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Geology of the Northwestern Wind River Mountains, Wyoming

BY

CHARLES LAURENCE BAKER

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ABSTRACT

A high and broad area in the Wind River Mountains exposes pre-Cambrian metamorphics, predominantly gneiss, intruded by acidic and basic rocks. By mid-Cambrian time these were deeply eroded to the widespread peneplain of the interior United States. Paleozoic sediments of Middle and Upper Cambrian, Upper Ordovician, later Devonian, earlier Mississippian, Pennsylvanian, and Permian—the usual northwestern Wyoming section—outcrop in the vicinity of Green River lakes, in the north part of the western flank. Most of the Mesozoic rocks in northernmost Green River Basin are concealed, but Dinwoody, Chugwater, Sundance, Morrison, and Upper Cretaceous are known. Cenozoic deposits occur, but their dating is uncertain.

Laramide orogeny produced, in the Paleozoic area, folds, two major westward thrusts, and three minor upthrusts. Faulting is extensive in pre-Cambrian rocks, but the age of most of the faults is unknown.

A peneplain, thought to be late Cenozoic, bevels pre-Cambrian and Paleozoic rocks. Subsequently there was stream incision to a maximum depth of 3500 feet during five erosion stages or subcycles. There were apparently at least two Pleistocene glacial epochs, and about 25 glaciers still exist.

INTRODUCTION

The Wind River Mountains, 125 miles long and 40 miles wide, extend northwest-southeast between Lat. 42 and 44 N. in west-central Wyoming, mostly as a high rugged range with an exceptionally large area above timberline and the highest altitude for the latitudes on the continent. They rise gradually in northeastern dip slopes of resistant Paleozoic rocks from the northeast-bordering Wind River Basin. The descent on the opposite southwest flank into the southwest-bordering Green River Basin is more abrupt; Paleozoic rocks do not outcrop on that flank except in the Green River lakes area adjacent to the Big Bend of upper Green River and in a much smaller area near Fremont Butte, southeast of the town of Pinedale. The northwest end is the drainage divide between the Pacific Ocean by way of the Columbia, the Gulf of California by way of the Colorado, and the Gulf of Mexico by way of the Missouri-Mississippi rivers. The south end of the range is flanked by the Red Desert Basin, without exterior outlet. Like other mountains of the Cordillera these owe their topographic prominence to a combination of uplifting and erosional differential etching of rocks of varying degree of resistance; crystalline rocks especially, including limestones and dolomites, are more durable in the prevalent cold climate, while poorly indurated or nonconsolidated Mesozoic and Cenozoic rocks disintegrate rapidly and are removed easily, especially from the arid or semi-arid lower intermontane basins where only a sparse vegetation protects the surface.

This paper presents the detailed geology of the Paleozoic area of the southwest flank, about 50 square miles, centering about 20 miles south of the northwest end (Pl. 1). Physiography and structure require consideration of a much larger area. Three topographic quadrangles of the U. S. Geological Survey cover most of the northwest range area: the Fremont Peak 30-minute quadrangle of the northwest end of the range and the Mt. Bonneville and Moccasin Lake 15-minute quadrangles; the northwest corner of the Mt. Bonneville joins the southeast corner of the Fremont Peak, and the Moccasin Lake is directly east of the Mt. Bonneville (Fig. 1).

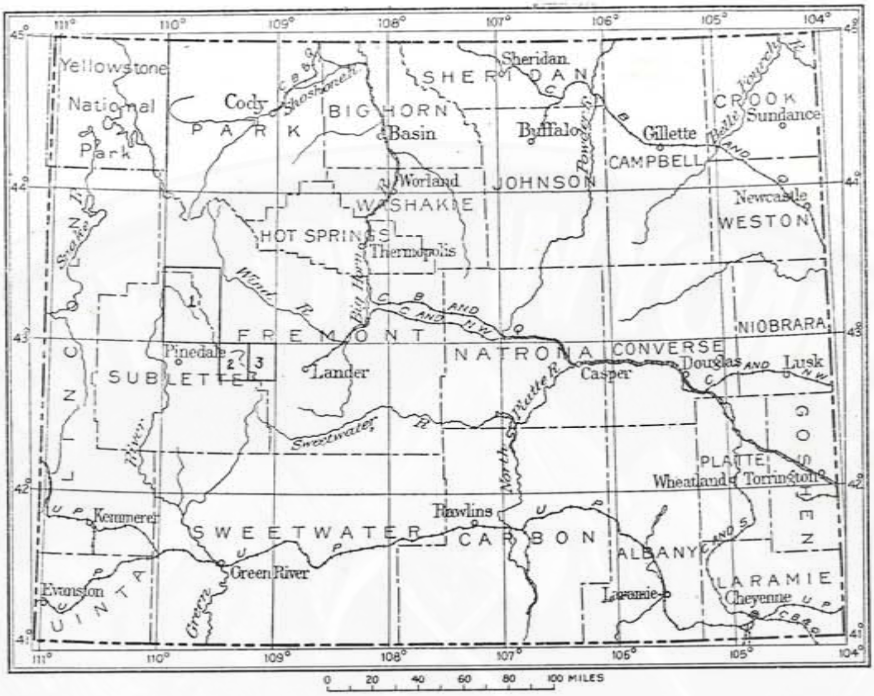

FIGURE 1.—*Outline map of Wyoming*

Showing location of Wind River Mountains. (1) Fremont Peak quadrangle, (2) Mt. Bonneville quadrangle, (3) Moccasin Lake quadrangle.

St. John (1883) gave an excellent general description of the geology. Baker in a 1909 reconnaissance recognized the Cenozoic peneplain, the westward thrusting in the Big Bend area of Green River, and the occurrence of Permian phosphate. Blackwelder's observations (1911; 1913; 1915; 1918) increased greatly the knowledge of physiography and Paleozoic stratigraphy. Atwood (1940) discussed the peneplain and later physiographic history.

PRE-CAMBRIAN BASEMENT COMPLEX

Pre-Cambrian rocks outcrop in an area about 30 miles broad. At the northwest, west of the Continental Divide, the oldest rocks are gray gneisses, extensively intruded by *lit-par-lit* and crosscutting pegmatite and quartz injections (Pl. 2, fig. 1). Schists, dominantly amphibolitic, and green quartzites are rare. With an eruptive contact west of the metamorphics is an extensive granitic intrusion overlapped farther west by Cambrian. Granitic rocks at the north are mostly fine-grained, in part at least quartz monzonite, but father south, between the South Fork Gypsum

Creek and the canyon of New Fork River, they are very coarse-grained and almost binary. A few pre-Cambrian diabase dikes intrude older rocks.

PRE-MID-CAMBRIAN PENEPLAIN

There is a noteworthy absence of less metamorphosed pre-Cambrian sediments like those in ranges farther west and northwest. Erosion of pre-Cambrian evidently continued until almost perfect peneplanation since contact of the Middle Cambrian Flathead sandstone is everywhere remarkably even. Moreover, Flathead basal conglomerate is relatively scarce, and its pebbles are small. Lower Flathead has considerable feldspar and chlorite in small particles and medium-grained quartz. Mature decomposition of granite directly beneath the surface is shown where the peneplain is stripped, as on the divide (Pl. 2, fig. 2) between Porcupine Creek and Green River (2 miles south of the head of upper Green River lake) and north of Clear Creek along the western margin of the granite (Pl. 7, fig. 2, left horizon); in both areas this peneplain surface is tilted westward and differs from the Cenozoic peneplain which bevels it in that its surficial rocks are deeply decomposed and disintegrated.

PALEOZOIC ROCKS

GENERAL STATEMENT

Paleozoic rocks of central Wyoming were deposited east of the Cordilleran geosyncline and on the northwest border of the "Colorado islands", overlapped from time to time by the sea but generally emergent. Consequently adjacent stratigraphic sections seldom have exactly the same thicknesses, great time breaks intervene, deposits locally thicken and thin, and the middle Paleozoic members thicken northwestward within the range. Furthermore, deformation caused considerable interstratal shearing. Paleozoic rocks on the northwestern flank of the range average about 4000 feet thick. Their areal distribution with two minor exceptions is shown in Plate 1, and a nearly complete section is exposed in White Rock (Pl. 3, fig. 1).

CAMBRIAN

The Cambrian strata are divided lithologically into five distinct formations, only two of which are named. The formations in ascending order are: (1) Flathead sandstone; (2) an alternating sandstone and sandy shale member; (3) the Death Canyon limestone; (4) the upper, dark-green, partly bentonitic shale; and (5) the Upper Cambrian upper limestone with edgewise conglomerate. The lower strata are Middle Cambrian, and the higher Upper Cambrian. Neither the exact contact between Middle and Upper Cambrian nor the exact top of the Cambrian is known. Possibly there are gaps in the depositional sequence which could be determined only by very careful paleontological study.

The Flathead sandstone is 255 feet thick on the east flank of Battleship Mountain (4 miles southwest of the south end of lower Green River lake) and 216 feet thick on the southeast flank of Sheep Mountain. On the main south fork of the South

FIGURE 1. GANNETT PEAK SCARP OF PRE-CAMBRIAN GNEISS
East from Wells Creek Glacier

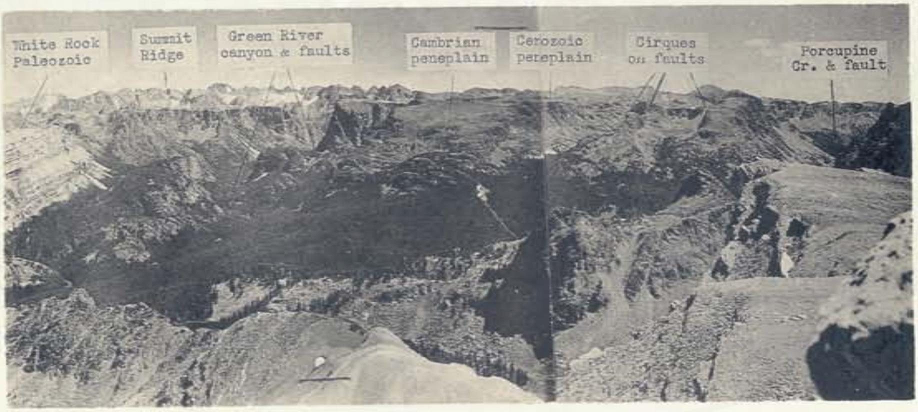

FIGURE 2. TILTED MID-CAMBRIAN AND CENOZOIC PENEPLAINS, HIGHEST SUMMIT PEAKS, AND EROSION STAGES IN GREEN RIVER CANYON
Southeast from Sheep Mountain

PRE-CAMBRIAN OF GANNETT PEAK RIDGE; PHYSIOGRAPHY OF UPPER GREEN RIVER

FIGURE 1. PALEOZOIC SECTION OF WHITE ROCK, FROM ACROSS GREEN RIVER CANYON
P€, pre-Cambrian gneiss; €, Cambrian; O, Ordovician; D, Devonian; M, Mississippian; Pa and Pt, Pennsylvanian Amsden and Tensleep

FIGURE 2. EASTERN THRUST, CENOZOIC PENEPLAIN, AND HANGING VALLEY OF THIRD SUBCYCLE
Slide and Clear Creeks

PALEOZOIC OF WHITE ROCK; THRUST AND PHYSIOGRAPHY, LOWER SLIDE AND CLEAR CREEKS

Fork Gypsum Creek on the east flank of the Battleship Mountain syncline the underlying coarse-grained quartz monzonite is partly leached, disintegrated, and decomposed for 8 to 10 feet below the base of the Cambrian; its original biotite is now largely chlorite. The contact is quite even. The lower Flathead consists of interbedded fine conglomerate, arkosic grit, and banded sandstone locally containing small angular quartz pebbles at the base and ranging from Indian red to light yellowish rusty brown. In places the beds are ribboned and variegated. Sandstone with numerous rows of small angular quartz particles is dominant. Small angular pink feldspar fragments are fairly abundant. The beds are of medium thickness, and the bedding is fairly distinct. Cross-bedding is common. The upper strata are ripple-marked and less indurated than the lower. So-called "fucoidal" markings occur on bedding planes, and casts of selenite crystals occur on the surfaces of the top layers.

