Miocene or early Pliocene. This conclusion agrees with Blackwelder's opinion [53] that the Wind River peneplain is younger than the mid-Tertiary deformation (which presumably deformed the Eocene rocks of the Green River Basin) but differs from his conclusion that the Wind River peneplain is probably of Pliocene age. The probable length of time necessary to dissect the Gilbert Peak surface and cut the Bear Mountain surface suggests that the Gilbert Peak surface may be considerably older than the Bear Mountain surface, though this sort of time evaluation is decidedly unsafe.

It is not clear to me which of Blackwelder's younger surfaces in the Wind River Range [54] should be correlated with the Bear Mountain surface of the Uinta Range. I am inclined to believe, however, that the Bear Mountain surface may be equivalent to Westgate and Branson's plain no. 3,[55] at the southeast end of the Wind River Range, where that plain appears to pass beneath beds of white to light-gray tuff and fluviatile deposits strikingly similar in general appearance to the Browns Park formation.

The fact that the tuffs in these deposits near the Wind River Range contain two rather distinctive varieties of hornblende that were also found in the tuffs of the Browns Park formation in Browns Park strengthens the suggestion that the two formations may be correlative. One variety of hornblende is apparently sodic and is moderately pleochroic (X=light yellowish green, Y=green, Z=light blue). The other hornblende is basaltic, has an extinction angle=0 and is strongly pleochroic (X=bright brownish yellow, Y=brown, Z=dark reddish brown).

COLLAPSE OF THE EAST END OF THE UINTA MOUNTAIN ARCH

During the deposition of the Browns Park formation the east end of the Uinta Mountain arch began to fail. A local angular unconformity within the Browns Park formation a few miles west of Lodore post office shows that the floor of Browns Park Valley was dropped slightly with respect to Cold Spring Mountain. But the major collapse of the arch, which occurred after the deposition of the Browns Park formation, involved the whole east end of the Uinta Range and a considerable area of country eastward into Colorado and Wyoming. Sears [56] has presented fully the evidence for this collapse and described the extent of the resulting graben. He summarized this graben movement as follows:

> The collapse was caused by a single large fault on the south [the Yampa fault of Powell; see fig. 17 and pl. 34], by flexures and distributive faulting on the north, by tilting and some faulting on the east, and by tilting on the west. Along the margins of the graben the Browns Park formation was given an inward dip by upward drag on the faults. As far east as Cedar Mountain [57] the Browns Park formation was tilted westward toward the drag syncline which lies just north of the Yampa fault. Guided by this sloping surface and this syncline, the drainage of the Axial Basin anticline (the eastward extension of the Uinta Mountain arch) naturally formed a westward-flowing major stream—Yampa River. Its course over the covered portions of Cross and Juniper Mountains was accidental.

TILTING OF THE MILLER MOUNTAIN BLOCK

The subsidence of the east end of the Uinta Mountains may have been genetically related to the uptilting of the Miller Mountain block, which extends northward from the Uinta fault as far as Aspen Mountain and includes Pine Mountain, Little Mountain, and Miller Mountain. (See pl. 36, *B*.) This genetic relation between the subsidence of one block and the tilting of an adjacent block is purely speculative, yet it was observed that the maximum northward tilt of the Miller Mountain block seems to be in the vicinity of Diamond Peak and Pine Mountain and that the tilt seems to diminish westward, so that in the vicinity of Cedar Mountain no abnormal northward slope of the

[53] Blackwelder, Eliot, Post-Cretaceous history of the mountains of central-western Wyoming: Jour. Geology, vol. 23, pp. 205–207, 1915.

[54] Idem, pp. 309–316.

[55] Westgate, L. G., and Branson, E. B., The later Cenozoic history of the Wind River Mountains, Wyo.: Jour. Geology, vol. 21, pp. 148–151, 1913.

[56] Sears, J. D., Relations of the Browns Park formation and the Bishop conglomerate and their role in the origin of Green and Yampa Rivers: Geol. Soc. America Bull., vol. 35, pp. 287–298, 1924.

[57] Not the Cedar Mountain mentioned elsewhere in this report but a lava-capped butte near Craig, Colo.

erosion surface is discernible. Parallel with this diminution of tilt the Uinta Mountain graben is deepest adjacent to Diamond Peak or somewhat east of it and diminishes in depth westward so that it is not appreciable in the vicinity of Phil Pico Mountain, which is a few miles southeast of Cedar Mountain. Eastward from Diamond Peak the relation between uptilt and graben movement is not evident because the surfaces are deformed and the existing remnants are too widely separated.

If the uplift of one block and the subsidence of the other were genetically related the movements of both blocks were probably nearly contemporaneous—that is, later than Browns Park in age. There appears to be, however, no way of telling which was the active block. As there is no evidence in the western part of the area of faulting or warping since the Gilbert Peak surface was formed, a comparison of the profile of the Gilbert Peak surface there—for example, the Hickey Mountain profile, which runs along the divide between Henrys Fork and the East Fork of Smith Fork—with the profile of the Gilbert Peak surface on the Miller Mountain block (fig. 20) should afford a measure of the tilt of the Miller Mountain block. This comparison is shown in figure 21, where both profiles are plotted with much exaggerated vertical scales so as to bring out their curvature. In making this comparison it was assumed that before tilting, the surface of the Miller Mountain block had the same gradient and curvature as the Hickey Mountain profile. Very likely this was not strictly true, because this particular part of the surface, as pointed out below, was probably formed with an originally steeper slope. Nevertheless, the difference in original gradient and curvature on two such smooth portions of the ancient plain, which are capped with a like amount of conglomerate of the same coarseness and structure, was probably not very great. In order to compare the average gradients of these profiles they were shifted until they fitted. Accordingly it was found that the Miller Mountain profile and the Hickey Mountain profile are exactly coincident if the point on the Miller Mountain profile whose altitude is 9,600 feet is superposed on the 9,050-foot point of the Hickey Mountain profile. But in order to make the curves fit, it was necessary to tilt one or the other a considerable amount from its natural position. As the field evidence indicates that the Gilbert Peak surface along the Hickey Mountain profile has probably not been disturbed since it was formed, this tilting is taken as an approximate measure of the amount the Miller Mountain bench has been inclined northward. Over the 19.6 miles of the Miller Mountain profile the average gradient is 102 feet to the mile, whereas over the corresponding length of the Hickey Mountain profile the average gradient is only 69 feet to the mile. According to these gradients the south end of Pine Mountain, at the south end of the Miller Mountain profile, was lifted about 570 feet, or, in round numbers, 600 feet, with respect to the north end of the Miller Mountain profile, which is in the low sag just south of Aspen Mountain.

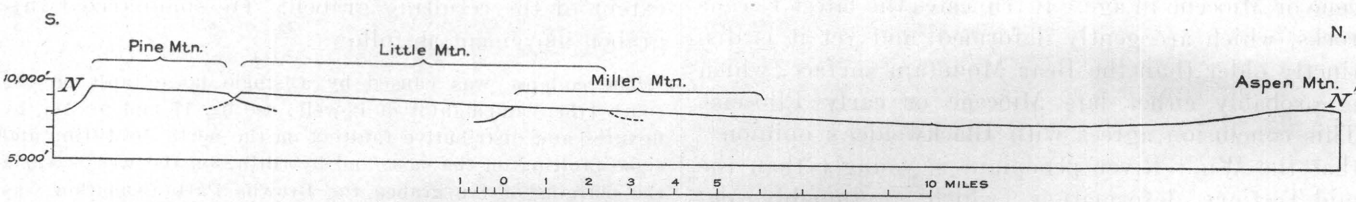


FIGURE 20.—The Miller Mountain profile, a composite profile along the line N–N′ of plate 34, showing remnants of the Gilbert Peak surface projected laterally into the plane of the section.

Rich [58] thought that the Gilbert Peak erosion surface east of the Green River had a steeper slope than would be expected of a peneplain. But at that time the concept of pediments and their steeper original slopes was not widely known. Believing that the present gradient was probably necessary to account for the transportation of the cobbles and large boulders of the Bishop conglomerate, he concluded that the Gilbert Peak surface or peneplain had been tilted up along with an uplift of the Uinta Mountains just prior to the deposition of the conglomerate. But, as noted above, the Bishop conglomerate has essentially the same coarseness, structure, and thickness farther west along Henrys Fork, on remnants of the Gilbert Peak surface that have considerably lower gradients and apparently have not been disturbed by faulting or warping since their formation. Accordingly I think it probable that the Miller Mountain bench acquired at least a part of its steeper northward slope after the deposition of the conglomerate and probably at the time the east end of the Uinta Range collapsed.

Although it appears that the Miller Mountain block has been tilted since the deposition of the Bishop conglomerate, that portion of the pediment between Aspen Mountain and the Uinta Range—that is, along the Miller Mountain block—probably was not cut down as rapidly as the pediment on each side, where no massive island-mount obstructed the drainage. Thus this portion of the pediment may have had a somewhat

[58] Rich, J. L., The physiography of the Bishop conglomerate, southwestern Wyoming: Jour. Geology, vol. 18, pp. 617–618, 1910.

steeper original northward slope than the pediment on each side. The curving strike of the 8,500-foot contour on Little, Miller, and Rife Mountains and the strike of the contours on Pine Mountain suggest that the original slopes were radial from a point near the south end of the line of profile N–N′ on plate 34 and that the original surface there was broadly fan-shaped. Though this part of the pediment has the form of a very flat cone, it has a remarkably smooth surface and evidently was cut by the lateral planation of streams in the same manner as the pediment farther west. If it had been cut by a stream that emerged from the mountains near the highest part of the fan—that is, somewhere along the line of profile N–N′—it would be analogous to the rock-cut fans described by Johnson.[59] That one or more streams emerged from that particular part of the range and flowed out over Little, Miller, and Pine Mountains, at least while the uppermost part of the Bishop conglomerate was being formed, is practically certain. The upper part of the Bishop conglomerate on these three mountains was derived almost exclusively from the schists of the Red Creek quartzite, whose only outcrop in the Uinta Range is in the vicinity of Red Creek, about 7 miles south-southwest from the south end of the line of profile N–N′.