The section on Sheep Mountain was measured near the bead of the easternmost creek entering the south end of lower Green River lake, its base being at 10,500 feet altitude at a point slightly less than 1 mile northeast of the summit of Sheep Mountain. The underlying pinkish-gray fine-grained biotite granite is decomposed to depths of at least 6 inches. The lower 130 feet of the Flathead is mainly quartzitic light rusty-brown cross-bedded sandstone in beds of varying thickness, interbedded with fine-grained arkosic conglomerate. Conglomerate and finer-grained sandstone are rarer in the upper strata. A $1\frac{1}{2}$-foot layer of purple, ferruginous, thin-banded, somewhat gritty quartzite separates the lower member from an overlying 50 feet of sandstone, similar to the lower, but containing pipelike concretions at the top. The uppermost 35 feet of the Flathead consists of the same kind of sandstone but contains thin interbeds of sandy shale in its upper part. About a square mile of Flathead is exposed on the Continental Divide in secs. 26, 27, and 35, T. 40 N., R. 108 W., and there is another outcrop, with higher Cambrian and Bighorn, mostly in sec. 34, same township.

No fossils have been found in the Flathead sandstone though they occur immediately above it. There is no proof that the Flathead is marine, and it may be largely a residual, feldspathic sand in part redeposited by streams and waves.

The lower shale formation is 120 feet thick in the Battleship Mountain section and 186 feet in the Sheep Mountain section. The lower 10 feet of the Gypsum Mountain section is dark-green finely fissile bentonitic, chloritic, and sericitic shale containing oboloid and linguloid brachiopods. The second member is poorly indurated medium-grained buff sandstone, 70 feet thick, weathering brown to light rusty, thin flaggy-bedded, and full of small pellets of glauconite in the upper half. This is overlain by 40 feet of dark dirty gray-green fissile shale with much sericite and occasional lenses less than 1 inch thick of dark butternut-brown micaceous limestone. A zone 24 to 29 feet beneath the top of the shale on the eastern slope of Gypsum Mountain contains numerous casts of whole trilobites (*Ehmaniella*). The fossiliferous shale—ordinarily dark dirty brownish-green—has numerous minute flakes of white mica and a considerable proportion of minute calcite crystals.

On Sheep Mountain is the following section, in descending order:

	Feet
1. Shale, olive drab, calcareous	25

6. Dolomite (?), shaly, nodular, laminated, forming recess	1	6
7. Limestone, nodular, light gray, laminated, weathering in thin, rough layers	4	
8. Limestone, compact, nodular, light gray, lithographic	1	
9. Limestone conglomerate, like those below, light gray; lithographic-textured pebbles in crystalline matrix		6
10. Limestone, light green, very nodular and irregularly laminated; forms recess		9
11. Limestone conglomerate like (13), nodular, both lithographic and crystalline	1	6
12. Mudstone, like (14) below but more limy	1	
13. Limestone conglomerate, sparsely glauconitic, light gray, crystalline, varying in thickness		9
14. Mudstone, nodular, limy, light green like (16), with small nodular concretions of fine-textured light-gray limestone	1	6
15. Limestone, with conglomerate at base 1 to 4 inches thick; limestone is light gray, brittle, fine-textured	1	5
16. Mudstone, limy, light green, with minute specks of sericite and glauconite, very irregular and nodular concretionary; apparently rill-marked	1	5
17. Limestone conglomerate with flattened shingle pebbles		7
18. Limestone, glauconite-specked, crystalline, fossiliferous, dark gray, with layer of flattened pebbles at top; weathers dark brown	1	
19. Shale, light sea green, finely fissile, dark dull green below; weathers purple brown	11	
Total	99	10

The Sheep Mountain section has a lower green argillaceous and limy zone 24 feet thick, a middle thin-bedded limestone topped with a layer of *Eoorthis*, 28 feet thick, and an upper thin platy gray limestone 30 to 40 feet thick.

The section on the west wall of lower Clear Creek has 50 feet of limestone conglomerate strata with trilobites at the base. The pebbles, most of which are greenish and flattened, range up to 2 inches in size. Most of the thin interbedded wedges and lenses of nonconglomerate limestone are fine-grained and dove-colored. Most of the limestones in the conglomerates are packed with small clear calcite oölites. Mud cracks and rill marks are common on the bedding planes of the denser fine-grained limestones. Next comes a 5-foot zone of limestone full of brachiopods, some probably *Eoorthis*. The upper 30 feet is denser, dove-gray, thin- and wavy-bedded limestone.

The lower part of the upper limestone formation (that is, the part below the sandstone parting) contains, 25 feet above its base in Sheep Mountain, the following trilobites of the *Cedaria* zone, as determined by Lochman: *Modocia* cf. *oweni* (Meek and Hayden), *Modocia* sp. Lochman, and a new genus. *Cameraspis, Tricrepicephalus* (?), *Modocia. Deadwoodia,* and two new genera of trilobites were found 70 feet above the top of the parting sandstone.

The total thickness of strata referred to the Cambrian is about 1200 feet on Gypsum Mountain and in lower Clear Creek valley and about 1100 feet on Sheep Mountain. Correlations with other sections in northwestern Wyoming are questionable because of overlap; lithologic members wedge out toward the east. Probably the lower shale division, the Death Canyon limestone, and the upper shale division are to be referred to the Gros Ventre formation, as originally named by Blackwelder (1918). That the limits of these distinct depositional units are strictly contemporaneous throughout western Wyoming is improbable, since the shore line of the basin probably was moving eastward during deposition.

The upper limit of the Cambrian strata is not known. No certain lithologic evidence of a time break between upper Cambrian and the Bighorn dolomite has been detected, and apparently such must be determined mainly on the fossil evidence.

CAMBRIAN FOSSIL HORIZONS

Trilobites collected from Cambrian strata were determined by Lochman, and Cooper determined the brachiopods. Most of the fossils were collected by Dr. F. E. Turner, Gordon Gulmon, and the writer. The horizons of these fossils from top downward are as follows:

UPPER CAMBRIAN

1. *Billingsella* (?) from 135 to 146 feet above the base of the buff, cross-bedded sandstone on White Rock facing upper Green River Lake and from 87½ to 103 feet above base of the sandstone on north wall of lower Clear Creek valley.
2. *Conaspis* and *Billingsella* (?) in a light-gray limestone containing milky-white chalcedony 131 feet above base of the same sandstone on White Rock near upper Green River Lake. Franconia equivalent, *Conaspis* zone.
3. At 87 to 99 feet above base of same sandstone on Sheep Mountain and north wall of lower Clear Creek; *Billingsella perfecta*.
4. "*Eoorthis remnicha*" and *Otusia* at 81 feet above base of same sandstone on Sheep Mountain. "*Eoorthis remnicha*" from 76 to 82 feet above base of same sandstone on north wall of lower Clear Creek valley.
5. Sixty-five to 70 feet above base of same sandstone, lower Clear Creek: probably a new species of *Burnetia*, *Elvinia roemeri*, *Cameraspis*, *Acrocephalites*, *Deadwoodia* (?). *Elvinia* zone of Franconia stage.
6. Two feet below base of sandstone: *Syspacheilus*.
7. Ten feet below base of same sandstone, lower Clear Creek: *Talbotina*, *Maryvillia;* (6) and (7) upper half of *Cedaria* zone.
8. Lower 50 feet of limestone overlying upper shale formation: *Modocia*, *Talbotina*, *Cedarina* (lower half of *Cedaria* zone of Dresbach stage).

MIDDLE CAMBRIAN

1. Sheep Mountain, 180 feet above top of Death Canyon limestone, in a conglomeratic limestone: *Olenoides* and several unidentified genera.
2. Sheep Mountain, 77 feet above top of Death Canyon limestone, in the top of an edgewise conglomerate 13 inches thick: *Marjumia* sp. Resser, *Marjumia tipperaryensis* Miller, *Glyphaspis tetonensis* Resser.
3. Twenty-four to 29 feet below base of Death Canyon limestone on Gypsum Mountain and 35 feet below base of the thick upper Death Canyon limestone on Sheep Mountain (fossils of No. 2 of section given in foregoing description): numerous whole carapaces of *Ehmaniella*.
4. In lower shale formation immediately above the Flathead; east flank of Battleship Mountain syncline, in lower 10 feet of chloritic and sericitic shale: linguloid and oboloid brachiopods.

BIGHORN DOLOMITE

The Bighorn dolomite is intercalated between the upper Cambrian and the Devonian Darby. Its exact upper and lower limits are uncertain. It may range from lower Cincinnatian to Niagaran, although it is not certain that the Niagaran is present, and possibly some of the strata are lower than Cincinnatian. On the west wall of lower Clear Creek valley the Bighorn dolomite is not over 490 feet thick; it is 600 feet thick on Gypsum Mountain and probably somewhat less than 500 on Sheep Mountain. This and the Madison are the two most prominent ridge makers among the sedimentary rocks (Pl. 3, fig. 1). The upper part is more massive and resistant, generally forming an overhanging cliff. The uppermost thin-bedded Leigh member is less resistant. The Upper Cambrian limestone forms the basal part of the Bighorn scarp. Fossils are rare in the Bighorn; ordinarily only occasional *Receptaculites* and *Streptelasma* are noticed. Purple fluorite occurs in vugs on White Rock.

The section of Bighorn dolomite on Gypsum Mountain is as follows:

	Feet	*Inches*
Top		
1. Dolomite, light cream gray, thin-bedded (Leigh member?). Some of upper part may belong to the Darby	75	
2. Dolomite, light gray, fine-textured, sugary, occasionally cherty, massive, rough, pitted-weathering	270	
3. Covered interval	40	
4. Limestone, dark gray, finely crystalline, with thin, irregular chert nodules; heavy-bedded	18	
5. Dolomite, light gray	2	
6. Limestone, irregularly silicified, very finely crystalline, light gray		10
7. Dolomite, light gray, weathering light buff or cream, fine sugary, varying from thin- to heavy-bedded; upper 120 feet mottled brown and buff on weathered surfaces; some chert about one-third the way above the base	170	
8. Dolomite, medium gray, fine sugary, thinly but irregularly banded, with light-gray bands separated by thinner brown bands; weathers light gray	26	
Base Total	601	10

No fossils have been found in either the top or bottom of the dolomite. Possibly much if not most of it was deposited either in water too deep for thick-shelled neritic organisms or possibly even in water unfavorable to any organisms. On the other hand, diagenetic changes may have destroyed most of the organic remains.

DARBY FORMATION OF THE DEVONIAN

The Darby consists of alternating magnesian limestone or dolomite, shale, and minor sandstone. A few fossils indicate its Devonian age. The strata are fairly weak, outcropping on a gentler slope between the precipitous scarps of the Bighorn below and the Madison above (Pl. 3, fig. 1). It is 285 feet or more thick on the west wall of lower Clear Creek valley, 384 feet (according to Blackwelder) on Sheep Mountain, and at least 300 feet on Gypsum Mountain. The following section comprises nearly all the strata in the vertical section south of Slide Lake where many beds have been thrust out through intraformational slipping:

	Feet	*Inches*
Top		
1. Magnesian limestone at top, light gray buff, irregularly fractured, fine powdered-sugar texture, many calcite geodes, no bedding planes. Lavender streaks at base	28	

	Feet	Inches
2. Mudstone, platy, both sandy and calcareous, lavender, light maroon to purplish	15	
3. Limestone, very sandy, ripple-marked, ribboned light gray to lavender. Basal $2\frac{1}{2}$ feet is a conglomerate	29	
4. Sandstone, clayey, thin- to irregular-bedded, secondary calcite, yellow	20	
5. Limestone, gray, weathering dark gray; fine sugary crystalline, rough surface	8	8
6. Sandstone, green; sand grains subrounded, etched, of variable sizes from coarse to fine; light green color probably caused by hydrous iron silicate; extremely fine-grained matrix looks like hardened bentonite		3
7. Limestone, buff, texture of brown sugar, very cavernous		6
8. Limestone, dense, fine-grained, gray; with thin green shaly interbeds	3	4
9. Mudstone, platy, sandy, green, with thin sandstone interbeds, grades down into bituminous dolomite	26	
Total	130	9

Blackwelder (1918) gave a detailed section on Sheep Mountain. There Dr. F. E. Turner found small limestone pebbles in the basal 1 to 6 feet, ostracoderm plates in an 8-foot bed of limestone about 33 feet above the base, an arthrodire jaw about 100 feet above the base, and species of *Atrypa* near the middle; Blackwelder found *Atrypa reticularis* about 135 feet above the base.

The section on Gypsum Mountain does not include the basal strata, the base being somewhere in the 100-foot thick thin-bedded dolomite, the lower part of which is the Leigh. The limestones in this section are perhaps all magnesian or dolomitic:

	Feet	*Inches*
Top		
1. Limestone, with geodes, cavernous, gray to buff, thin- to medium-bedded, very fine-textured, an aquifer for underground water	64	
2. Shale, fairly fissile and regularly laminated, gray, weathering purple	10	
3. Mudstone, irregularly laminated, with much fine sand, dark gray, weathering purplish	6	
4. Limestone, finely crystalline, thin irregular laminae with brown dendritic manganese dioxide, yellowish tan, very clayey	19	
5. Covered but revealing some thin interbedded limestone and shale; upper half largely very light-green shale	55	
6. Limestone, thin-bedded, nodular, mottled light and dark gray, weathering in part pink, with numerous small dolomite crystals	4	
7. Sandstone, platy-bedded, tan, medium-grained, poorly consolidated; white layer 1 foot thick at 13 feet above the base. Thin red-brown layer in the middle	20	
8. Covered in part, largely thin-bedded, light- and dark-gray limestone. At top 3 feet of dark-brown bituminous finely crystalline limestone	27	
9. Limestone, medium-bedded, finely crystalline, brown gray, somewhat bituminous	5	
10. Partly covered, but mainly thin-bedded gray limestone; some layers are bituminous	27	
11. Covered largely but with some light-green shales. Some thin platy sandy and limy beds, tan, brown, and gray. The strata are largely interbedded shale, mudstone, and very fine-textured green sandstone. The upper 10–15 feet contains more shale	50	
12. Limestone, finely crystalline, very light gray	2	

13. Dolomite, dark gray brown, coarse, sugary-textured, very bituminous....	8	
14. Dolomite, thin-bedded, very fine-grained, light gray....................	10	
15. Chert, thin-bedded, gray to brown..		6
16. Dolomite, dark brown, fine sugary-textured, very bituminous...........	6	6
Base Total..	314	

MADISON LIMESTONE OF THE LOWER MISSISSIPPIAN

The Madison limestone is the most conspicuous cliff former among the sedimentary rocks; it forms a single escarpment. On the west side of White Rock overlooking upper Green River Lake the Madison cliff is notably buttressed and recessed (Pl. 3, fig. 1). No attempt has been made to subdivide the Madison; in the main it is heavy- to medium-bedded gray limestone, cherty in various layers, with a fauna comprising mainly brachiopods, horn corals, and crinoids; *Spirifer centronatus* is common. The Madison ranges from 565 to over 1000 feet thick in the plunging syncline of Sheep Mountain, much of the variation being attributable to intraformational slip. It is 830 feet thick on the west wall of lower Clear Creek. Both base and top are very definite, the basal beds resting on the eroded upper Darby limestone which is 28 feet thick just south of Slide Lake, 64 feet thick on Gypsum Mountain, and 80 feet thick on Sheep Mountain. At the upper contact the Amsden sandstone unconformably overlies the Madison.

AMSDEN AND TENSLEEP SANDSTONE, LIMESTONE, AND SHALE

The strata tentatively grouped as Amsden and Tensleep consist of four units, from base upward; a lower sandstone, a red and yellow clay member, an alternating limestone and sandstone member, and an upper sandstone referred to the Tensleep. A few fossils and fossil casts, mostly marine, have been found in these strata; *Neospirifer cameratus* occurs near the top of the Tensleep sandstone. There is yet no indication that any of these strata are older than Pennsylvanian. The combined Amsden and Tensleep are 630 feet thick on the west wall of lower Clear Creek and 618 feet on White Rock. The section on White Rock, from top downward, is as follows:

	Feet
1. Tensleep sandstone, buff, medium-grained, cross-bedded; locally quartzitic and contains segregations of chert (?) of practically all colors, but particularly red and pink; rests with irregular contact on (2)................................	300
2. Amsden limestone, very fine-grained, medium-bedded, whitish-gray, alternating with sandstone and clays................................	120
3. Limestone, as in (2)................................	38
4. Clay member, yellow tan and sandy at base, grayish above, upper 15 feet red joint clay................................	75
5. Sandstone, buff, cross-bedded, platy to massive, medium-grained................	85
Total................................	618

PHOSPHORIA FORMATION

The following section of the Phosphoria, which may not include the uppermost strata, is exposed on the ridge of White Rock northwest of the summit:

Top

	Feet	Inches
1. Limestone, light gray, coarsely crystalline, with a little glauconite; contains fossil casts and small cavities filled with calcite	4	
2. Chert, light gray and milky, with small nodules of tan-brown limestone; lower half forms a prominent bench	10	
3. Covered	3	
4. Mudstone, nodular, gray, mostly changed to hornstone	8	
5. Mudstone, shaly, nodular, with lenticles of coarsely crystalline calcite	5	6
6. Phosphate rock, bituminous, oölitic, dark brown		2
7. Mudstone, nodular, platy, light gray, more indurated and siliceous than underlying	5	
8. Phosphate rock, oölitic, rich in phosphate		3
9. Mudstone, nodular, platy, light gray	8	6
10. Shale. black, bituminous, some dark gray; weathers gray to brown	14	
11. Mudstone, nodular, platy, drab gray, weathering brown, phosphatic and bituminous	29	
12. Phosphate rock, rich, full of *Orbiculoidea*	1	
13. Sandstone, phosphatic, dark brown gray, medium-grained in lower half and fine-grained in upper half; cherty above, contains vertical borings filled with sand. *Spiriferina pulchra* abundant at the base	8	
Second prominent outcropping ledge above the base.		
14. Dark-gray layer of vertical borings filled with medium-grained sand	1	
15. Sandstone, phosphatic and calcareous, dark brown, weathers dark gray, glauconitic; thin, irregular, platy-bedded; contains *Lingula;* more calcareous in upper part	8	6
16. Covered interval, largely nodular argillaceous limestone and shale; some calcareous sandstone in upper part; at the base there are several feet of cavernous light-gray limestone with solid bitumen in the vugs	100	
17. Sandstone with *Orbiculoidea.* Upper 2 feet is coarse-grained with more numerous *Orbiculoidea;* lower 5 feet is well indurated, medium gray, with a small amount of glauconite and numerous small black particles	7	
18. Sandstone, glauconitic, calcareous cement, with gray oölitic phosphate; has calcite nodules and fillings	3	
19. Limestone, gray, fine-grained	1	
20. Limestone, nodular, geodic, fine-grained, with brown and milky chert and quartz. Irregular contact at base	2	
Total	218	11

Probably the next underlying bed is medium-bedded, light-gray calcareous sandstone, 9 feet thick, underlain by 12 feet of bluish-gray shale which rests on the Tensleep sandstone. If so, the total thickness of the section is about 240 feet.

A section which does not include the uppermost strata was made in the trough of the Sheep Mountain syncline; the order is from the top downward:

	Feet	Inches
1. Limestone, fine-grained, phosphatic, irregular-bedded dark gray, weathering yellowish; has borings filled with calcite	10–13	
2. Shale and limestone interbeds, phosphatic, brown	17	
3. Shale, limy	17	
4. Shale, dark blue, phosphatic	26	
5. Phosphate rock, very dark brownish gray; bottom contact somewhat irregular	6	

	Feet	Inches
6. Limestone, very phosphatic, gray, weathering yellowish, fossiliferous; contains a little chert; irregularly bedded and fractured	25	
7. Limestone, fine sandy and shaly, light gray; upper 7 feet phosphatic	40	
8. Limestone, dolomitic at top grading down into limy, cherty, phosphatic, and glauconitic grit	17	
9. Chert, irregular, flaggy, grading downward into fine shaly sandstone; greenish gray	6	
10. Chalcedony, nodular and lumpy, sometimes roughly prismatic, with calcite geodes	2	
11. Sandstone, limy, cherty, very irregularly platy, with thin prismatic layer of chert and calcite	5	6
12. Sandstone, dark gray to dark bluish brown, fossiliferous and phosphatic, considerable glauconite; weathers grayish brown	8	6
13. Chert, much-fractured, light gray, weathering yellowish	10	
Total	180	

Dr. F. E. Turner measured the following composite section farther north on Sheep Mountain:

	Feet	Inches
Top		
Dinwoody Formation		
1. Covered interval below exposed Chugwater red beds	81	
2. Limestone, gray, flaggy; weathers brownish and greenish	45	
3. Sandstone, limestone, and shale alternating, flaggy-bedded, gray	30	
4. Sandstone, fine-grained, gray, flaggy, weathers brown, alternating with 3- to 6-inch thick beds of gray flaggy limestone	6	
5. Shale, sandy, light gray	10	
6. Limestone, fine-grained, dense, light gray, with *Lingula*	1	
7. Sandstone, brown-gray, irregularly bedded, with pebbles at the base	4	
Total	136	
Phosphoria Formation		
8. Covered	25	
9. Limestone, creamy gray with green specks (not glauconite)	2	
10. Chert, gray, nodular, very irregular-bedded	12	6
11. Shale, brownish-blue, phosphatic	4	
12. Limestone, dark, dirty, phosphatic		6
13. Covered	6	
14. Chert, irregular, nodular, gray	4	
15. Shale, hard, gray, cherty, phosphatic	3	
16. Chert, medium gray, weathering light gray	3	
17. Shale, thinly laminated, irregular-bedded; alternates with 2-foot limestone layers becoming more prominent toward top	10	
18. Shale, thinly laminated, brown blue, phosphatic; weathering bluish	10	
19. Shale, more massive		9
20. Shale, thinly laminated, brown blue; grades upward into conchoidally fracturing, phosphatic shale; weathers bluish	25	
21. Limestone, phosphatic, black, granular	6	

22. Limestone, with many branching bryozoans, cherty in upper 3 feet, *Derbya*, *Spiriferina* 9 feet below top	19	
23. Limestone, massive, weathering light gray	12	
24. Limestone, partly massive, weathering yellow	12	
25. Limestone, light gray, platy, fine-grained; chert in upper 2 feet	5	
26. Limestone, light gray above and dark gray "peppery" below	12	
27. Chert, thin-bedded, gray; irregular and platy in lower 5 feet	15	
28. Sandstone and limestone, with *Orbiculoidea*, gray	12	
29. Chert	6	
Total	204 to 215	9

Small veinlets of turquoise were noted near the small lake south of the middle of the south line of sec. 34, T. 39 N., R. 109 W. A number of the strata of the Phosphoria contain large amounts of bitumen.

MESOZOIC ROCKS

Most of the Mesozoic rocks on the southwest flank of the northwestern part of the range are covered by Cenozoic; this is particularly true of the comparatively weak Cretaceous strata. The lower Mesozoic strata contiguous to the older rocks are badly sheared, fractured, and crumpled. Apparently the only fairly complete Mesozoic section is on the northwestward-plunging anticline extending from the Big Bend of Green River southeastward beneath Little Sheep Mountain into the lower northwestern flanks of Gypsum and Sheep mountains. The Mesozoic succession was not studied in detail.

A portion of the Dinwoody Triassic was included with the last section. The red (strictly speaking, salmon-colored) strata resting upon the Dinwoody are herein grouped together as Chugwater; possibly the upper part of this succession is Jurassic, while the lower is probably Triassic. The best-exposed section of the Chugwater, and the one least likely to be seriously disturbed by shearing, is in the NW. ¼ sec. 36, T. 39 N., R. 109 W., in the north spur of Sheep Mountain which forms part of the west rim of Green River valley west of lower Green River lake. A partial section beginning at the contact of the overlying Sundance and extending downward is as follows:

	Feet
1. (a) Red siltstone with concretionary limy beds at top. (b) Mostly red and buff cliff-forming fine-grained sandstone. (c) Red siltstone at base (Total of a, b, and c)	530
2. Mostly red siltstone with some platy thin-bedded gray sandstone. Thin platy beds of pink sandstone at base	150
3. Limestone, buff, laminated	3
4. Mostly red siltstone, at least	630
Total	1313

Below these strata is perhaps 500 feet of red silty sandstone.