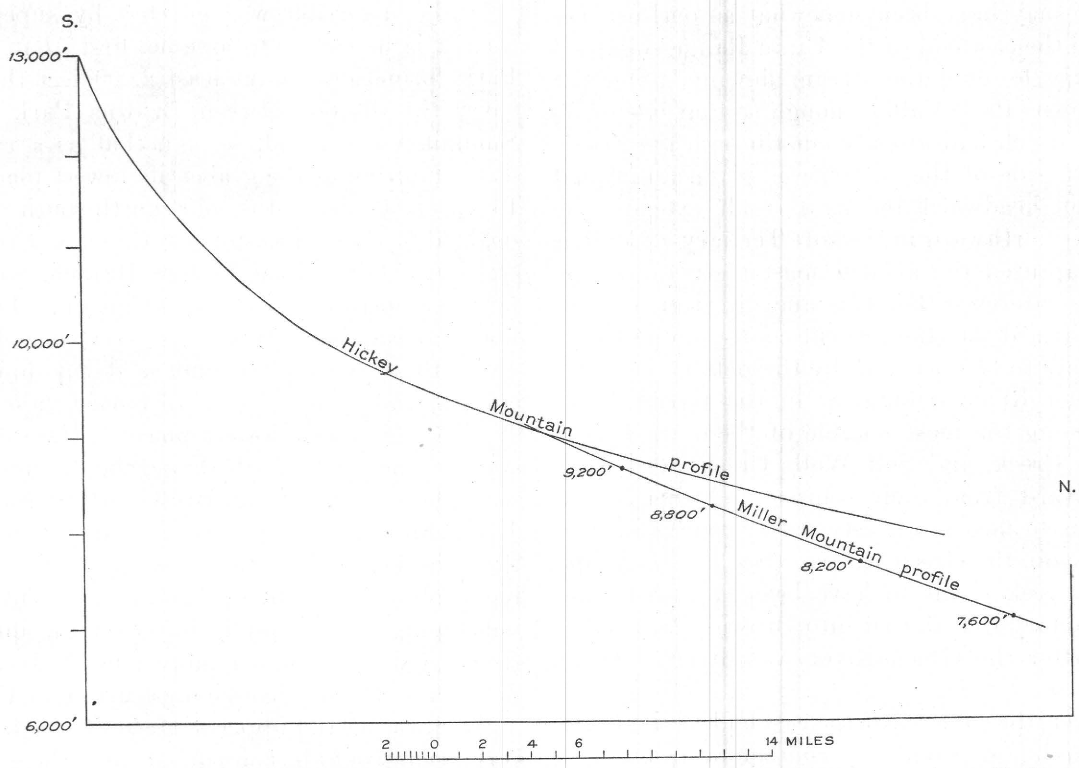


FIGURE 21.—Miller Mountain profile shifted so that its curvature agrees with the curvature of the Hickey Mountain profile, in order to compare the slopes of the two profiles.

Nevertheless, the somewhat fan-shaped form of this part of the pediment may be due wholly to the presence of the large obstruction offered by Aspen Mountain, which must have deflected the streams from the Uinta Range so that they were forced to flow at one time northeastward and at another time northwestward to pass around it. Such a deflection of streams that were actively cutting laterally and therefore continually shifting their courses would of necessity give rise to a cut surface shaped somewhat like a fan. Whether the streams emerging from the Uinta Range could have cut a rock surface having this form without the aid of a large island-mount is not evident from my studies in this area.

MAJOR DRAINAGE CHANGES

Before the east end of the Uinta Range collapsed by block faulting a master stream presumably flowed through the Green River Basin at a considerable distance north of the mountains. This stream had as a part of its tributary system the long northward-flowing streams that drained the north flank of the Uinta Range. As the divides are lowest on the east side of the basin the master stream probably flowed generally eastward and may have joined the ancestral Platte or some similar stream that flowed to the Gulf of Mexico, as suggested on page 177. It might, however, at this stage have turned southward and drained

[59] Johnson, Douglas, Rock fans of arid regions: Am. Jour. Sci., 5th ser., vol. 23, pp. 389–416, 1932.

into the Uinta Basin, although there is no direct evidence to suggest this course. But after the collapse of the east end of the Uinta Mountain arch, the ancient master stream was diverted southward from the central part of the basin to essentially the present course of the Green River, so that ultimately it entered the hard rocks of the Uinta Mountains and flowed eastward through the ancient Browns Park Valley. How this change in the major drainage of the region came about can only be surmised, as the significant features of the landscape where the Green River enters the mountains have been deeply eroded and so effaced. The sequence of events that led to this change may have been somewhat as outlined below. When the east end of the Uinta Range collapsed it apparently lowered the stream flowing along the ancient Browns Park Valley enough so that one of its tributaries, which had already cut through the divide on the north side of the valley, was given additional power to cut headward and as a result extended its course so far northward in the soft Tertiary rocks that it finally captured the ancient master stream of the basin. The inference that this ancient river was diverted southward into the present course of the Green River appears to be borne out by the pattern of many of the Green River tributaries in the Green River Basin. Among the most notable of these are Blacks Fork, Sage Creek, and Salt Wells Creek. All these flow northward from their sources and then swing around so as to flow southeastward or southwestward before they join the Green River. (See fig. 11 and pl. 34.) Red Creek seems to have been captured by a similar tributary that flowed into Browns Park either before or after the Green River was diverted to its present course.

If, however, the collapse of the east end of the Uinta Mountain arch was essentially contemporaneous with the rise of the adjacent block to the north, the rising block may have been an obstacle across the eastward or southeastward path of the ancient master stream and thus aided in diverting it southward into the Browns Park Valley at Flaming Gorge.

When the Green River first entered the Browns Park Valley it flowed on the uppermost beds of the Browns Park formation and apparently followed the course of the ancient Browns Park stream eastward beyond the east end of the Uinta Mountains, where it may either have turned southward and joined the ancestral Yampa River, which flowed westward along the south side of the mountains, or it may have flowed on eastward to join the Mississippi drainage system. But soon after it entered the Browns Park Valley it was diverted sharply southward, so that it came to run directly across the axis of the Uinta Mountain arch along the present site of Lodore Canyon, thereby decreasing its length by many miles. (See pl. 42, *C*.)

Sears considered two ways in which this diversion may have come about. He wrote:[60]

> Lodore Canyon may be due to headward erosion and piracy by a stream which ran southward in the slight depression left after filling the lower portion of Summit Valley. On the other hand, if the white sandstone (Browns Park formation) was thick enough to cover the site of Lodore Canyon, Green River may have originally turned southward along this line, being diverted by the westward tilt of the Browns Park formation. The thickness of sandstone needed to cover Lodore Canyon seems to argue against the second possibility, but the entrenched meanders of Lodore Canyon and the topography in its vicinity point to superposition rather than to headward erosion.

If the diversion was effected by superimposition, then it is necessary to assume, first, that the Browns Park formation was at least 2,000 feet thick so as to cover the divide between Browns Park Valley and Summit Valley, and, second, that as a result of the down-faulting of the graben its lowest place happened to lie just above the old north-south valley once drained by the ancestor of Cascade Creek and its tributary, here called Lodore Branch, which headed near the north end of Lodore Canyon. Then, according to these assumptions, the river turned southward along this lowest place and as it cut downward discovered and occupied the old buried valley. (See pl. 42, *B*.) That this lowest place or transverse depression in the surface of the graben nearly coincided with the contact of the Browns Park formation and Uinta Mountain group seems unlikely, for if it had, then the river in cutting downward would probably have followed this line of contact as it cut downward, developing long slip-off slopes on the quartzite and thus acquiring a much more sinuous course than it now has. If the diversion occurred in this manner, its position on the upper surface of the Browns Park formation would be consequent upon the graben movement, but the course of the river in Lodore Canyon would nevertheless be superimposed through the medium of the Browns Park formation.

Although the maximum thickness of the Browns Park formation as now known is only about 1,200 feet,[61] this can hardly be regarded as a serious obstacle to the hypothesis that the course of the Green River through Lodore Canyon is superimposed, because it is evident that the Browns Park formation has been deeply eroded and may once have been considerably thicker. A somewhat more serious objection, in my opinion, is the assumption that the lowest place in the graben should have been so situated that it would permit the river to discover 10 miles or more of a buried valley.

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[60] Sears, J. D., Relations of the Browns Park formation and the Bishop conglomerate and their role in the origin of Green and Yampa Rivers: Geol. Soc. America Bull., vol. 35, p. 303, 1924.

[61] Idem, p. 286.

Piracy by Lodore Branch, a tributary to Cascade Creek, seems a rather more likely means by which to explain the course of the Green River through Lodore Canyon. The present topography indicates that Summit Valley and its tributary valleys were rather wide and flat-bottomed. One of these tributary valleys headed near the north end of Lodore Canyon, and portions of it are still discernible, as shown at the letter *d* in plate 43, *B*. On the basis of these and other remnants of the former drainage system of Summit Valley plate 42, *A*, was constructed to show my conception of the topography and drainage of the region prior to the deposition of the Browns Park formation.

Plate 42, *B*, shows this same region after the Browns Park formation had filled the Browns Park Valley and after the graben movement had progressed far enough to divert the ancient master stream of the Green River Basin into the channel of the ancient Browns Park stream. Flowing at this level, the river would be an easy prey of the smaller stream Lodore Branch of Cascade Creek, whose course to one of the master streams of the Uinta Basin (perhaps the ancestral Yampa) along the south flank of the Uinta Mountains must have been considerably steeper than the long course of the Green River Basin stream either eastward to the Platte or southward around the east end of the Uinta Mountains. Once diverted into the channel of Lodore Branch, the increased gradient would have caused the new Green River to cut actively downward and form Lodore Canyon. (See pls. 41, *B*, and 42, *C*.)

This explanation calls for only a small additional thickness of the Browns Park formation and is essentially independent of any particular low place in the graben. Also, it seems more plausible to assume that the Green River came to occupy a preexistent valley along the site of Lodore Canyon by capture rather than by discovery through superimposition. Moreover, the explanation agrees with the apparent reversal of the courses of Vermilion Creek and Cottonwood Creek. (See pl. 42, *B*, *C*.)