Chugwater strata exposed on lower Mill Creek north of lower Green River lake have a lower mainly red, fine-grained, extensively ripple-marked sandstone member containing, in the middle, some fine sugary-textured tan to very light-green dolomite carrying calcite concretions and interbeds of purple silt. In the upper part in ascending order are (1) thinly laminated ripple-marked clayey maroon sandstones, (2) interbedded purple and thin light-green silt, and (3) "rauchwacke" (cavernous) tan and gray fine sugary-textured dolomite with small selenite crystals, evidently a residue from solution of gypsum. Part of the strata are sheared out here on the western flank of a tightly pressed and over-turned anticline although the red beds are not overturned.

The gypsum strata in the upper Chugwater generally have been dissolved from the higher outcrops where there has been heavier precipitation; they are exposed in the drier, lower sage-brush country, such as along the South Fork of Gypsum Creek. The Chugwater group outcrops extensively west of Green River below the Big Bend. As usual in the Rockies, the weak Chugwater is the "zone of lubrication" of the soles of thrusts.

The following section of the Sundance was made on lower Mill Creek just north of the outlet end of lower Green River lake:

	Feet	Inches
Morrison formation at top. Basal sandstone and conglomeratic sandstone.		
1. Reddish residual clay soil; limestone buff, fine-textured, much disintegrated	5	
2. Clay with some sandstone	11	6
3. Sandstone, gray, cross-bedded, medium-grained	6	
4. Conglomerate of small pebbles of black and white chert	1	6
5. Clay, gray below, green above	103	
6. Sandstone, medium-grained, cross-bedded, light gray, rather evenly and thinly laminated	27	
7. Clays, sandy, gray	117	
8. Sandstone, limy, glauconitic, light gray, flaggy	5	
9. Clays, light gray, with thin platy sandstone beds in the middle 5 feet	20	
10. Sandstone, glauconitic, soft, medium grayish green, platy; has limy nodules with *Gryphaea*	13	
11. Clay, gray drab	19	
12. Bed with small pebbles		6
13. Covered in part but mainly light-gray *Gryphaea* limestone	4	6
14. Sandstone, glauconitic, light gray, fine-grained, platy-bedded	3	
15. Limestone of *Gryphaea* shell breccia, medium gray	2	
16. Sandstone, gray green, medium-grained, platy-bedded, with numerous glauconite pellets	9	
17. Clay	233	
18. Limestone, oölitic, gray	1	
19. Clay, gray drab	62	
20. Limestone, oölitic, gray	5	
21. Clay	55	
22. Limestone, platy, fine-textured, dark gray		6
23. Clay	12	

24. Limestone, fossiliferous, gray		6
25. Clay, gray-drab	35	
Total thickness of Sundance	750	

Camptonectes is a common Sundance fossil.

Cretaceous rocks are exposed locally in the northern part of the Big Bend of Green River, south of the stream and at the south base of Little Sheep Mountain. Most apparent is the Mowry—dark blue-gray clays with thin interbeds of bentonite. Strata referred to the Cretaceous were noted also at the old D. M. Gray coal mine, a short distance east of the middle of the west line of sec. 20, T. 36 N., R. 109 W., about 1 miles east and a little south of the Willow Creek Ranger station. In 1909 two beds of coal were exposed, the upper 4 feet thick, and the lower 3 feet thick, separated by a black shale parting dipping southeast (overturned). The coal is bituminous, shiny black, with a fracture approaching conchoidal. It contains a little sulphur and slakes freely when weathered.

CENOZOIC DEPOSITS

Most of the lower country of the uppermost Green River Basin is covered with boulders, gravels, cobbles, and yellowish sands, partly sorted and stratified. In the valleys these are largely glacial or fluvioglacial. Possibly Wasatch is a 200-foot-thick capping of interstratified gravels, boulders, and sands, dipping about 7° NNW., resting upon Upper Cretaceous dipping 57° NE. on Little Sheep Mountain in the south-central part of T. 39 N., R. 109 W. On the north shore of Halfmoon Lake, about 3 miles east of Fremont Lake (T. 34 N., R. 107–108 W.), pre-Cambrian gneiss is overlain by interbedded light-gray laminated volcanic ash, brown arkose, and bentonite.

Boulder beds resembling the Pinyon conglomerate of the Mount Leidy Highland and southeastern Yellowstone Park (Pinyon Mountain) lie on the west against gneiss northeast of Union Pass in secs. 20 and 21, T. 41 N., R. 108 W. The boulders, well rounded and up to 1 foot in diameter, are mainly quartzites, largely brown, pink, and red but with some gray, white, and black. Some of the boulders are crystalline quartz, and some are jasper and carnelian. There is a small amount of arkosic yellow sand matrix. The topography is of gently rounded contours; the slope is away from the gneiss to the east. Most of the drainage is underground. The boulders most probably were derived from the Beltian terrane of the upper pre-Cambrian though possibly from Paleozoic and Mesozoic quartzites, but no exposures of the parent rocks are known in the Wind River Range.

Yellow arkosic sands outcrop in the valley of Warm Springs Creek from half a mile to a mile north of Union Pass (T. 41 N., R. 108 W.).

There are interstream ridges eroded from gravel, boulders, and sand between Roaring Fork and Fish Creek basin in the southeast quadrant of T. 40 N., R. 109 W.; also they form the northwest and southeast walls of New Fork Lakes in the northeast quadrant of T. 36 N., R. 110 W., the ridge northwest of Willow Lake in the north part of T. 35 N., R. 109 W., the high ridge forming the northwest wall of Fremont Lake basin, the high ridge just south of Halfmoon Lake (T. 34 N., R. 108 W.), and the ridge rising on the north of Boulder Lake (T. 33 N., Rs. 107 and 108 W.). These may be veneered by older morainic deposits, judging by the large surface boulders. Similar gravels cap Flattop and Little Flattop mountains between New Fork and Willow lakes. Black Butte, in the corner between T. 36 N., Rs. 110 and 111 W., and T. 37 N., R. 110 W., rising 900 feet above the valley of Green River (to the west and north), appears to have been eroded from poorly stratified boulders, gravels, and sands.

These deposits may be a veneer upon older rocks. They are of uncertain age. Possibly they are remnants of alluvial debris aprons deposited during the 9000- and 8500-foot erosional subcycles, or they may belong to an older glacial stage or stages, or they may be Wasatch.

STRUCTURE

PALEOZOIC AREA

The Laramide orogeny in the Green River lakes probably formed at first a series of folds and then, with increasing stress, two westward thrusts and between them three minor upthrusts. Displacement increases north-northwestward on the eastern thrust but southward on the western and ends in northward-plunging anticlines in the area between. The three minor high-angle thrusts may be imbrications off the main sole of the western thrust, their surfaces possibly rotating by "back-folding". The western two of the intermediate blocks lobe to the west as if pushed in that direction by the eastern thrust. The northeast strike and prevailing northwest dip of the Paleozoic rocks between lower Green River lake and the north end of the western thrust indicate movement northwestward, as if a force couple developed rotational shearing stress.

The mountain area between New Fork and Green River lakes is west of the mountain flank to the north; its east and west boundaries are the two westward or main thrusts. The western thrust changes to the north into a north-northwest-plunging anticline extending to the middle of the Big Bend of Green River. East of it is a syncline, plunging likewise, whose trough is followed by Green River for about 6 miles downstream from upper Green River lake. The intermediate minor thrust blocks plunge north into the south flank of this syncline and, to the east of the north end of the western thrust, change into asymmetrical anticlines with steeper east flanks and northeast plunge. East of lower Green River lake the eastern major thrust overrides, on the east flank of the syncline, the fractured steeper-dipping flank of a narrow anticline. South-southeast of the latter, southwest of the eastern thrust, is a north-northwest-plunging syncline through White Rock; on both flanks of this the weak shaly Cambrian and Darby strata are thinned by stretching and shearing.

The eastern thrust cuts the Paleozoic area at the southeast end of the White Rock ridge (Pl. 7, fig. 2). The overriding pre-Cambrian gneiss and granite in the saddle between Green River and Slide Lake is ground into a zone of fine fragments a quarter of a mile wide; the Paleozoic rocks of the sole are dragged westward until they are vertical (Pl. 7, fig. 2). To the north, between Slide Lake and the Clear-Mill creek divide saddle, a block of Madison limestone 3 miles long has been dragged up and forward from the east flank of the White Rock syncline so that it overrides, in a subsidiary thrust, the section from Madison to high Chugwater, striking mostly at right angle to the thrust (Pl. 3, fig. 2); probably some red Amsden, from a distant view, overlies Madison in the dragged-up block on the divide between Slide Lake and Clear Creek. The outcrop is inaccessible because of instability of greatly shattered rocks on the steep slope. Between Clear Creek and Roaring Fork, in the narrow ridge just northwest of lower Green River lake, apparently the thrust sheet in its former extent dragged westward underlying Paleozoic rocks of the sole into a westward-overturned north-plunging anticline. South of Roaring Fork pre-Cambrian is thrust upon overturned Sundance. Trace of the thrust is mostly covered north of Roaring Fork.

The surface trace of the western thrust is mostly covered by slides from the scarp of resistant pre-Cambrian and Paleozoic rocks of the thrust sheet down onto the weak Mesozoic (especially Chugwater) rocks of the sole; the upthrust edge produces a prominent though likely resequent fault scarp (Pl. 4, fig. 2). The fault ends at the north, in the northwest spur of Gypsum Mountain, in a recumbent double anticline, overturned to the west at its south end. Paleozoic rocks are overturned about 45° on the west side of the thrust in the ridge north of the South Fork Gypsum Creek. There are two exposures of the fault on the north wall of the lower end of Jim's Creek canyon. In one of these (Pl. 4, fig. 1), showing Cambrian thrust over Darby with three parallel thrusts in pre-Cambrian visible farther east across the canyon, the fault surface (in the foreground) dips 45° N. 40° E. In the valley, under the fault, Tensleep, Amsden, Madison, and Darby are overturned. The westward-sloping ridge just north of the south fork of Jim's Creek is veneered with Middle Cambrian dipping 30° about S. 70° W.; this Cambrian overrides Bighorn dipping opposite (ENE.) and overturned 25°, the Bighorn overriding the Chugwater. Two miles south at the east end of upper Boulder basin pre-Cambrian granite rests on Phosphoria, overturned 60°. On the north wall at the mouth of New Fork River canyon pre-Cambrian granite rests upon low Paleozoic; the whole Paleozoic section and at least part of the Chugwater is overturned about 45°. There is extensive talus along the scarp base farther south; about a mile east by south of the Willow Creek ranger station pre-Cambrian of the north-facing scarp of Little Flattop Mountain lies above overturned Upper Cretaceous. There is a fairly broad syncline, with gentler west flank, west of the fault scarp; Chugwater and Sundance are therein exposed.

The high-angle thrust fault underneath upper Green River lake and just north of it cuts diagonally across the entire Paleozoic section in the west flank of the syncline under White Rock. Near the foot of the northwest end of White Rock ridge, half a mile from Clear Creek, the fault overrides Madison, overturned 10°. Thrust up along it, north of Clear Creek, is the northern end of the White Rock syncline, whose axis there is turned to the west-northwest and whose axial plunge is steepened greatly by a combination of upthrust and formation of the narrow anticline just east. The high-angle upthrust followed by the upper course of Porcupine Creek ends in a short, steeply northward-plunging, eastward-overturned anticline about 1½ miles west of the upper end of lower Green River lake. The western of the three high-angle minor thrusts ends northeastward in the anticline exposing Cambrian at the head of South Fork Gypsum Creek and the southeast foot of Gypsum Mountain. Flanking on the east is the north-northeast-plunging syncline extending through the summit of Battleship Mountain (2 miles south by west of the summit of Sheep Mountain).