Sears[62] and Hancock[63] have shown that the course of the Yampa River was superimposed through the Browns Park formation. Its meanders are entrenched, and it has cut narrow canyons through two dome-like mountains of hard rocks, Juniper and Cross Mountains, that rise from a lowland of the Browns Park formation. Below these canyons it enters another series of narrow canyons along the south flank of the Uinta Range, where it meets the Green River. Its present course is independent of both topography and structure. Likewise Sears[64] has shown that the course of the Green River upstream and downstream from Lodore Canyon was superimposed through the Browns Park formation. Its present course is almost independent of topography and structure. It flows in wide, well-formed meanders whose amplitude is approximately the same where the river flows through hard Uinta Mountain quartzite as where it flows through the soft Tertiary rocks. Only at one place in comparatively hard rocks do the meander loops seem to have enlarged by ingrowth or incision. At Flaming Gorge two loops of the river apparently have elongated northwestward. These loops have long slip-off slopes on the inner sides and high, steep, undercut cliffs on the outer sides. The slip-off slopes, however, nearly coincide with dip slopes of hard beds. Here the structure has evidently modified the course of the river as it cut downward, but elsewhere the river has entrenched itself in hard rocks quite independent of the structure.

But after the Green River enters Lodore Canyon it flows southward for nearly 10 miles in a course which is remarkably straight compared to its meandering habit both upstream and downstream. This suggests that the conditions controlling the river's action along this straight stretch differ from those either above or below. This portion of the river in Lodore Canyon may owe its comparative straightness to the fact that at the time of capture it had a somewhat steeper gradient than its former course. In other words, the most apparent difference between the regimen of the river in Lodore Canyon and the regimen of the river both upstream and downstream from the canyon is this probable steeper slope. Hence, as the river meanders rather widely in rocks of the same kinds above and below Lodore Canyon, it may be that the comparative absence of meanders in the canyon is determined largely by the steeper bed slope there.

That the gradient remained steep through the canyon-cutting cycle is shown by the fact that the general land surface in the Green River Basin is now roughly 1,000 feet higher than large areas of the land surface in the Uinta Basin. Moreover, this large difference in the levels of the two basins, which are not widely separated, suggests that the gradient of the Green River through Lodore Canyon may have become progressively steeper as the canyon was deepened. Accordingly the river may also have straightened itself gradually as it cut the canyon progressively deeper. This suggestion finds some support in the sculpture of the canyon walls. The upper half of some of the steepest walls show crescentic reentrants of small radius. (See

[62] Sears, J. D., Relations of the Browns Park formation and the Bishop conglomerate and their role in the origin of Green and Yampa Rivers: Geol. Soc. America Bull., vol. 35, pp. 282, 303–304, 1924.

[63] Hancock, E. T., The history of a portion of Yampa River, Colo., and its possible bearing on that of Green River: U. S. Geol. Survey Prof. Paper 90, p. 188, 1915.

[64] Sears, J. D., op. cit., p. 298.

pl. 44, *A*.) These I interpret as meander scars formed when the river was flowing at higher levels and when the regimen of the river was such that the rate of down-cutting permitted a moderate amount of lateral cutting.

MORPHOLOGIC FEATURES YOUNGER THAN THE BEAR MOUNTAIN EROSION SURFACE

The only erosion surfaces below or younger than the Bear Mountain surface which I studied are in the northwestern part of the area, along Blacks and Smith Forks of the Green River. These include the Tipperary and Lyman benches, with which have been correlated a few other unnamed remnants. (See pl. 34.) These younger surfaces are much smaller in area than the older surfaces. They are, however, degradational features formed chiefly by the lateral planation of streams. They truncate the beds of the Bridger and Green River formations, which dip gently eastward or northeastward. All are capped by gravel, which ranges in thickness from a thin veneer to 10 or 12 feet. Well-rounded cobbles of Uinta Mountain quartzite predominate, though chert and other quartzite cobbles and pebbles are moderately plentiful. The material ranges in size from coarse sand to cobbles about 6 inches in diameter. In many places, and perhaps generally, the gravel is cemented rather firmly with a white cement that resembles caliche and is manifestly secondary.

As these younger surfaces were only the moderately wide, flat bottoms of valleys at the time they were formed, they were straths.[65] Since their formation they have been trenched by the streams that cut them, and their remnants might therefore appropriately be called "strath terraces", in accordance with the nomenclature proposed by Bucher.[66]

Below remnants of the Bear Mountain surface in Tps. 14 and 15 N., R. 112 W., and the eastern part of T. 14 N., R. 111 W., small remnants of younger terraces were mapped. These terraces, however, were not correlated with one another nor with other erosion surfaces in the area. Some of them may perhaps be correlative with the Tipperary and Lyman strath terraces, though I found no evidence upon which to base such correlations.

TIPPERARY EROSION SURFACE

The older of these surfaces or straths below the Bear Mountain surface was originally much larger but is now represented by relatively narrow strath terraces—the Tipperary bench, an unnamed remnant between Spring Creek and the Bridger bench, and an unnamed remnant running down to Smith Fork between the East Fork of Smith Fork and Little Dry Creek. This surface is also represented by two small remnants that rise above the Lyman bench—one just west and the other just east of the town of Lyman. (See pl. 34.) The original strath merged upstream with the flood plains of Blacks Fork and Smith Fork and was evidently cut by Blacks Fork, Smith Fork, and the East Fork of Smith Fork, which at that time appears to have flowed nearly due north from the State boundary line along the present course of Little Dry Creek and thence on out along the Tipperary bench. (See fig. 22.)

Parts of two former stream courses are now plainly discernible on the north end of the Tipperary bench. From the eastern rim, which is the higher, the bench drops down rather abruptly to a wide tread, which in turn breaks off in a similar manner to a still lower tread on the west. The shallow troughs or stream courses lie close to the steep slopes that make the risers between the treads. The treads are about 25 feet apart at the north end of the Tipperary bench but merge upstream into a single surface. They resemble the treads on the next lower or younger surface, the Lyman bench, but differ from them in being broader and apparently independent of the dip of the beds which they truncate. These treads appear to have been formed in consequence of two successive captures of the East Fork of Smith Fork by small tributaries to the remainder of the Smith Fork drainage system.

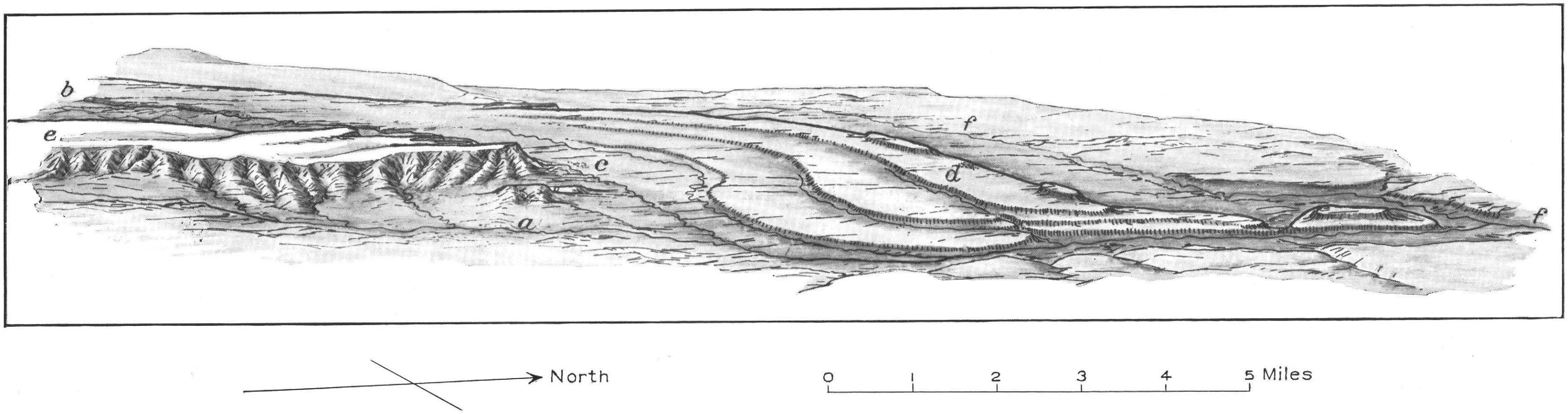
If the drainage on the Tipperary surface just prior to its dissection were as indicated in figure 22, then when the streams began cutting downward the stream fed by the West Fork of Smith Fork, Gilbert Creek, and Willow Creek would have lowered its bed more rapidly than the East Fork of Smith Fork, because its drainage area was nearly 50 percent greater. Thus small tributaries to this stream would be enabled to work headward and tap the East Fork as soon as the bed of the West Fork stream had become significantly lower than that of the East Fork. So also as the western stream lowered its bed progressively upstream, successive tributaries upstream would be able to capture and divert the eastern stream.

According to this hypothesis the easternmost or highest tread on the end of the Tipperary bench was cut when the East Fork of Smith Fork was graded with respect to the long course marked "original course" in figure 22. In like manner the two successive treads were cut when the stream became graded with respect to each new and shorter course established by the two successive captures. (See fig. 22.)

Finally the East Fork of Smith Fork was captured by another short tributary about 6 miles farther up-