PROBABLE THRUST OUTLIERS

Four hills in the southern half of T. 37 N., Rs. 109 and 110 W., extend for 3 miles to the east of the Pinedale-Green River lakes road south of Boulder Creek. Much brecciated, recemented Bighorn dolomite caps the hills, flanked by loose Cenozoic accumulations; bedrock is covered. To the east on Boulder Creek, the lowest outcrop of the western thrust is at 9000 feet, the easternmost Bighorn outlier has that rock down to about 8800 feet, and the westernmost outlier has it down to about 8000 feet. Hence if the hills are outliers of the western thrust either it originally moved downgrade, its surface was downwarped subsequently, or the outliers have lowered upon removal by solution of once-underlying soluble rocks or by undermining upon removal of underlying clay. There are some mineralized spring-fed ponds near the base of the westernmost outlier. Outlier Bighorn dips steeply east and has weathered in high slender "hoodoo" pinnacles in the second hill from the east (the one in center middle distance, Pl. 4, fig. 2) and has greatly slumped in the other outliers. The masses are too large to be glacial erratics; the easternmost has an area of about 100 acres. Black Butte, between the westernmost outlier and Green River, whose top is 1000 feet higher than the river flood plain at its base, shows no outcrops other than sand and gravel but may have a solid rock core. Green River swings abruptly to the west around the north bases of Black Butte and the three western Bighorn outliers. They are near the end of the broad southeastern-plunging main anticline of the Gros Ventre Range, the westernmost outlier being a little east of a line continuing a remarkable nearly straight south-southeast course of New Fork River, parallel to the strike of the westward thrusts in the area farther east. Other, subordinate, rocks in the outliers are Madison and Cambrian.

PRE-CAMBRIAN AREA

Although pre-Cambrian rocks are commonly fractured seldom is the fracturing so conspicuous and easily traceable long distances as in the fresh rock above timber line in the Wind River Mountains, where deep trenches and canyons follow many of the fracture zones, adjacent to some of which scarps still persist. The map (Pl. 1) contains only a few of the more conspicuous fracture zones in the southeast part of the Fremont Peak quadrangle; many more can be traced on the Mt. Bonneville and Moccasin Lake quadrangles. Major streams not only occupy fracture zones, but major passes or saddles between those flowing opposite directions do likewise. Fractures strike from northwest through north to northeast, and some are transverse. Some are found only in pre-Cambrian rocks, and it is possible that in part at least they were formed in pre-Cambrian time.

The Flathead sandstone, about 1 square mile in area, on the Continental Divide

FIGURE 1. EXPOSURE OF WESTERN THRUST
Jim's Creek canyon

FIGURE 2. KLIPPEN OF WESTERN THRUST (FOREGROUND AND NEARER MIDDLE DISTANCE); WESTERN THRUST SCARP (FAR DISTANCE); CENOZOIC PENEPLAIN (ON HORIZON); EROSION SUBCYCLES (MIDDLE DISTANCE)
From klippe hill east of Black Butte

WESTERN THRUST AND KLIPPEN

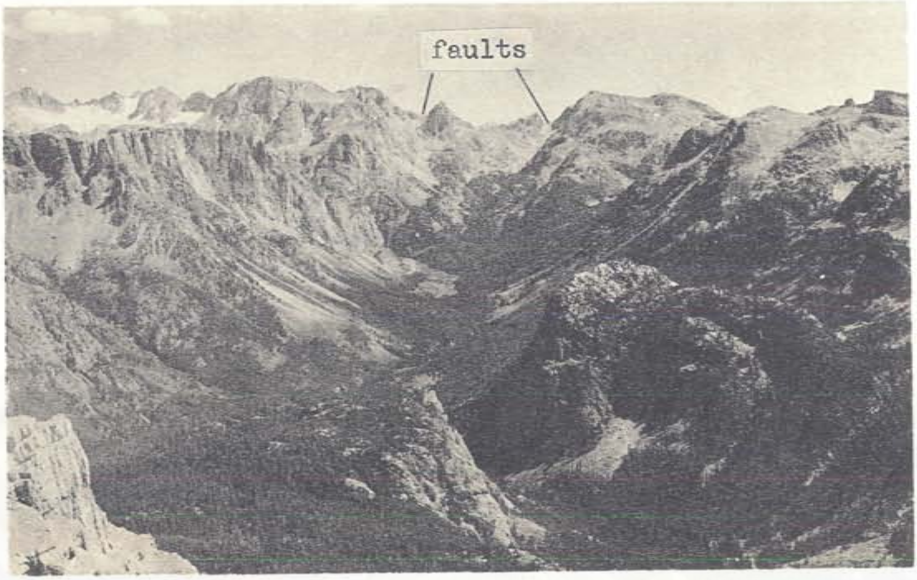

FIGURE 1. UPPER GREEN RIVER CANYON AND FAULTS

FIGURE 2. TRAIL CREEK FAULT RIFT (RIGHT OF CENTER)
Cenozoic peneplain, with felsenmeer, foreground and middle left

FAULT RIFTS OF UPPER GREEN RIVER CANYON AND TRAIL CREEK

12 miles north of Squaretop Mountain is downthrown to the north against pre-Cambrian, the fault crossing the divide with west-northwest strike; between the Divide and Simpson Pass 2 miles southeast a fault-line scarp 1000 feet high surmounts the 10,500-foot erosion shelf.

Faults of the Paleozoic area extend into the wholly pre-Cambrian area. (*See* Plate 1.) The eastern thrust continues south-southeastward from the saddle at the east base of White Rock down Elbow Creek below its bend; the creek, flowing south-southeast into northwest-flowing Green River, follows it. The river is in the fault zone as far upstream as the upper end of Threefork Park (Pl. 5, fig. 1), from which the fault extends through the east wall of the main canyon up the lower Stroud Creek valley and southeastward to Island Lake. It is paralleled, in upper Green River canyon, by another fracture zône passing through Granite Lake, its surface forming, farther southeast, the southwest wall of the river canyon, and, beyond Threefork Park, where it dips 45° ENE., it is followed by the river's middle fork. Another fault, joining the second near the mouth of Trail Creek, extends up the creek (the valley to the right in Pl. 5, fig. 2) through Green River Pass and Summit Lake and thence down Pine Creek to Fremont Lake.

The fault beneath upper Green River lake extends up the deep canyon, partly filled by slide rock, through the small unmapped lake and deep notch at the west base of Squaretop Mountain. The next upthrust to the west has a much-fractured quarter-mile-wide zone of very unstable rock at the head of Porcupine Creek, south of which it is occupied by a valley tributary to New Fork River. The western upthrust fault, south of where it ends in an anticline, crosses South Fork Gysum Creek, is followed by its tributary heading just east of Saltlick Mountain, and produces a broad swale in the granite in the 10,500-foot erosion stage at the head of Jim's Creek drainage.

The upper, deeper canyon of Roaring Fork is in a fault zone joined by six fractures followed by streams of the south canyon wall. Simpson Pass ($9\frac{1}{2}$ mi. north and 2 mi. east of Squaretop Mountain, foreground, Pl. 6, fig. 1), is a saddle on a wide fault zone of high-angle westward thrusting; the brecciated zone in the pass is several hundred yards wide and equally wide 2 miles to the south in the landslide zone of the Clear Creek-Roaring Fork divide. North of the pass (Pl. 6, fig. 1) Bow Lake is in the fault zone; a fault branching from it at the head of Bow Lake probably continues northeast down Jakey's Fork canyon. Near the pass a diabase dike is displaced horizontally about a mile.

The deep canyon and cirque, containing a large landslide, north-northwest of the middle of the lower lake on Clear Creek, is in a fault zone. Faults form the side walls of a cirque a mile east of upper Porcupine Creek (Pl. 2, fig. 2, at right); the same view, just to the left, shows another valley following a fault. Ross lakes, on West Torrey Creek east of the Continental Divide, occupy a fault rift 2000 feet deep, crossed at its south end by a transverse rift 1500 feet deep.

Rectangular drainage, produced by fractures crossing at right angle, is notable in upper Boulder Creek basin on the Mt. Bonneville quadrangle; a great rift up to 2000 feet deep, eroded in a fracture zone, strikes N. 25° W. across this quadrangle, followed by the head of South Fork Bull Lake Creek; thence across the Continental

Divide it forms a pass, continues in the headwaters canyon of Middle Fork Boulder Creek, produces the saddle at the east base of Mt. Bonneville, and continues down the headwaters canyon of East Fork River.

Fault zones near the Continental Divide on the Fremont Peak quadrangle, suspected to have late Cenozoic displacement, will be discussed in the section on physiography.

The California Co. Pinedale Unit No. 1 boring, situated in the center of SW $\frac{1}{4}$ NE $\frac{1}{4}$ sec. 14, T. 31 N., R. 104 W., 14 miles south of the town of Pinedale, altitude of surface at boring stated to be 6942 feet, reached what is reported to be the Green River-Wasatch contact at 4050 feet depth, the top of the Fort Union at 6850, and was thought to be still in the Fort Union (Paleocene) where drilling ceased at more than 10,000 feet (more than 3000 feet below sea level). If the underlying Cretaceous is from 9200 to 11,780 feet thick, as in the Rock Springs dome, if Morrison, Sundance, and Chugwater combined are 2850 feet thick and the Paleozoic is 4000 feet thick, the top of pre-Cambrian at the well site would be more than from 19,000 to 21,500 feet below sea level. Pre-Cambrian reached an altitude of at least 14,000 feet above sea level in the summit of the Wind River Range. Therefore structural relief may be as much as 35,000 feet between the range summit and the bottom of the Green River Basin.

PHYSIOGRAPHY

FREMONT PENEPLAIN

The Fremont peneplain, which bevels tilted Paleozoic rocks of Sheep (Pl. 6, fig. 2), Gypsum, and Battleship mountains, is best preserved in the area entirely above timberline in the northwest part of the range, especially both sides of Green River and, on the east side of the Continental Divide, between Jakey's Fork and North Fork Bull Lake Creek. The 10,500-foot erosion subcycle, in early old age stage, has destroyed it south of New Fork River, vestiges farther south being confined mainly to the Continental Divide and contiguous interstream ridges, which have greater differential relief, since they are narrower and scattered, and hence were eroded more in later time.

Possibly its better preservation in the northwest sector is attributable to its location at the headwaters of the hydrographic divide, where streams thousands of miles from their base levels are still in early youth. Its surface slope was too gentle to produce ice movement and thus it was protected by ice and snow cover during glacial times. Perhaps its altitude is so high that precipitation has been low in its arctic climate and therefore erosion by running water has been relatively slight.

Extensive peneplain flats are interstream divides between Roaring Fork (Pl. 10, fig. 2) and Clear Creek and between the latter and Slide Lake (Pl. 7, fig. 2). Squaretop Mountain summit and the high flats both sides of Green River canyon (Pl. 2, fig. 2) are part of the peneplain. Goat Flat (Pl. 7, fig. 1), the area at the north base of Horse Ridge (Pl. 9, fig. 2, left), and the flat west of Ross lakes rift are peneplain remnants east of the Continental Divide.

Small, low residual knobs (Pl. 7, fig. 1) are scattered sparsely over the peneplain

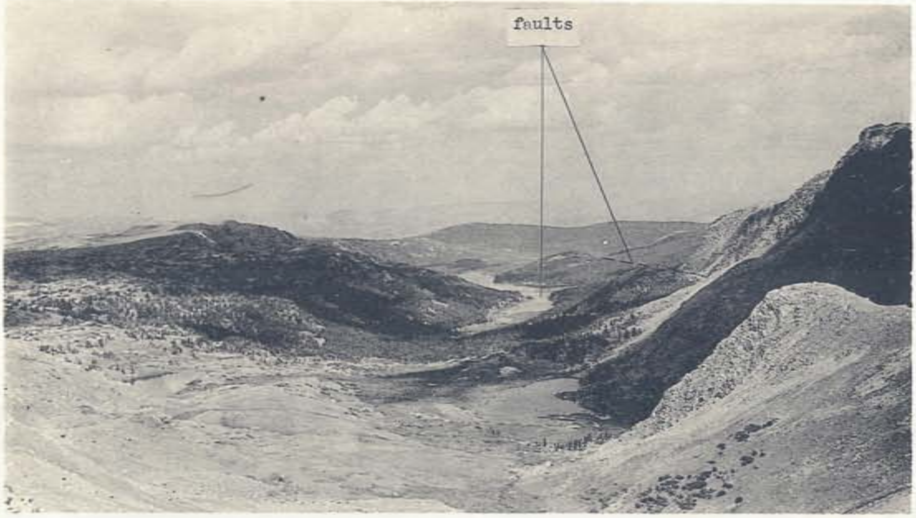

FIGURE 1. BOW LAKE RIFT FROM NEAR SIMPSON PASS
First erosion subcycle to left, second in middle

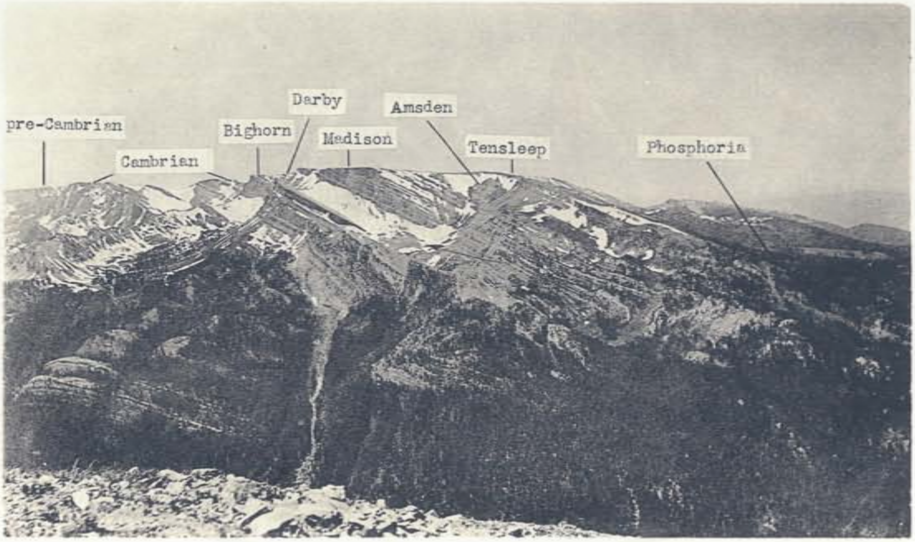

FIGURE 2. CENOZOIC PENEPLAIN BEVELING TILTED PALEOZOICS OF SHEEP MOUNTAIN
From ridge east of lower Green River Lake

BOW LAKE RIFTS AND SUBCYCLES; PENEPLAIN ON SHEEP MOUNTAIN

FIGURE 1. GOAT FLAT
East from south base of Downs Mountain ridge

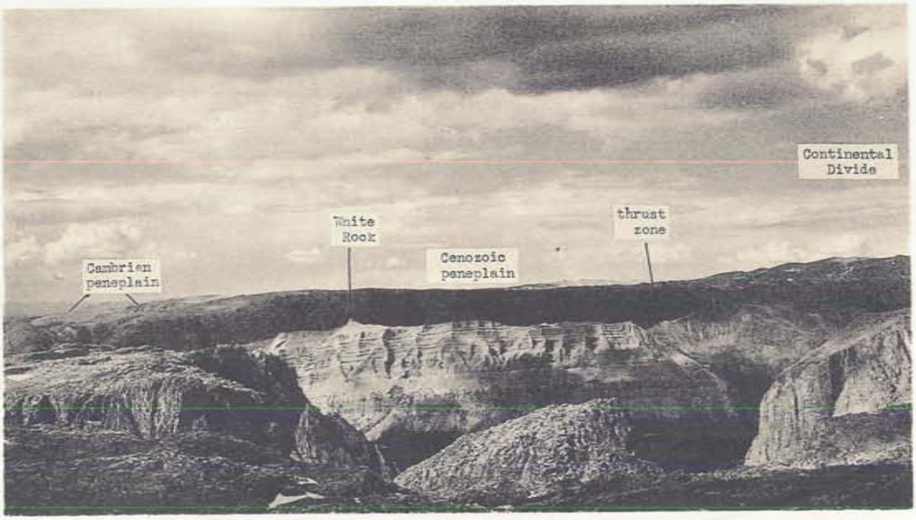

FIGURE 2. EAST FROM ACROSS GREEN RIVER CANYON

CENOZOIC PENEPLAIN

surface, some are solid rock, others are heaps of large angular boulders such as the summit of Downs Mountain, rising 350 feet above the flat surface. In places there is a mantle of disintegrated and partly decomposed rock. More often the surface (a felsenmeer, foreground, Pl. 5, fig. 2) is strewn with angular slabs, finer fragments having been removed by nivation, wind deflation, or running water. On the Continental Divide, in secs. 26 and 35, T. 40 N., R. 108 W., the peneplain surface is subhorizontal Flathead sandstone.

Lowest known peneplain remnants are at 11,200 feet altitude between South Fork Gypsum Creek and New Fork River within 2 or 3 miles of the western brink of the western thrust sheet. Original peneplain surfaces are at 11,500 feet on Gypsum Mountain and 11,600 on Sheep Mountain. Thence eastward the peneplain rises about 50 feet per mile for about 10 miles to 12,000 feet east of Green River canyon. There is greater surface slope to 13,000 feet along the Continental Divide at the north foot of Downs Mountain (Pl. 7, fig. 2, right horizon); increase in slope is above the 12,000-foot contour. The northward slope along the Continental Divide from there is 1500 feet in $10\frac{1}{2}$ miles, the Divide being shifted to the west in a great lobe in the much-fractured, easily eroded rocks of the Bow Lake basin. In $4\frac{1}{2}$ miles due north of the 13,000-foot flat at the north base of Downs Mountain the downward slope is 1000 feet; erosion later has lowered the surface here. Slope to the west from the Divide here is about 500 feet in $1\frac{3}{4}$ miles; east of the Divide, west of the Ross Lakes rift, it is about 100 feet in 2 miles. The eastward slope in Goat Ridge is about 200 feet per mile for 2 miles. The northeastward slope of Horse Ridge (Pl. 9, fig. 2, left horizon) is 500 feet in 7 miles. The gentler-sloping part of the peneplain surface east of the Continental Divide extends up to 12,500–12,600 feet but west of the Divide to only 12,000.

Several possibilities exist for the higher gradients in the Continental Divide section: its upwarping subsequent to peneplanation; it may be a low residual stream divide of the peneplain or of a rock pediment, it may be an exhumed part of the mid-Cambrian peneplain, or part of some other older and higher eroded surface.

The highest ridge of Wind River summit peaks is 12 miles long—from 2 miles north of Gannett Peak to 3 miles south of Knife Point Mountain. It rises quite abruptly from the peneplain surface; rise on the east takes place within about 1 mile from the Divide, or considerably nearer to it than on the west. The steep summit ridge was thought to be a monadnock area by Blackwelder (1913) and by Atwood (1940), but closer study suggests that it may be upfaulted since peneplanation.

Because all pre-Cambrian crystalline rocks both in the ridge and areas flanking it are substantially of the same order of resistance, abruptness of the ridge's rise and its extreme ruggedness in middle mature stage of erosion are somewhat unfavorable to the monadnock hypothesis, as may be seen in a number of views (Pl. 2, fig. 2; Pl. 5; Pl. 8, fig. 1; Pl. 9; Pl. 11, fig. 1, right horizon). The straight-based, lengthy, and steep-sloped scarps (Pl. 2, fig. 1; Pl. 8; Pl. 9, fig. 2; Pl. 10, fig. 1) suggest origin by late faulting. One scarp, more reduced than the others (middle distance, just below horizon, Pl. 11, fig. 1), lies at the northeast edge of the subdued surface of the 10,500-foot erosion subcycle, its base being the fairly straight course of a stream flowing southeastward into Island Lake (Pl. 1). The Titcomb Lakes basin east of it, in the 10,500-foot subcycle, has three faults parallel to the valley course, best visible from the Divide peaks at the basin's head; the east fault is at the base of the long, straight, and very steep scarp from a mile south of Fremont Peak summit north to the base of Mt. Helen (Pl. 10, fig. 1). The ice field (Pl. 9, fig. 2, right of center), 4 miles long, apparently partly fills a rift at the east foot of Gannett Peak ridge; seen in profile in the left horizon, same view, Horse Ridge, though modified by subsequent erosion, may be an uparched part of the peneplain, Dry Creek basin, with its important tributaries on the west side of the main stream, having developed on the east-northeast flank of the arch (Pl. 1). Possibly late faulting in the Gannett-Fremont peak ridge changes northward into an upwarp of the peneplain which extends to 7 miles north of Downs Mountain.

The Fremont peneplain is considered Pliocene by Blackwelder (1915) and by Atwood (1940); Atwood correlates it with the peneplain of the southern Rockies which he extends nearly to the shore of the Gulf of Mexico. Bauer (1934) and the Bransons (1941) think it is Eocene, holding that the nonvolcanic part of the White River detritals is sediment derived from its dissection. S. H. Knight (personal communication) thinks that subcycle surfaces in southeastern Wyoming, developed since peneplanation, are perhaps a series of pediment benches, presumably of the middle Cenozoic, preserved by a pyroclastic cover, whose removal subsequently resurrected the older topography.

No vestige of pyroclastic cover is known in the Wind River Range, and the north-flanking Absaroka volcanics are dissected by the erosion subcycles to be described. Bauer quite possibly is correct about there being a peneplain near the close of the Eocene, but it is not apparent that it is the Fremont peneplain. If erosion continued after Eocene, there was ample time since for a later peneplanation or for peneplanation of a rejuvenated surface from which may have been derived the White River deposits of the Wind River and Red Desert basins; furthermore, it is not at all unlikely that deposits in central Wyoming now grouped together as White River may prove to be complex of channel fillings, of different ages, such as are now known on the High Plains from Wyoming to Texas. If the region lay low and flat from the end of Eocene till late Cenozoic, so that there was little or no erosion, then, the Fremont peneplain can be Eocene.

The upper Green River canyon (Pl. 2, fig. 2; Pl. 5, fig. 1) and other canyons of the Wind River Range are thought to support the opinion that all rejuvenation subsequent to the Fremont peneplain is relatively recent. Although the Green River canyon walls are gneiss, resistant in solid state, the rock is visibly greatly fractured. The peneplain surface extends to the canyon rim; walls above the limit of glaciation are nearly vertical. The cross profile is very characteristically U-shaped. Depth below peneplain level is 3500 feet. It is a Pleistocene canyon.

No more than three glacial epochs have been determined— or suggested—for the Rockies. Possibly mountains were not yet sufficiently high for development of extensive glaciers during earlier epochs of northeastern North American ice sheets.

There are two types of drainage in the present higher mountains: the adjusted, subsequent main valleys and deep canyons in the weaker rocks of the fracture zones, and consequent streams flowing down from the Continental Divide ridge more or less at right angles to it. Consequent drainage is possibly an inheritance from a residual divide area of a peneplain or rock pediment, but it may be an outcome of tilting, faulting, or folding of a former peneplain or rock-pediment surface.

EROSION SUBCYCLES SUBSEQUENT TO PENEPLANATION

Five-stage valleys intrench the Fremont or summit peneplain to a maximum depth of 3500 feet. A valley-within-valley topography results, a concave stream profile rising upstream with gradually increasing gradient to a knickpoint of rejuvenation above which upstream a similar profile is repeated. A cross-valley profile has a series of rock-cut low-gradient benches above which rise steeper slopes on the outer sides and below which on the inner sides are steep slopes to next lower benches. Interstream ridge profiles of the western range flank are a series of terrace steps. The various valley stages, being products of incomplete erosion cycles, will be termed subcycles.

Great terracelike steps, in which the mountains rise from their southwest base between Green and Sweetwater rivers, are plainly visible looking northeast from the lowest terrace west of New Fork River flood plain on the Pinedale-Yellowstone Park road south of the Cora road junction and also near Cora postoffice. From the former place the foreground is the broad flood plain of the New Fork with a low terrace remnant to the left, just east of the river. Above is a bench or flat at 7400 to 7600 feet, another at 7800 to 8000, then an 8500-foot level of Flattop Mountain, the ridges flanking New Fork and Willow lakes, well developed still farther north, next the 9200 to 9300 foot level of Little Flattop Mountain and the ridge between the heads of Fremont and Willow lakes and at 9600 feet, 2½ miles north of upper New Fork Lake, next higher is a very extensive plateau at 10,300 to 10,500 feet, with the highest summit ridge of the Continental Divide on the horizon.