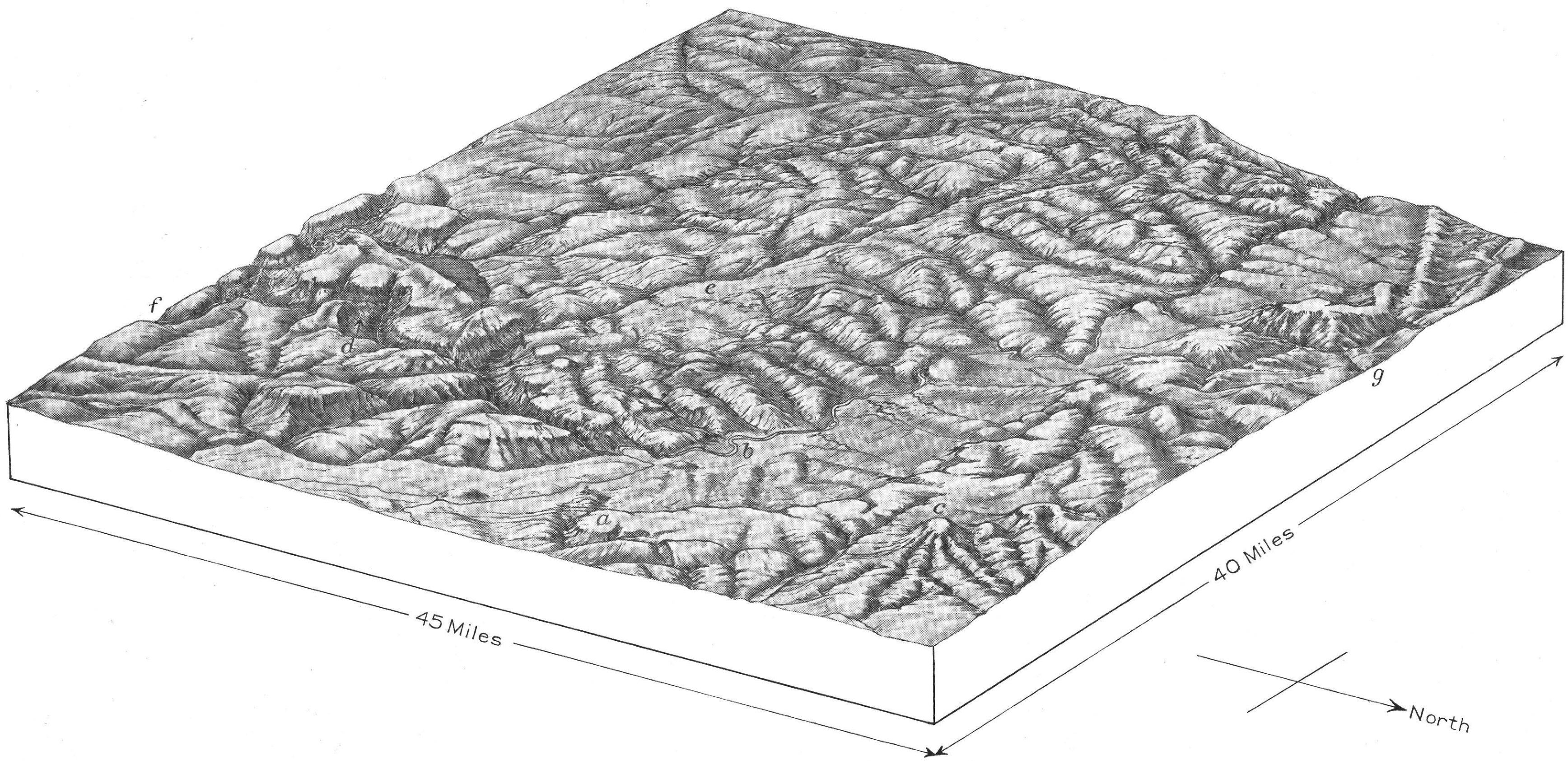
[65] Geikie, Archibald, The scenery of Scotland, 2d ed., p. 156, 1887.

[66] Bucher, W. H., Strath as a geomorphic term: Science, vol. 75, pp. 130–131, 1932.



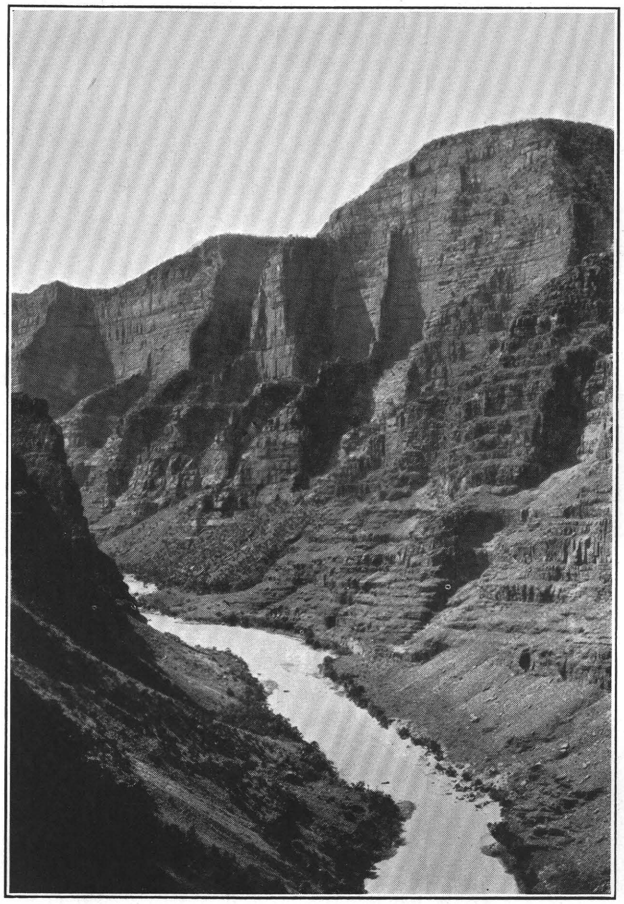
A. BLOCK DIAGRAM SHOWING THE TREADS ON THE NORTH END OF THE LYMAN BENCH BETWEEN THE TOWNS OF LYMAN (*d*) AND MOUNTAINVIEW (*c*).

The diagram also shows Little Dry Creek (*a*), Smith Fork (*b*), the Tipperary bench (*e*), and Blacks Fork (*f*).



B. BLOCK DIAGRAM SHOWING THE PRESENT TOPOGRAPHY OF THE EAST END OF THE UINTA RANGE AND THE COURSE OF THE GREEN RIVER (*b*) THROUGH BROWNS PARK IN THE FOREGROUND AND THENCE SOUTHWARD THROUGH LODORE CANYON (*d*).

The nearly flat bench or shelf that extends along the west side of Lodore Canyon for a few miles southward from *d* represents, in my opinion, a remnant of the ancient valley of Lodore Branch, which was a tributary to Cascade Creek before the Green River came to occupy the site of Lodore Canyon. The diagram also shows Cold Spring Mountain and Irish Canyon (*a*), the Green River in Browns Park (*b*), Diamond Peak (*c*), Cascade Creek in Summit Valley (*e*), Yampa River (*f*), and Red Creek (*g*). Based on topography of the Powell Survey adjusted to recent base maps of the Forest Service and the United States Geological Survey.

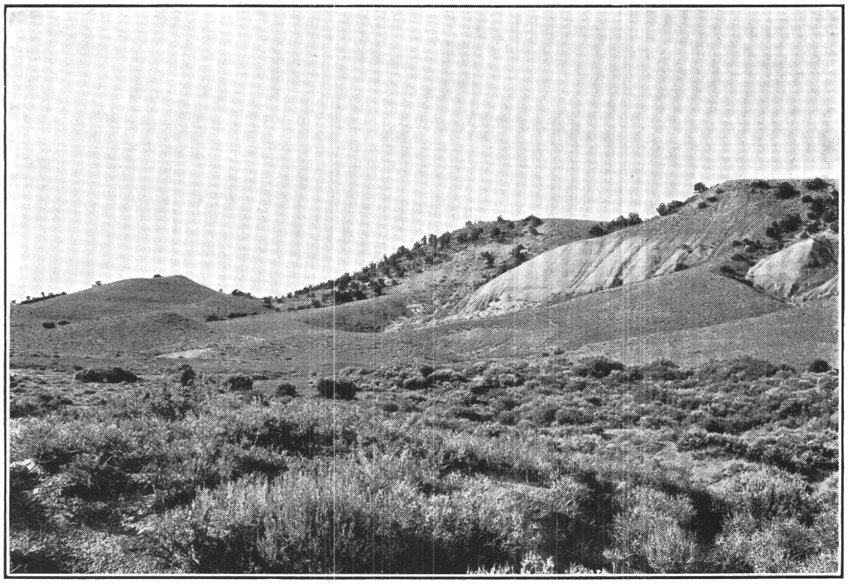


A. LODORE CANYON, SHOWING A SERIES OF CRESCENTIC REENTRANTS INTERPRETED AS MEANDER SCARS IN THE UPPER PART OF THE WEST WALL NEAR THE NORTH END.

Photograph by James Gilluly.

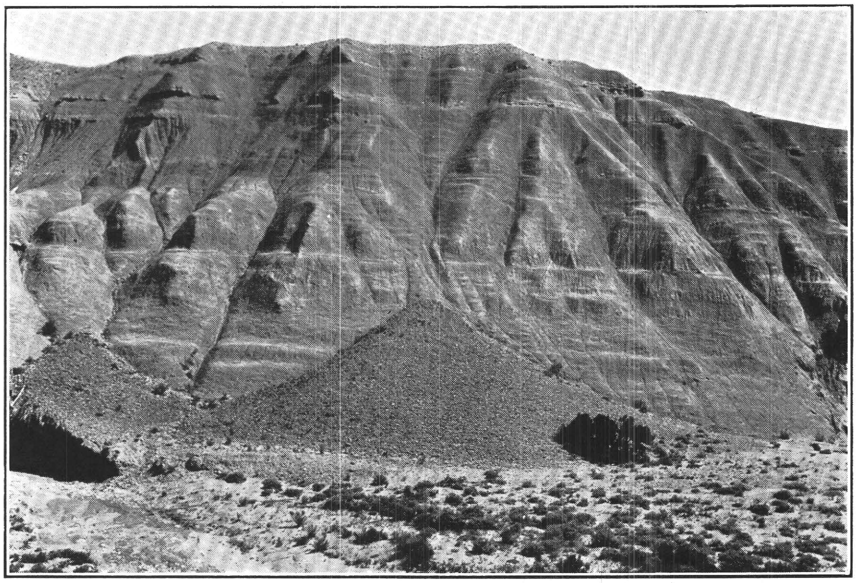
B. VIEW NORTHWARD DOWN BLACKS FORK FROM THE CREST OF A FRONTAL MORAINE OF THE BLACKS FORK STAGE, SHOWING IN THE MIDDLE DISTANCE A LONG LOW TERMINAL MORAINE OF THE SAME STAGE.

Beyond and to the left is Bridger Butte and a portion of Bridger bench. Moraines of the Little Dry (oldest) stage are perched on Bridger bench at a point about due west of the moraine from which this photograph was taken.



A. BEHEADED GRAVELLY ALLUVIAL CONES LEFT BY THE RETREAT OF THE EASTERN ESCARPMENT OF THE TIPPERARY BENCH NEAR MOUNTAINVIEW, WYO.

The level tops at the right are made by the gravel capping of the Tipperary bench.



B. GRAVELLY ALLUVIAL CONES FORMING AT THE FOOT OF SMALL GULLIES THAT SAP THE GRAVEL LAYER AT THE TOP.

Smaller gullies that head below the gravel are also shown at the right.

stream and abandoned its course along the Tipperary bench. When graded with respect to the third and considerably shorter course, it cut the small strath terrace that lies just east of the junction between the East and West Forks of Smith Fork, in the western part of T. 13 N., R. 115 W. (See pl. 34.) The gradient along this new course was about 162 feet to the mile, as contrasted with the average gradient of 120 feet to the mile along its last abandoned course on the Tipperary bench. Still later it moved a little farther to the south and occupied essentially its present course. This final change may have been brought about by another capture, but it seems a little more likely that the stream assumed this position after the retreat of a lobe of ice that came down the valley of the East Fork at this time and left the small terminal moraine at the upper end of the steep terrace in secs. 20 and 21, T. 13 N., R. 115 W. (See pl. 34.)

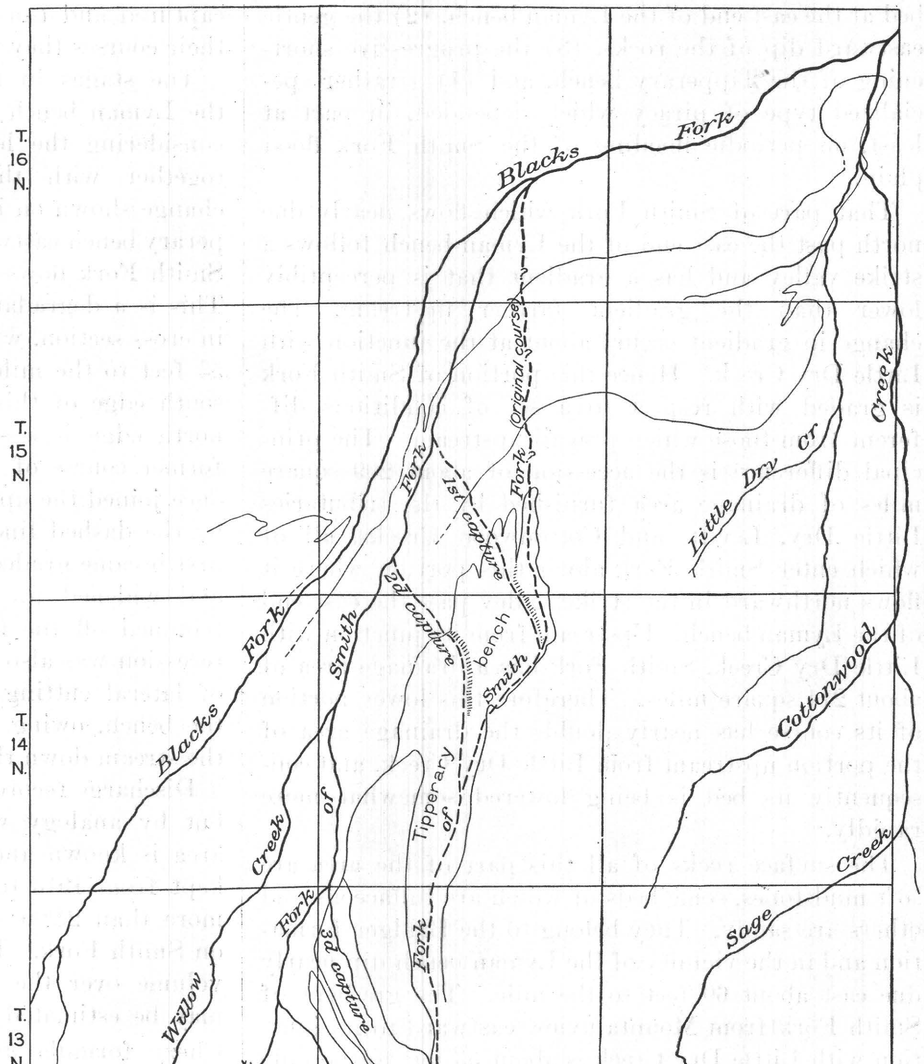


FIGURE 22.—Sketch map of the Tipperary bench immediately after the Smith Fork glacial stage, showing the probable sequence of changes in the course of the East Fork of Smith Fork which led to the cutting of treads on the north end of the Tipperary bench.

LYMAN EROSION SURFACE

At the time of its formation the Lyman surface was even less extensive than the Tipperary surface. It is now represented in this part of the area only by the Lyman bench and a few small terrace remnants. (See pl. 34.) The Lyman bench lies only 50 to 75 feet below remnants of the Tipperary surface, with which it merges upstream in the vicinity of Robertson.

At the north edge of the Lyman bench are two small remnants of the Tipperary surface, one west and the other east of the town of Lyman. Below these remnants is a series of four rather wide treads, the lowest of which is the present flood plain of Smith Fork, on which the town of Mountainview is situated. (See pls. 34 and 43, *A*.)

At the east end of the bench these treads are about 50 feet apart except the lowest one, which is only about 20 feet above the bed of Smith Fork. Upstream the treads all merge into one surface, the Lyman bench, which itself merges yet farther upstream with the present flood plains of both Smith Fork and Blacks Fork.

The origin of these treads appears to be related to (1) the relatively low level of the Smith Fork stream bed at the east end of the Lyman bench, (2) the gentle eastward dip of the rocks, (3) the progressive shortening of the Tipperary bench, and (4) a rather specialized type of piracy which depended, in part at least, on periodic flooding of the Smith Fork flood plain.

That part of Smith Fork which flows nearly due north past the east end of the Lyman bench follows a strike valley and has a gradient that is perceptibly lower than the gradient farther upstream. The change in gradient occurs about at the junction with Little Dry Creek. Hence this portion of Smith Fork is graded with respect to a set of conditions different from those which prevail upstream. The principal difference is the accession of about 209 square miles of drainage area furnished by the tributaries Little Dry, Levitt, and Cottonwood Creeks, all of which enter Smith Fork along this portion where it flows northward in the strike valley past the east end of the Lyman bench. Upstream from its junction with Little Dry Creek, Smith Fork has a drainage area of about 214 square miles. Therefore this lower portion of its course has nearly double the drainage area of the portion upstream from Little Dry Creek, and consequently its bed is being lowered somewhat more rapidly.

The surface rocks of all this part of the area are soft mudstones, some beds of which are tuffaceous and others are sandy. They belong to the Bridger formation and in the vicinity of the Lyman bench dip nearly due east about 60 feet to the mile. The gradient of Smith Fork from Mountainview eastward to its junction with Little Dry Creek is about 55 feet to the mile and hence is nearly coincident with the dip. In general tributary streams working headward from strike valleys tend to establish their courses parallel to the dip, as it presents the steepest available gradient and therefore the stable direction. Accordingly there is ever a tendency for the tributaries of the stream in one strike valley to work headward up the dip and divert the stream in the next higher strike valley and eventually develop a rectangular drainage pattern. The effect of this process is illustrated by the courses of all the streams in this part of the Bridger Basin. Blacks Fork runs eastward across T. 16 N., Rs. 114 and 115 W., and Smith Fork runs almost due east from Mountainview nearly to Levitt Creek. Both streams here run down the dip toward the lowest strike valley. Also, the upper portions of Sage and Cottonwood Creeks run northeastward, in accordance with the northeast dip of the beds in that part of the area. (See pl. 34.) The progressive shortening of comparatively high divides like the Tipperary bench has apparently made it possible for these streams to be captured and thus diverted, so that through part of their courses they flow down the dip.

The stages in the development of the treads on the Lyman bench can perhaps be best understood by considering the lowest and most recent tread first, together with the comparatively recent drainage change shown on it. From the north end of the Tipperary bench eastward to Little Dry and Levitt Creeks Smith Fork flows in a flood plain about a mile wide. This is a degradational feature which is nearly level in cross section, with a downstream gradient of about 53 feet to the mile. Smith Fork now flows near the south edge of this flood plain or strath. Along the north edge is a small stream, which represents the former course of Smith Fork and which apparently once joined the upper part of the stream, as indicated by the dashed lines on plate 34. When Smith Fork first became graded in this old channel it cut laterally and widened its flood plain. This lateral cutting trimmed off the tip of the Tipperary bench, whose recession was also aided by the somewhat greater rate of lateral cutting on the west or northwest face of the bench, owing to the slow eastward migration of the stream down the dip.

Discharge records are not available for Smith Fork, but by analogy with Blacks Fork, whose drainage area is known and on which discharge records were kept from 1913 to 1924, floods amounting to a little more than 2,200 second-feet have probably occurred on Smith Fork. The average depth of a flood of this volume over the Smith Fork flood plain or strath may be estimated by using a simplified form of the Chezy formula $v=c\sqrt{rs}$ and combining with it the definition for the discharge of streams, $Q=wdv$. In the Chezy formula r is the hydraulic mean depth—that is, the area of the channel cross section divided by the total wetted perimeter of the cross section. In wide, shallow natural streams, however, r is essentially equal to the mean depth d, which may therefore be substituted for r, or $v=c\sqrt{ds}$.

Substituting $v=c\sqrt{ds}$ in $Q=wdv$, we have

$$Q=wdc\sqrt{ds}$$

where Q=discharge, in second-feet=2,210
w=width of channel in feet=4,270
s=slope, in feet per foot=0.01
c=Kutter's coefficient=15.[67]

Then d, the average depth of water, =0.49 foot, or about 6 inches. That floods of this magnitude are not extraordinary seems probable, because the discharge

[67] This coefficient varies widely for different natural stream channels, especially for wide, very shallow channels like this one. The value 15 is the mean of several values, which in turn depend upon the probable roughness of a channel of this type, kindly calculated for me by Mr. W. W. Rubey, of the Geological Survey, who also contributed the mathematical analysis of the channels.

records of Blacks Fork for the interval from 1913 to 1924 show two other floods of nearly the same size as the one from which the discharge of 2,210 second-feet for Smith Fork was estimated. Unusual floods such as occur at greater intervals would obviously make the sheet of water proportionately deeper. On a flood plain whose gradient is about 53 feet to the mile the mean velocity of this sheet of water would probably be only about 1 foot a second, or perhaps less. A sheet of water of this sort would not only drain off through the main channel but also spill over any low place into Little Dry Creek upstream from Smith Fork. In this manner any low swale or incipient tributary to Little Dry Creek within the limits of the Smith Fork flood plain but upstream from the main eastward channel would at times of flood receive an abnormal supply of water and so would cut headward up the dip and ultimately divert the main stream into its own somewhat shorter channel. Thus the present position of Smith Fork is apparently due to capture by a small tributary to Little Dry Creek which cut headward through the flood plain, probably at flood stages of the main stream. As the courses of small streams draining the slope east of the Tipperary bench are entirely obliterated by the formation of the flood plain along Smith Fork, they can have no influence in localizing the next southward position of the main channel except perhaps at their very junction with Little Dry Creek, where they may leave a notch too low to be destroyed by the flood-plain cutting.