Another view (Pl. 4, fig. 2), northeastward from the westernmost outlier of Bighorn dolomite just east of the Cora-Green River lakes road, shows the five-stage topography of the western range flank, in the environs of the western thrust scarp. There the Fremont peneplain is on the horizon. Next below it, at the extreme left, the north shoulder ridge of Gypsum Mountain, beveling upper Paleozoic rocks, is the bench of the 10,500-foot subcycle. In the center mesa is the 9500-foot bench, to both left and right of which, in part in deep shadow to the left, is the bench sloping down to 9000 feet. In heavy timber in the middle distance the 8500-foot flat is visible, eroded in the left middle distance by valleys of the erosion substage which extends down to the broad Green River valley at 7600–7700 feet.

Topography of much of the uppermost Green River basin is shown in Plate 1. The 8500-foot subcycle extends upstream to the head of Threefork Park (middle, Pl. 5, fig. 1), forms a prominent bench at 8475 feet on the east side of lower Green River lake, and is even more prominent east of the river between 8300 and 8400 feet, from 3 miles east of the mouth of Roaring Fork downstream to the middle of the Big Bend. The 9000-foot broad valley bench is a hanging valley stage extending down to the brink of the inner gorge. It is conspicuous north of the river at the base of White Rock (at foot of Paleozoic scarp at left, Pl. 2, fig. 2, and the wooded flat, Pl. 3, fig. 1) where it is partly the exhumed mid-Cambrian peneplain. Hanging valleys of the same subcycle occur on Porcupine Creek, above the slide down a 30-degree dip slope of Phosphoria on Slide Creek (middle, Pl. 3, fig. 2), in the lower lake basin on Clear Creek, while on Roaring Fork it extends down to between 8700 and 8800 feet. The 9500-foot stage is generally obliterated in the steep canyon walls but persists in the Granite Lake bench a mile east of Squaretop Mountain, in the Slide Lake basin and the now nearly filled lower lake basins on Tourist and Pixley creeks. On middle Porcupine Creek it reaches to the base of the flanking cliffs. The 10,500-foot subcycle is found in practically all the uppermost courses of the western tributaries of Green River. The flat on the north side of lower Roaring Fork canyon in the foreground and middle distance of Figure 2 of Plate 10 shows one of its broad flattish-floored valleys, trenched at the right by the 1500-foot deep inner canyon. It is the stage of Green River Pass (gap to right of center, Pl. 5, fig. 2) between Trail and Pine creeks, with its numerous small glacial ponds; 2 to 3 miles east Stonehammer and three other lakes farther upstream along Stroud Creek are in this stage.

Longitudinal valley profiles exhibit five stages of erosion on all major streams on both sides of the Continental Divide in the northwest half of the range.

The headwaters basin of Fish Creek, of the Snake-Columbia drainage, is filled in part with glacial deposits extending down to 8700 feet altitude. However, the four older substages are discernible in places. The 10,500-foot stage at the head of the easternmost Fish Creek tributary crosses the gap in the Continental Divide into the headwaters of Jakey's Fork; in Figure 1 of Plate 6 it is between Bow Lake and the Divide ridge to the left and has on its bench about 50 small glacial ponds, with the gap across the Divide at the left margin. A lower valley stage farther down the same tributary descends to 9800 feet. The flatter parts of the Fish-Warm Spring creeks divide are probably referable to the 9500-foot stage. The 9000-foot stage exists in the headwaters of the westernmost tributaries, on the Fremont Peak quadrangle, of Fish and Warm Spring creeks, and the lowest part of the broad low-sloping divide between Green River and Fish Creek. The broad open valley stage of the Union Pass cycle of Blackwelder (1915) seems more likely a composite of the 8500- and 9000-foot subcycles, with, in part, drift-filled valleys; beaches of a former shallow glacial lake occur in sec. 10, T. 40 N., R. 107 W. The view (Pl. 11, fig. 2) northwest across Fish Creek basin from the Green River divide has main Fish Creek just to right of center; ridges of the middle distance have subdued relief of advanced erosion, and the areas without timber have undrained glacial cover.

The 10,500-foot subcycle, with a longer erosional history, has developed more extensively than any subsequent one. Generally it has attained early old age with hills rising as high as 1000 feet or more above the valleys, and it is considerably modified by glaciation. Blackwelder (1915, p. 198) states that "The broad plateau remnants at 10,000–10,500 feet east of Pinedale may not be parts of the summit peneplain, but rather the result of a later cycle". This is certainly the case; in fact, the lower flat truncating upper Paleozoic rocks shown by him (1915, p. 196, Fig. 14, left) is a remnant, at 10,500 feet, of the first subcycle. This earliest subcycle, southeast of New Fork River canyon, produces a plateaulike area many miles in extent, covered with hundreds of glacial lakes and ponds, its valley heads being sites of the

FIGURE 1. PENEPLAIN AT BASE, EAST-SOUTHEAST FROM FLAT NORTH OF KENNY LAKE

FIGURE 2. NORTHEAST FROM WELLS CREEK GLACIER

WESTERN SCARP OF SUMMIT RIDGE

FIGURE 1. NORTH FROM FREMONT PEAK SUMMIT

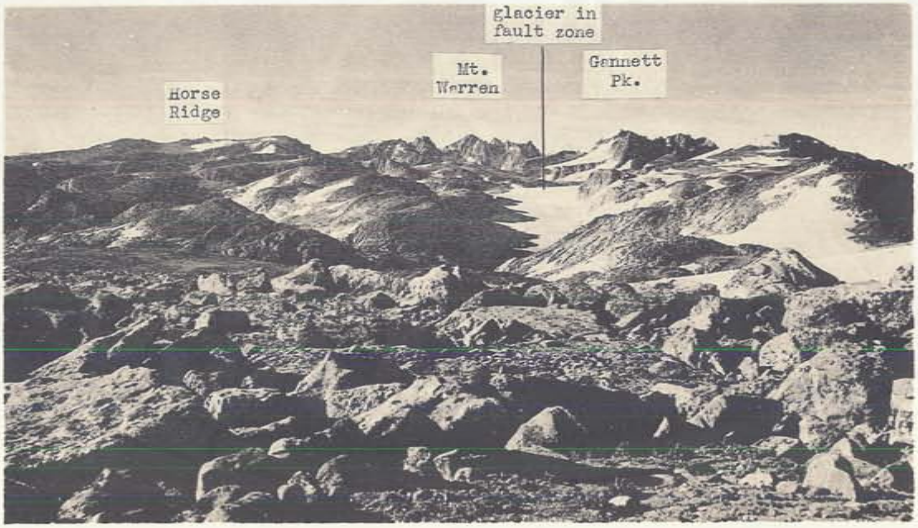

FIGURE 2. SOUTH FROM PASS AT SOUTH END OF DOWNS MOUNTAIN RIDGE

HIGHEST SUMMIT RIDGE

larger cirques bordering the summit ridge of the range. Generally its gentler valley slopes reach the timberline. Its average level descends to about 9500 feet in the southwest corner of the Mt. Bonneville quadrangle. A representative view of the subcycle northeast of Fremont Lake (Pl. 11, fig. 1) shows the subdued topography of its subsummit plateau with the summit ridge on the horizon; Fremont Peak is at the right.

Subcycle multiple-stage valley development was produced, so far as we now can conceive, by some combination of the following four factors: local base levels in canyons of the three major drainages outside the Wind River Range, changes in climate, regional uplift, and localized range uplift. Indications of the last, since the beginning of Lower Eocene (Wasatch), are uptilting of Wasatch in both range flanks, post-Oligocene faulting of 2000 feet displacement in the Red Desert on the south flank (Nace, 1939), and the persistence of the enclosed basin of the Red Desert. The coals, carbonaceous strata, lacustrine beds, and flora of the Wasatch, unless the plants changed greatly their habitat subsequently, strongly suggest that the mountain ranges of Wasatch time did not rise sufficiently high above intermontane basins to exclude, so much as they do now, moisture-bearing winds.

PLEISTOCENE GLACIATION

Relatively little attention has been given to glaciation so that this discussion is to be regarded as preliminary. Only two main glacial epochs have been determined, though quite possibly older ones exist. The two glaciations have occurred since the beginning of the third subcycle because the older moraines cover the surfaces of that subcycle.

The older glacial stage was the more extensive. Its moraines—well grassed over, with pitted plains, naked boulders, and shallow ponds—occur on both sides of the Green River Valley in Aspen Ridge (T. 36 N., R. 111 W.) and between New Fork Lakes and Black Butte (Ts. 36, 37 N., R. 110 W.) where they spread out across the valley for 10 miles east to west, producing probably a local base level on Green River below which three stream terraces have been cut. The Green River glacier of this older stage was about 50 miles long or twice as long as it was during the later stage. The ice reached as low an altitude as about 7700 feet.

The glacier was about 7 miles wide northwest of the Big Bend of Green River where its moraine fills practically the entire basin of Wagon Creek and reaches up to just above 9000 feet altitude. To the east it merged with the extensive moraine with swamps and ponds in the upper basin of Fish Creek where very probably it was augmented by ice flowing from the Continental Divide forming the east margin of Fish Creek basin. Possibly the dividing ridge between Fish Creek and Green River, upon which are scattered possibly glacial boulders, was formed during a receding stage of the older glacier.

A glacial lake between 9800 and 9900 feet on the north side of Little Sheep Mountain—about 2000 feet above the present channel of Green River—was formed during the older glaciation. A large glacial boulder of schistose rock occurs at an altitude of more than 10,600 feet on the mountain ridge just north of lower Clear Creek and east of lower Green River lake; it is 2600 feet above the lake. A number of large erratics of crystalline rock occur on White Rock about 2500 feet above the level of upper Green River lake. They are common at 10,600 feet altitude on top of the ridge east of Porcupine Creek and far from the moraine of the later glaciation. Glacial boulders occur at 9900 feet altitude on the north spur of Sheep Mountain and the north divide of Mill Creek.

The height to which glacial ice extended in upper Green River Canyon is well marked on the canyon walls. Squaretop Mountain exhibits representative conditions. The uppermost 1000 feet of the cliff is notably steeper than the lower slopes and exhibits subvertical fractures. Where the base of the mountain flares out, the rock is polished, and horizontal lines, produced by glacial scoring, are quite notable. From this it is determined that the ice reached an elevation about 2500 feet above the present stream.

During the last glaciation the ice did not reach as far down Green River as the axis of the Big Bend. Two recessional pauses are represented by moraine dams at the lower ends of each of the two Green River lakes and by moraines at the lower end of New Fork Lakes and the constriction in the lakes. A terminal moraine of this glaciation forms the dam of Fremont Lake and reaches to the east end of the town of Pinedale where the altitude may be as low as 7200 feet. On the east side of the Wind River Range the moraine of the Torrey Creek glacier reached below 7500 feet, and that of the glacier in the valley of the South Fork of Little Wind River down to 6300 feet altitude or lower. The rather inconsequential size of the moraines suggests either little debris or brief duration of the later glaciation. Perhaps most of the loose weathered rock was transported during the earlier glaciation and in the interglacial epoch.

The broad basin of postmature topography of the first subcycle southwest of the Continental Divide and southeast of New Fork River was covered by an ice cap where glaciers merged from the high basin rims. Many shallow lakes were formed, and much of the weathered mantle was removed by the ice cap, the ice reaching the lowlands through the canyons of Lake, Pine, Fremont, and Long Lake creeks. The gentler-sloped peneplain flats were little affected by glaciation; here the snow and ice had a protecting effect, the slope gradients being insufficient for ice movement. Where the steeper-sloping peneplaned surface had been dissected by streams, as along the Continental Divide in the Downs Mountain area, there was some glaciation of the valleys. Cirque action is notable in the short steep tributary canyons dissecting the rims of the peneplaned surface, but in the later stage glaciers forming these cirques were short and of the corrie type, producing relatively small terminal moraines. The hanging valleys noted are attributable mainly to steepening of stream gradients ("knickpoints") between different erosion cycles.

The high, steep, and long ridges bounding the basins of New Fork, Willow, Fremont, Halfmoon, and Boulder lakes may be at least in part veneered with lateral moraine deposits; however, the cores of these ridges may be of much older deposits. Glacial deposits are more extensive at the foot of the first (10,500 feet) subcycle ridge because that surface was extensive from New Fork Lakes southward and had its loosened mantle very largely scraped off by glaciers.

Well-developed cirques are scarce in the Wind River Range, because they are

FIGURE 1. FREMONT PEAK-MOUNT HELEN SCARP AND TITCOMB LAKES MULTIPLE RIFT
North from Island Lake

FIGURE 2. PENEPLAIN AND FIRST EROSION SUBCYCLE
Northeastward from lower Roaring Fork canyon

RIFTS AND SCARP; PENEPLAIN AND FIRST SUBCYCLE

FIGURE 1. FIRST EROSION SUBCYCLE
Between Fremont Lake and Fremont Peak

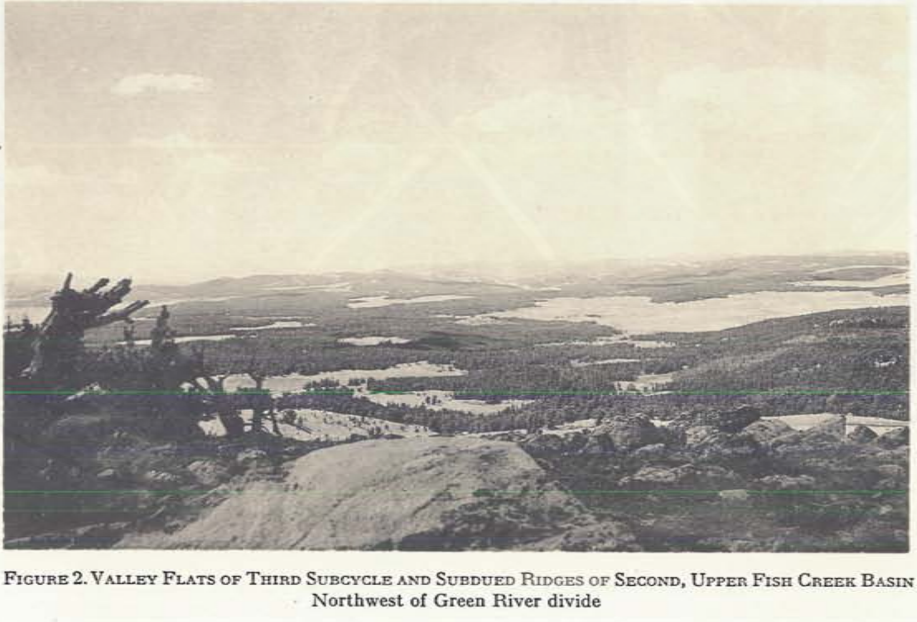

FIGURE 2. VALLEY FLATS OF THIRD SUBCYCLE AND SUBDUED RIDGES OF SECOND, UPPER FISH CREEK BASIN
Northwest of Green River divide

FIRST, SECOND, AND THIRD SUBCYCLES

unusual in massive rocks like gneiss and granite. Some of the most typical cirquelike valley heads known are those of the Grand Canyon of the Colorado, formed not by glaciation but perhaps at least in part by nivation. Their occurrence in the Grand Canyon makes it likely that the cirques of the Uinta Mountains, Glacier National Park, and the Canadian Rockies were developed at least in part by streams. Alternating layers of resistant and less resistant rock favor cirque formation. There are great compound cirque areas, resembling those in the Uinta Mountains, at the headwaters of Dinwoody and Bull Lake creeks and Little Wind and Popo Agie rivers, all east of the Continental Divide, in places where more of the peneplain persists on the intercanyon divides.

At present 9 glaciers and 3 "glacierettes" are known west of the Continental Divide, and 13 glaciers east of the Continental Divide in the Fremont Peak quadrangle. Several more occur farther south down to the Wind River Peak area. The largest glaciers are on the east where they do not all face the shaded north, although on the west side of the Divide seven out of nine glaciers face north, and the other two face south. Probably the glaciers on the east flank are larger because much loose snow drifts over the Divide during winter blizzards, the prevailing winds being westerlies as they probably were during the Pleistocene. All west-flank glaciers visited in 1937 and 1939 were in active retreat, ice fronts being separated from terminal moraines by lakes. In 1937 the glacier at the head of Green River (Wells Creek) had two marginal lakes on its east side, and the glaciers had withdrawn from their lateral moraines. Judging from records of precipitation at Kendall and Pinedale in the Upper Green River Basin from 1931 to 1935 there was a marked deficiency of precipitation, and the last decade was abnormally hot.

Snow drifting into depressions where the force of wind is diminished or checked explains in part the glaciers west of the Continental Divide. Another factor is that the steep valley walls above the ice produce snowslides down onto the ice during all seasons. Snowslides are very frequent in late spring and early summer, and the soft, powdery, and dry snow of the winter must then frequently slide from the steep slopes bounding the sides and heads of the glaciers.

Inasmuch as there are no higher mountains westward to the Pacific, except isolated volcanic peaks, precipitation at altitudes above 10,000 feet in the Wind River Range should probably be 40 to 50 inches annually computed as rainfall. However, whether the maximum amount is around 10,000 or around 13,000 feet is not known. Because a large area in the range has an altitude above 10,000 feet Pleistocene glaciers were extensive. Snowfall then as now should have been greater on the west or windward side of the range.

Glacial grooving of Madison limestone on the west shore of lower Green River lake is still quite plain, and striae appear fresh on the gneissic rocks along Clear Creek between the lower lake and the Natural Bridge.

Apparently deposition has exceeded erosion in the gentler-gradient stream valleys of the Upper Green River Basin and its tributaries since the last great retreat of the glaciers upstream from their lowest end moraines, owing to the damming by the moraines. Green River and Green River lakes were so named because of the green water, produced by fine detritus carried in suspension. The upper lake is probably shallow, storm waves keeping rock flour in suspension. For 4 miles above the head of this lake, Green River broadly meanders through a meadow, and a considerable delta has filled in the head of the lake. A delta is growing between the two lakes supplied with sediment from Porcupine and Clear creeks as well as some sediment from the upper lake. Three lakes among Clear Creek operate as settling basins for glacial material, the lower lake being clear and blue. Clear Creek now enters the outlet stream of the upper Green River lake; when the topographic map was made it flowed into the lower lake and did so as late as 1909. A sandy barrier beach has been built by storm waves at the head of the lower lake, and this has advanced appreciably with the delta edge during the last 30 years.

Some of the formerly glaciated narrow, steep-walled, and deep canyons tributary to uppermost Green River have their channels choked with great blocks of angular debris fallen from the canyon walls; in places the streams flow for considerable distances underground through the landslide blocks. Among these Pixley, Tourist, and Wells creeks and the creek at the west base of Squaretop Mountain are noteworthy. Removal of former ice support of the steeper valley cliffs probably in part caused the great talus slopes.

The basin of lower Clear Creek at the mouth of Slide Creek was formerly a lake. The strand line of a former lake in Fish Creek valley is prominent in sec. 10 and vicinity, T. 40 N., R. 109 W.

In August 1939 M. W. Beckman and the writer found five new glaciers and three "glacierettes." There is also a "hanging" or "corrie" glacier on the south wall of Stroud Creek canyon midway between Green River Pass and Mount Warren not shown on the Fremont Peak topographc map. Photographs and a map of these glaciers have been filed for record with F. E. Matthes, Chairman of the Committee on Glaciers of the American Geophysical Union.

LANDSLIDES

Noteworthy landsliding in bedded sedimentary rocks down steep dip slopes over steepened by cirque undermining occurs on the southeast limb of the Battleship Mountain syncline and on the plunging front of the western thrust on the northwest slope of Gypsum Mountain; Bighorn, Darby, and Madison rocks have slid down unsupported bedding planes. The Flathead sandstone at the south limit of its outcrop on the ridge east of Porcupine Creek, dipping down the slope of the ridge, is settling toward the valley, blocks having broken loose and slumped, thus forming deep trenches and chasms along the fractures. The south side of Battleship Mountain exhibits a large landslide in the Bighorn dolomite; the easily removed soft Cambrian shales in part flowed out from beneath under the pressure exerted by overlying Bighorn, Darby, and Madison rocks. Likewise landslides occur in the steep heads of valleys excavated in strongly shattered fault zones as well as alongside walls of such valleys.

UNDERGROUND SOLUTION

Natural bridges, sinkholes, and underground channels are fairly common in this range where Bighorn or Madison carbonate strata underlie valleys. The Natural

Bridge on lower Clear Creek is one instance, as are a number of lakes with underground outlets in the Battleship and Gypsum mountain areas. Two of these lakes in the Battleship Mountain syncline are not mapped on the topographic sheet.

TERRACES OF GREEN RIVER VALLEY

The numerous terraces in Green River valley need much more study. They begin upstream at the mouth of Clear Creek and extend up to 9000 feet altitude—that is, to the level of the third subcycle of erosion and to the beginning of the older of the known glacial stages. Some of these terraces are rock-cut, others are in part lateral moraines, and still others are fluvioglacial, interglacial, and postglacial, both depositional and erosional. They are extensively developed in the valleys of the New Fork, East Fork, and other tributaries of Green River.

Three rock-cut terraces occur east of lower Green River lake, the highest at 8650 feet altitude, the second at 8475 feet, which is the most prominent above the mouth of the Roaring Fork, and the lowest at 8300 feet. Roaring Fork valley is ponded for 3 miles upstream from the top of the 8650-foot terrace. The 8300-foot terrace is very prominent for 6 miles both above and below the mouth of Roaring Fork.

At least nine terraces are discernible on the north wall of Green River valley between the mouth of Roaring Fork and the Big Bend. Some of these appear to be lateral moraine ridges, more extensive on the north wall because of stronger ice movement toward that wall around the convex side of the bend. The 8300-foot ridge and perhaps some of the others appear to be the tops of hogback ridges of more resistant Mesozoic strata; glacial ponds and lakes occur in the strike valley at the north base of the 8300-foot ridge. Stream incision of the terminal and recessional moraines of the last glaciation is not greater than 100 feet.

Resistant Phosphoria strata at the warm springs (Old Kendall) have produced a local base level at 7700 feet on Green River above the rapids at that point. East of the river is a terrace 200 feet above this level. Downstream from the rapids is a prominent terrace 50 feet above the river and also mounds of a higher terrace.

At the mouth of Gypsum Creek is a terrace 50 feet above the river, another 75 feet above, and a prominent bench at 8200 feet. A broad terrace occurs at 8000 feet on the west side of Green River north of Black Butte, and a bench at 7800–7900 feet on the west side of the butte makes the divide on the road at the east foot of the butte.

In the 7700-foot terrace on the west side of New Fork valley north of Cora are many boulders of varicolored quartzite, of an unknown source.

Three terracelike benches on the sides of the ridge bound New Fork Lakes on the north. These slope downstream until their level merges with end moraines, one downstream from the lakes, one recessional terminal moraine forming the dam for the lower lake, and the other the marked constriction between the two lakes. Such benches, supposedly tops of lateral moraines, are found on the ridges above Fremont and Boulder lakes.

Series of terraces, developed on the Cenozoic deposits along East Fork River east of Boulder, also flank on the southwest the crystalline ridge forming the north rim of the Cenozoic basin at the head of Sweetwater River.

There are several stream terraces in Green River Basin belonging to lower subcycles, but they are outside the mountain area proper. Perhaps they can be correlated with the three main retreat stages of the most recent glacial epoch. A lower subcycle occurs in the Wind River Basin on lower Torrey Creek and the South Fork of Little Wind River beginning at an upper altitude of 7500 feet. This is not shown on upper Green River, which flows above that level; the channel of Wind River is 1000 feet lower. Rapids extend down Green River from the Lower Green River Lake to the Big Bend, which is the farthest extent of the moraine of the last glaciation. Below this the river meanders in a flood plain as far as the lowest terminal moraine of the older glaciation in T. 36 N., R. 111 W. (just south of Black Butte). In the vicinity of Daniel postoffice (northeast quadrant, Big Piney quadrangle) the wide valley of Green River, there bending abruptly from a south to an east course, has a number of stream distributaries and one fairly large swamp, the valley ranging in altitude from 7150 feet downstream to 7400 feet upstream. Unless there is a more resistant rock barrier downstream valley filling may be caused by overloading by glacial deposits though, conceivably, both causes operate.

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State Geological Survey, Vermillion, S. D.

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