This hypothesis seems to me to offer a plausible explanation for the saltatory migration toward the inside of the curve of Smith Fork at Mountainview, and the successive abandonment of one channel after another, so as to leave a series of rather regular treads, all of which merge with the present flood plain a little way upstream from the north end of the Tipperary bench. The regularity of the treads seems to depend on the balance between the time necessary for the stream to trim off the tip of the Tipperary bench and cut a moderately wide flood plain and the time required for a minor tributary to work headward along the south side of the flood plain far enough to capture the main stream. Accordingly no climatic or other external control seems necessary to account for this regular series of treads. But as part of the main stream is now diverted to irrigate the Lyman bench the normal flow is reduced, and hence the normal power of lateral cutting is impaired, whereas the headward growth of the potential pirate tributary that depends on high flood stages is relatively little affected by this diversion, and therefore the captures may in the future occur more frequently and in consequence the treads may be narrower.

The whole series may have begun by the capture of Smith Fork by a tributary to Little Dry Creek while Smith Fork was cutting laterally at the level of the highest tread, on which the town of Lyman is now situated. At this stage the north end of the Tipperary bench was probably nearly 3 miles north by west from its present position. It has thus receded most rapidly southward and moderately eastward. Its recession has made possible the repeated diversion of Smith Fork, and the gentle east dip of the beds has made the eastward portion of each new course the stable direction and thus aided in the saltatory migration of the stream through a series of successive channels, all roughly parallel with one another.

BEHEADED ALLUVIAL CONES

Most of the erosion surfaces in the northwestern part of the area discussed in this report were cut on beds of easily erodible mudstone of the Bridger formation. Consequently the escarpments below the capping of rather loosely bound gravel are generally steep and naked badland slopes. In the normal recession of some of these badland escarpments of moderate height a topography characterized by low, asymmetric, gravelly alluvial cones has been left. (See pl. 45, *A*.) These cones, which are of diverse sizes, are beheaded alluvial cones and therefore have their steep faces toward the retreating badland escarpment.

The steps in the growth and beheading of these cones appear to be as outlined below. Certain gullies incised in the face of a badland escarpment widen upward so that they expose a comparatively long segment of the gravel capping at the top. Water flowing down these gullies builds alluvial cones consisting of a mixture of gravel and mud washed from the weathered mudstone escarpment. (See pl. 45, *B*.) The surfaces of these cones slope at angles ranging from 10° to 23°. Other narrower gullies head below the gravel capping. Water running down these gullies collects only mud, which spreads out at the foot of the escarpment into alluvial cones whose surfaces slope so gently as to appear nearly flat. Both sorts of cones are aggradational features and contrast markedly with the wasting mudstone escarpment, which normally has slopes ranging from 40° to 50°. As the gravel cones grow and coalesce the mudstone face between them retreats, tending to leave a slight depression along the contact between the cone and the badland escarpment. This line of contact intercepts the rills and minor gullies on the mudstone slope and thus collects the rain wash from that part of the escarpment between two adjacent cones. Accordingly, as the gravel cones grow they intercept more and more of the drainage and lead it into the gully that drains out between two cones. Then, as the badland escarpment retreats, the drainage course along the contact between the cone and the escarpment deepens and diverts to itself the water from the main gully, which had formerly spread over the cone. Once the water that spread over the gravel cone is diverted to the contact gullies, these deepen rapidly and by headward erosion sever the gravel cone from the badland escarpment. Hence the gravel cones have steep slopes facing the parent escarpment, and, like those of the parent escarpment, these are at first naked badland slopes, but as they weather they become less steep and acquire a sparse scattering of cobbles from the cone itself.

Successive gravel cones or groups of cones then follow as the escarpment retreats, and their positions are determined by the sites of the lower ends of gullies that tap the gravel layer at the top. The lower courses of these gullies appear generally to have been deflected to one side or the other of an earlier gravel cone, and consequently the successive cones come to have an alternate or staggered arrangement. Obviously, however, a stream that runs parallel to the escarpment and close to it prevents the development of this sort of topography by removing the alluvial material from the foot of the escarpment.

GLACIAL HISTORY

No attempt was made to study systematically the glacial deposits, and only those moraines that gave promise of clarifying the relations between the erosional history and the glacial history of the region were mapped. Atwood[68] recognized two distinct epochs of glaciation in the Uinta Mountains. Of these two epochs he said that "the earlier was presumably the longer, for the ice of that epoch was thicker and extended farther down the canyons than the ice of the later epoch." He added, however, "Some data have been collected which suggest a threefold division of the glacial deposits but not sufficient to demonstrate three distinct epochs."

Bulky terminal moraines perched on remnants of the Bear Mountain surface at two and possibly three localities north of the limits of Atwood's work seem to indicate rather clearly a glacial epoch considerably older than Atwood's "older glacial epoch." Also two old stages of glaciation seem to be separable along Henrys Fork between Beaver Creek and Burnt Fork, though the evidence obtained from that locality is not conclusive.

The three glacial stages in the Uinta Range may for convenience be called the "Little Dry" (oldest), the "Blacks Fork", and the "Smith Fork." The Little Dry stage is so named from Little Dry Creek, which flows along the west side of a large terminal moraine on Cottonwood bench, a broad remnant of the Bear Mountain surface that lies between Little Dry and Cottonwood Creeks. The intermediate stage is referred to as the Blacks Fork stage because of the extensive moraines left by the glaciers of that stage in the valley of Blacks Fork. The youngest stage is called the "Smith Fork stage", because of the extraordinarily long train of lateral moraines of that stage in the valley of the East Fork of Smith Fork.

On plate 34 the moraines of the Little Dry and Blacks Fork stages are shown only in part, and none of the moraines of the Smith Fork stage are shown.

MORAINES OF THE LITTLE DRY GLACIAL STAGE

The deposits of the Little Dry stage are represented by portions of massive terminal moraines perched on remnants of the Bear Mountain surface. These were found on the Bridger bench in Tps. 14 and 15 N., Rs. 116 and 117 W., and on the broad bench between Cottonwood and Little Dry Creeks. (See pl. 34.)

Old moraines that probably belong to the Little Dry stage were also found farther south on the Bridger bench in T. 12 N., R. 117 W. Apparently, also the great mass of morainic material south of Henrys Fork between the Middle Fork of Beaver Creek and Burnt Fork belong to this oldest stage. (See pl. 34.) The base of the glacial debris at the last-mentioned locality is some distance above the present valley floors and presumably rests on a remnant of the Bear Mountain surface, though this is by no means certain. This great accumulation of moraines between Burnt Fork and the Middle Fork of Beaver Creek, which makes up the greater part of a barren group of hills locally known as the "Bald Range", appears to be the combined deposit left by glaciers of the Little Dry stage that came down Henrys Fork, the West and East Forks of Beaver Creek, and Burnt Fork.

These oldest moraines are characterized by their great bulk, deep soil, and smoothly rounded forms, which merge into the adjacent surface features almost imperceptibly. They are not conspicuously bouldery, though in a few places boulders 1 to 2 feet across are plentiful, and locally also large angular blocks of quartzite are sparsely scattered over the surface. The surfaces of these large boulders are checked and somewhat dull, but they are not deeply weathered. Probably, however, this is because they consist of dense vitreous quartzite that is nearly as resistant to weathering as vein quartz. Some of the smaller cobbles crumble readily, yet on the other hand many of those found in the outwash in front of the moraines are plainly striated.

[68] Atwood, W. W., Glaciation of the Uinta and Wasatch Mountains: U. S. Geol. Survey Prof. Paper 61, p. 12, 1909.

These oldest moraines appear to be the deposits of heavily loaded valley glaciers that approached the piedmont type where they emerged from the canyons and spread out on the pediment portion of the Bear Mountain surface. Perhaps the great bulkiness of these moraines is due to the fact that the glaciers which deposited them were the first glaciers to occupy the ancient stream valleys and for that reason had a vast quantity of soil and deeply weathered rock easily available for transportation. The apparent predominance of fine-grained material in these oldest moraines agrees with this hypothesis.

MORAINES OF THE BLACKS FORK GLACIAL STAGE

The evidence that the Blacks Fork stage (Atwood's "older glacial epoch") is intermediate between the Little Dry and Smith Fork stages is found in three moraines of the Blacks Fork stage that rest on remnants of the Tipperary surface. Of these moraines one frontal and one terminal are in the valley of Blacks Fork in the southwestern part of T. 14 N., R. 116 W. (See pl. 44, *B*.) They rest on the nearly level floor of a wide valley about 200 feet below the pediment on which the moraines of the oldest stage are perched. (See pl. 34.) Apparently this valley was cut after the moraines on the Bridger bench were deposited, for the strip of moraine-covered pediment is obviously narrower than the original bulky transverse moraine, and the valley walls are free from morainic material. The other terminal moraine of the Blacks Fork stage, which rests on a remnant of the Tipperary surface, is on the west side of Little Dry Creek in secs. 20 and 21, T. 13 N., R. 115 W. Although this moraine rests on a remnant of the Tipperary surface, the evidence of two older stages of glaciation is less clear here because the Tipperary surface and the Bear Mountain surface are separated by only a narrow interval. (See pl. 34.)

The moraines of the Blacks Fork stage differ from the moraines of the oldest or Little Dry stage in being rather conspicuously bouldery, but they have much more soil than the moraines of the youngest stage. Indeed, in smoothness of outline, depth of soil, and weathering of the boulders they resemble the oldest moraines more closely than they do the youngest, yet a sufficiently long period of erosion intervened between the two oldest stages to cut the wide valley of Blacks Fork and the rather extensive Tipperary strath.

The moraines of the Blacks Fork and Little Dry stages are apparently separable also on the west side of Burnt Fork 3 to 4 miles south of the Wyoming-Utah boundary line. At this locality lateral moraines of very rugged form flank a high hill formed by the upturned edges of the Tertiary conglomerate. Atwood[69] mapped these moraines, which seem rather clearly to belong to the Blacks Fork stage. The Little Dry stage of glaciation, however, is probably represented by the bulky moraines farther north, near the State boundary. (See pl. 34.)

MORAINES OF THE SMITH FORK GLACIAL STAGE

I did not map any of the moraines of the youngest stage, whose glaciers terminated in canyons farther upstream than the glaciers of either of the other two stages. These moraines, however, are so fresh and their original configuration is so little modified that they cannot be confused with the deposits of the earlier glaciers. Yet despite this evident difference in age between the youngest moraines and the moraines of the intermediate stage, the effect of fluvial erosion that occurred during the interglacial time is astonishingly slight. The valley floors were cut down only a few feet, and the new flood plains were widened only at some distance out from the canyons and not extensively even there. During that interval of erosion only the very tips of the two transverse moraines of the intermediate stage in the valley of Blacks Fork were trimmed off. Elsewhere the valley floor with its veneer of ground moraine has remained almost unaffected since the second stage of glaciation.

CORRELATION WITH THE GLACIAL STAGES OF NEIGHBORING RANGES

The three stages of glaciation in the Uinta Mountains appear to be correlative with the glacial stages that are revealed in the Wind River Range, where Blackwelder[70] distinguished the Pinedale, Bull Lake, and Buffalo stages of glaciation, of which the Pinedale is the youngest. The deposits of his Pinedale stage seem to be so closely analogous to those of the youngest or Smith Fork stage on the north flank of the Uinta Mountains as to be virtually identical with them. His Bull Lake and Buffalo stages resemble the two older stages in the Uinta Mountains in being separated by an interval of time which, as Blackwelder[71] said, "was several times as long as the next succeeding interglacial interval, and many times longer than the postglacial epoch." Likewise they resemble the Uinta Mountain stages in the scarcity of boulders on the oldest moraines and the moderate abundance of them on the moraines of the intermediate stage. Furthermore, the deposits of Blackwelder's Buffalo stage are analogous to the deposits of the oldest (Little Dry) stage in the Uinta Mountains, in that both appear to represent extensive glaciers that spread out over a rather old erosion surface, which later was considerably dissected before the advance of the intermediate glacial stage.

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[69] Atwood, W. W., op. cit., pl. 4.

[70] Blackwelder, Eliot, Post-Cretaceous history of the mountains of central western Wyoming: Jour. Geology, vol. 23, pp. 321–333, 1915.

[71] Idem, p. 332.

In the Wyoming Range of western Wyoming Rubey [72] recognizes an old glacial stage, which resembles the Little Dry stage in the Uinta Mountains in that it spreads out rather broadly on remnants of an extensive erosion surface considerably above the valleys that contain the moraines of the younger glacial stages.

In the San Juan Mountains of southwestern Colorado Atwood and Mather [73] have also distinguished three glacial stages, the Wisconsin, Durango, and Cerro, whose relations suggest that they also may be correlated with the three stages in the Uinta Mountains.

Gilbert [74] showed by a theoretical analysis that the same combination of climatic elements that favored the growth of lakes also favored the growth of glaciers. Then by the relations of the shore lines of the ancient Lake Bonneville to the moraines he was able to demonstrate that the maximum high-water stages of the lake lagged just a little behind the maximum extensions of the glaciers. Furthermore, he showed that the climatic changes which so closely linked the glacial and lacustrine stages in the Bonneville Basin were regional in scope and linked in a similar manner the glacial stages of the Sierra Nevada with the high-water stages of Lakes Mono and Lahontan, which occupied hydrographic basins contiguous to the Bonneville Basin. Thus by analogy it seems probable that the glaciers in the Uinta and Wind River Ranges expanded and contracted in response to the same climatic changes that controlled the growth and decay of the glaciers in the nearby Wasatch Range. Hence Blackwelder,[75] who has examined the moraines and shore lines along the Weber River in the western part of the Uinta Range, appears to be abundantly justified in concluding that Gilbert's two glacial and high-water lake stages—the first and second Bonneville epochs—may be correlated with the two youngest stages of glaciation in the Uinta and Wind River Ranges. The oldest or Little Dry stage of glaciation in the Uinta Range, however, finds no counterpart in the history of the Bonneville Basin as revealed by the shore features of the ancient lake.

I have no way of correlating the glacial stages of the Uinta Range with the standard section save by analogy with Blackwelder's sequence in the Wind River Range. Thus the Smith Fork, Blacks Fork, and Little Dry stages of the Uinta Range appear to be the respective equivalents of the Pinedale, Bull Lake, and Buffalo stages in the Wind River Range, which Blackwelder [76] has suggested may be the respective equivalents of the Wisconsin, Iowan, and Kansan stages of the standard section.

[72] Rubey, W. W., personal communication, April 1932.

[73] Atwood, W. W., and Mather, K. F., Physiographic history of the San Juan Mountains of Colorado: U. S. Geol. Survey Prof. Paper 166, pp. 69–83, 1932.

[74] Gilbert, G. K., Lake Bonneville: U. S. Geol. Survey Mon. 1, pp. 260, 269–318, 1890.

[75] Blackwelder, Eliot, Pleistocene glaciation in the Sierra Nevada and Basin Ranges: Geol. Soc. America Bull., vol. 42, pp. 914–919, 1932.

INTERPRETATION OF THE EPOCHS OF DISSECTION

EROSION INTERVAL BETWEEN THE GILBERT PEAK AND BEAR MOUNTAIN SURFACES

The Bridger bench, in the western part of the area, will be considered as representative of the Bear Mountain surface in the following discussion. But as the Bridger bench has on it two moraines of unknown depth, which conceal the true profile, it was necessary to estimate the position of the erosion surface beneath them. This was done graphically by fitting a portion of the Hickey Mountain profile to the parts of the Bridger bench profile (fig. 23) not covered by the moraines or the thin outwash apron in front of them. (See fig. 24.) This is obviously only an approximation and is based on the assumption that the profiles of the two benches are alike. The error introduced by this assumption, however, is probably not large, for the two benches were cut on the same rocks by the same or closely analogous streams and apparently under nearly the same climatic conditions.

A comparison of the profile of the Bridger bench, after eliminating the morainic humps, with the Hickey Mountain profile of the Gilbert Peak surface shows that the Bridger bench has a somewhat steeper gradient. This comparison was made in two ways. First, the profile of the Bridger bench was projected southeastward along the average strike of the Gilbert Peak and Bear Mountain surfaces so as to lie in the plane of the Hickey Mountain profile. When projected in this manner into the same vertical plane that portion of the Bridger bench profile between the bend in the line of section northward to a point 1 mile north of Bridger Butte in figure 23 corresponds with the part of the Hickey Mountain profile (fig. 12) from its north end south to a point 2 miles south of the bend in the line of section. This direct comparison showed the average gradients for the two surfaces given in the table on page 197.

The gradients of the two profiles were also compared by extrapolating each curve out to a common point far out in the basin. The extrapolations were made by plotting the altitudes against the distances on double logarithmic paper and then shifting each curve, first along one coordinate until the data plotted as a straight line, and then along the other coordinate

[76] Idem, p. 918.

until the points fell into a straight line.[77] Extending these straight lines for each profile out to a common point in the basin did not give quantitatively reliable results, yet three of the four extrapolations agreed in indicating the probability that the surfaces diverge basinward—that is, that the lower surface has a steeper gradient than the other.

Average gradient of Bear Mountain and Gilbert Peak surfaces

Bridger bench profile (Bear Mountain surface), from bend in line of section (fig. 23) to point 1 mile north of Bridger Butte		Hickey Mountain profile (Gilbert Peak surface), from north end (fig. 12) south to point 2 miles south of bend in line of section	
Distance up profile (miles)	Average gradient (feet per mile)	Distance up profile (miles)	Average gradient (feet per mile)
0– 5	40	0– 5	50
5–10	60	5–10	60
10–15	80	10–15	80
15–20	130	15–20	90
20–25	250	20–25	120

If it is assumed that both surfaces were formed with the same gradients, then this basinward divergence suggests that the Gilbert Peak surface was tilted slightly southward before the Bear Mountain surface was cut. But as there is no field evidence to indicate a regional tilt in any direction in this part of the area since the Gilbert Peak surface was formed, it seems more reasonable to assume that each surface still possesses its original slope.

The apparent divergence of these two surfaces basinward seems to eliminate the possibility that the erosion interval between them resulted from an uplift of the Uinta Range with respect to the basin decreasing progressively in amount from the mountains to a minimum at the center of the basin, for if it were due to this sort of movement, then, other things being equal, the surfaces should converge basinward. Moreover, they might actually meet at a baselevel common to them both if there had been no change in the central part of the basin. On the contrary, the basinward divergence seems to indicate that the temporary baselevel in the basin that controlled the streams during the formation of the Gilbert Peak surface was considerably lowered during the interval between the Gilbert Peak and Bear Mountain erosion cycles, so that when the Bear Mountain surface was cut the streams issuing from the Uinta Mountains were controlled by a new temporary baselevel, which stood at a much lower altitude with respect to the mountains. This lowering of the baselevel might have been brought about by any one or any combination of the following causes: (1) Removal of an obstacle athwart the master stream either by cutting through or going around it; (2) broad regional uplift without significant deformation in the area considered here and general headward erosion, so that the beds of the master stream and all its tributaries were lowered; or (3) cyclical changes in the climate from an arid phase of lateral planation to a more humid phase of down-cutting and back again to an arid phase of planation.

The Bear Mountain surface, then, may owe its apparent steeper slope to having been cut during a somewhat shorter interval of planation than that which produced the Gilbert Peak surface, for the slope of desert plains presumably decreases very gradually until in extreme old age, perhaps when deflation becomes predominant, it reaches nearly a dead level.[78] On the other hand, it might owe its steeper slope to having been cut under a slightly more arid climate than that which prevailed while the Gilbert Peak surface was being cut. Furthermore, other factors, such as the relations between the volume and the load or the character of the load, which might not necessarily have been dominated by climate, might conceivably also have caused the streams of the Bear Mountain erosion cycle to become graded with respect to somewhat steeper bed slopes.

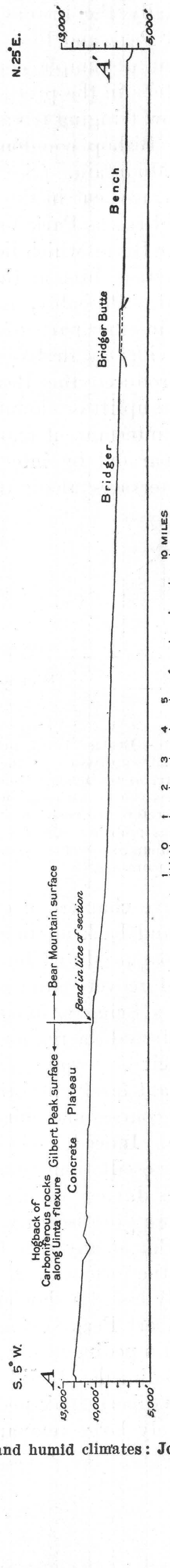

FIGURE 23.—Profile of the Bear Mountain surface along the Bridger bench from the Gilbert Peak surface on Concrete Plateau northward beyond Bridger Butte. Though the top of Bridger Butte stands a little above the Bridger bench, it is treated in this report as a part of the Bear Mountain surface. The part of the profile from the bend in the line of the section northward to *A'* is compared in **figure 24** with the Hickey Mountain profile of figure 12.

[77] This method of extrapolating curves of the general type $yx^n=k$ is discussed fully on pages 78–79 of the "Manual for the oil and gas industry under the Revenue Act of 1918 (revised ed.)", published by the Treasury Dept., Washington, 1921.

[78] Davis, W. M., Rock floors in arid and humid climates: Jour. Geology, vol. 38, pp. 6–10, 1930.

Actually the history of the interval between the Gilbert Peak and Bear Mountain cycles was probably not that of simple continuous erosion. That there were steps in the process is evident from remnants of a narrow fringing terrace about 100 feet below the top of the Bishop conglomerate along the east side of Cedar Mountain. (See pl. 34.) Furthermore, the several terraces cut in the †Uinta quartzite on the south side of Browns Park Valley and terrace remnants like Bridger Butte, which lie a little above the Bear Mountain surface, hint at the probable complexity of this interval. Probably, also, similar interruptions occurred in other parts of the area, but all traces of them were evidently destroyed in the extensive planation that produced the Bear Mountain surface. Either regional uplift or climatic changes might have worked in this intermittent manner. Successive stages of uplift separated by intervals of rest would have produced terraces along the ancient streams. So, also,

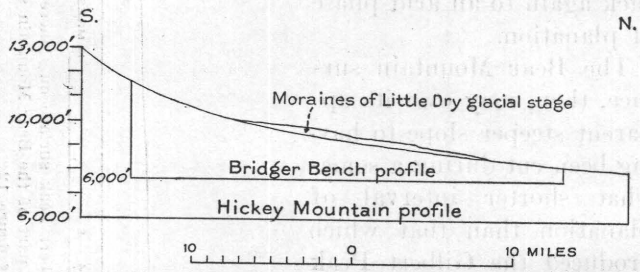

FIGURE 24.—Bridger bench profile of the Bear Mountain surface of figure 23, superposed on the Hickey Mountain profile of figure 12. The part of the Bridger bench profile above and below the moraines coincides closely with the curvature of the Hickey Mountain profile, and therefore the position of the Hickey Mountain profile below the moraines probably coincides approximately with the position of the Bear Mountain surface and hence indicates the probable thickness of the moraines.

successive changes in climate from dry to relatively moist and back again would have produced terraces like those produced by halts in a broad regional uplift. Moreover, either a long-continued halt in uplift or a long-continued dry phase of climate could have affected the regimen of the streams in such a way that their basinward portions were held at essentially a constant level while they cut laterally through their middle courses and thus produced the Bear Mountain surface. Indeed, a combination of regional uplift and climatic oscillations could equally well account for this interval during which erosion predominated, and I see no way to discern which cause was the more effective. But at any rate the stable conditions that permitted the formation of the Bear Mountain surface apparently lasted a shorter time than those under which the Gilbert Peak surface was produced, for the Bear Mountain pediment was less extensive than the Gilbert Peak pediment. It did not invade the range as deeply as the Gilbert Peak pediment, and furthermore comparatively large remnants of the Gilbert Peak pediment cut on soft Tertiary rocks still rise from the Bear Mountain pediment, even at a considerable distance out from the mountains.

A long interval of fluviatile aggradation followed the cutting of the Bear Mountain surface and resulted in deep burial of much of it by beds of the Browns Park formation. The original extent of this formation is quite unknown. Volcanic ash also contributed to the growth of the Browns Park formation, but the vents that furnished this material are not known. Exactly similar glass tuff mixed with beds of somewhat coarser lithic tuff form a narrow strip along the northern edge of the Green River Basin adjacent to the Wind River Mountains. These beds may possibly be correlative with the Browns Park formation or they may be older and correlative with the White River formation a few miles to the east, in the valley of the Sweetwater River.

EROSION INTERVALS BETWEEN THE SURFACES LATER THAN THE BEAR MOUNTAIN SURFACE

The number and areal extent of remnants of former erosion surfaces along the upper reaches of Blacks Fork, Smith Fork, and their tributaries indicate that only a moderate amount of erosion has occurred there as compared with that in adjacent portions of the area. In order to make an approximate measure of the volume of rock removed from the Wyoming portion of the area since the deposition of the Bishop conglomerate, I constructed five cross sections showing profiles of the present topography along 500-foot contours drawn on the reconstructed surface of the Bishop conglomerate. In these cross sections the area between the line representing the reconstructed Bishop surface and the profile of the present topography represents the amount of material eroded since the Bishop epoch. If it is assumed that the area of the cross section along each profile is representative of a strip of country halfway to the next adjacent profile on each side, then the product of the average width of this strip and the area of the cross section representing eroded material gives an approximate measure of the volume of material eroded from that strip. The sum of the volumes for each strip along each 500-foot contour shows that a little less than 269 cubic miles of material has been removed from an area of 1,545 square miles since the Bishop epoch, or about 0.2 cubic mile to the square mile. But in that part drained by Blacks and Smith Forks the average volume of material removed is only about 0.1 cubic mile to the square mile—that is, the average depth of erosion is only about half as great as in that part of the area drained directly by the Green River and Henrys Fork. Apparently the area drained by Blacks and Smith Forks is as yet unaffected by a rejuvenation of the Green

River system that has caused the main stream to entrench itself deeply. In this entrenchment only the short direct tributaries have kept pace with the main stream. Blacks Fork, on the other hand, is a long tributary and, moreover, is anomalous in that it flows many miles northward, opposite to the flow of the Green River, then swings eastward in a wide curve, reverses its own direction, and flows southward for some miles roughly parallel to the river before actually joining it. That the upper part of the Blacks Fork drainage system is still in an earlier cycle is also shown by the insignificant changes in the valleys since the retreat of the last glaciers. Consequently in seeking an explanation for the alternating sequence of downward cutting and lateral planation of the streams in the upper part of the Blacks Fork drainage system, this last rejuvenation, whose magnitude was apparently great, need not be considered.

As pointed out on page 196, the two youngest glacial stages represented in the valleys of the Blacks Fork drainage system are fairly well correlated with the two high-water stages of the Pleistocene lakes to the west. The high-water stages of the lakes indicate conditions favorable to full, strong streams, capable of active downcutting, whereas the low-water levels of the interglacial stages indicate conditions tending toward a more arid type of streams, one of whose principal characteristics is strong lateral planation. Accordingly it seems rather probable that the climatic control exerted on the regimen of Blacks Fork, Smith Fork, and their tributaries caused them to cut the Tipperary and Lyman surfaces during the interglacial stages and likewise caused them to dissect these two surfaces during or just after the corresponding glacial stages. The present moderate entrenchment of the streams suggests a return to conditions more humid than those that prevailed during the cutting of their flood plains.

By analogy with this part of the erosional record it might be inferred that the dissection of the Bear Mountain surface was brought about largely by the increased power of the streams during the oldest or Little Dry glacial stage. The inference that a relatively moist climate accompanied the Little Dry stage of glaciation seems sound, but the erosion between this oldest glacial stage and the cutting of the Tipperary surface was so much greater than that which followed either the Blacks Fork or the Smith Fork stage that it may mean either that one or more glacial stages intervened between the Little Dry and Blacks Fork stages or that the streams were enabled to cut more vigorously by reason of a moderate uplift of the region. However, no evidence is available, so far as I am aware, to substantiate or to refute these suggestions. On the other hand, the greater amount of erosion after the Little Dry glacial stage might have been due to much greater humidity, to a longer time interval, or to a more vulnerable position of the whole region owing to its having been uplifted prior to the cutting of the Bear Mountain surface.

PRESENT DRAINAGE PATTERN

The streams of today in this part of Wyoming and Utah show in their pattern a marked influence of two stages in their development. The older of these stages is represented by the general tendency for the streams to flow northward away from the Uinta Mountains, a habit presumably acquired in consequence of the original uplift of the range and accentuated by later downwarping of the rocks in the center of the Green River Basin. Moreover, this habit apparently persisted throughout the Tertiary period until, as outlined on pages 185, 187–190, the collapse of the east end of the Uinta Range made possible the capture of the ancient master stream that had been flowing eastward across the basin and diverted it so that it flowed not only toward but through the range itself.

This major event has left its impress on the regional drainage pattern in the form of reversed courses of portions of many of the streams, so that they flow out toward the basin, then turn around and flow mountainward until they join the master stream. This partial reversal of the drainage is well illustrated by Blacks Fork and Bitter Creek and its two principal tributaries, Little Bitter and Salt Wells Creeks. The tendency to reverse the drainage direction is now the dominant tendency, owing to the deep entrenchment of the Green River, which in turn has greatly accelerated the headward cutting of its short direct tributaries. Henrys Fork and perhaps also Beaver Creek apparently flowed northward through the low gap between Hickey Mountain and Sage Creek Butte and so were at one time tributaries of Cottonwood Creek. But they appear to have been diverted into their present much shorter courses by a short tributary to the Green River which worked its way rapidly westward by reason of its steep gradient. Recently a tributary to Henrys Fork, Stoufers Dry Creek, captured the headwaters of the Little Dry Creek in T. 14 N., R. 111 W. (not to be confused with the Little Dry Creek farther west, which is a tributary of Smith Fork). (See pl. 34.) Even now the divide between these two creeks is so slight that the water from the upper part of the stream sometimes flows down Little Dry Creek instead of Stoufers Dry Creek.