Geology of the Uinta River-Brush Creek Area Duchesne and Uintah Counties, Utah

GEOLOGICAL SURVEY BULLETIN 1007

DEPARTMENT OF THE INTERIOR
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By DOUGLAS M. KINNEY

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GEOLOGY OF THE UINTA RIVER-BRUSH CREEK AREA, DUCHESNE AND UINTAH COUNTIES, UTAH

By Douglas M. Kinney

ABSTRACT

The area described in this report includes 870 square miles of almost uninhabited country on the south flank of the Uinta Mountains lying in Duchesne and Uintah Counties, north and east of Roosevelt and Vernal, Utah. U. S. Highway 40 crosses the southeastern part of the area and continues westward to Vernal, Roosevelt, Heber, and Salt Lake City. Utah State Highway 44 connects Vernal with Manila, Utah, and with other towns on the north flank of the Uinta Mountains. The area lies on the northern border of the Colorado Plateau.

The oldest exposed rocks are quartzitic sandstone and sandy shale of Proterozoic age that belong to the Uinta Mountain group. They crop out on the northern border of the area. The Lodore formation of Cambrian age overlies the Uinta Mountain group from Brush Creek eastward to the Green River. The formation consists of coarse-grained sandstone and arkose and thickens eastward. Both the Lodore formation, east of Brush Creek, and the Uinta Mountain group, west of Brush Creek, are overlain by 1,000 to 1,200 feet of light-gray cherty limestone, with some sandstone near the top, which is mapped as the limestone unit of Mississippian age. This limestone unit is of early, or, in part, late Mississippian age. It is succeded by black shale of late Mississippian age. The black shale unit thins toward the east from 280 feet to 25 feet or less. The next overlying formation is the Morgan formation of Pennsylvanian age, which consists of a lower light-gray cherty limestone member and an upper member of interbedded red sandy shale, light-buff to gray sandstone, and gray fossiliferous limestone. The lower member is 300 to 400 feet thick, and the upper member is 700 to 1,000 feet thick. The Morgan formation grades upward into the massive, crossbedded Weber sandstone of Pennsylvanian age, which ranges from 1,000 to more than 1,200 feet in thickness.

The Park City formation of Permian age, 100 to 200 feet thick, overlies the Weber sandstone and grades upward into the Moenkopi formation. The Park City formation consists of gray slabby limestone, gray shale, sandstone, and greenish-gray phosphate rock. The Moenkopi formation, of Early Triassic age, consists of reddish-brown and greenish-gray, fine-grained sandstone and siltstone and is 800 to 1,000 feet thick. The lower 300 feet of the Moenkopi, east of Red Mountain, rapidly changes in color from red to gray. The Moenkopi is unconformably overlain by the Shinarump conglomerate, of Late Triassic age, which is as much as 95 feet thick. The Shinarump grades upward into the Chinle formation, which consists of varicolored shale overlain by red to tan ripple-marked sandstone. The Chinle, 230 to 260 feet thick, grades upward into the tangentially crossbedded, light-gray Navajo sandstone of Jurassic(?) age. The Navajo sandstone is 700 to more than 1,000 feet thick.

The San Rafael group overlies the Navajo sandstone and is composed of the Carmel formation of Middle and Late Jurassic age, and the Entrada sandstone and Curtis formation of Late Jurassic age. The Carmel consists of red and white fine-grained silty sandstone and siltstone, gray platy mudstone, fossiliferous limestone, and pink gypsum. It thins from almost 400 feet in the west to 120 feet on the Green River. The Entrada, a light-gray, massive, crossbedded, fine- to medium-grained, friable sandstone, thins eastward from 240 feet on Whiterocks River to 105 feet at Split Mountain. The Curtis formation consists of greenish-gray, medium- to coarse-grained, thin- to massive-bedded, highly glauconitic sandstone overlain by dark greenish-gray shale with thin beds of fossiliferous, glauconitic, sandy, oölitic limestone. The Curtis varies from 150 to 270 feet in thickness. The San Rafael group is overlain by the continental Morrison formation of Late Jurassic age, which consists of variegated red and light-gray siltstone and shale, red and gray fine-grained silty sandstone, and fine- to coarse-grained sandstone. The Morrison is 800 to 900 feet thick.

In the area studied, the basal formation of the Cretaceous system is the Dakota sandstone of Early(?) and Late Cretaceous age, which ranges from 50 to 135 feet in thickness. The formation is comprised of light-gray to tan, fine- to coarse-grained sandstone, with pebbles of dark-gray and black chert. The Dakota is overlain by the Mancos shale of Late Cretaceous age, which is divided into three members, the thin Mowry shale member at the base, the thin Frontier sandstone member, and a thick upper shale member of light-gray siltstone and shale. The Mowry shale member, 30 to 125 feet thick, consists of dark brownish-gray clay shale overlain by dark-gray, fissile, siliceous shale containing abundant fish scales. The Frontier sandstone member of the Mancos, 140 to 270 feet thick, consists of tan-weathering, gray sandy shale overlain by tan, fine- to medium-grained, calcareous sandstone. The upper shale member of the Mancos is 4,900 feet thick east of the Green River. Thin limy sandstone beds are present in the top part of the upper member. The Mancos shale is overlain by the Mesaverde formation, of Late Cretaceous age, which is found only in the southeastern part of the area. The Mesaverde consists of light-gray, fine- to medium-grained, partly crossbedded, speckled sandstone overlain by dark-gray shale, dark-brown lignitic shale, and brown lignite. Two miles east of the Green River, the formation is 1,175 feet thick.

The older Tertiary rocks (Eocene and Oligocene) overlying the Mesaverde formation consists of light-gray sandstone, marl, sandy shale, and tan-weathering pebble conglomerate. To the west, the Tertiary rocks, which overlie the Mancos shale and older rocks, consist of tan to red, fine- to medium-grained sandstone. The younger Tertiary rocks are referred to the Bishop conglomerate and are tentatively assigned a Miocene age. The Bishop consists of light-tan to red conglomerate in a matrix of coarse-grained sandstone. Chalky-white tuffaceous sandstone is found in the lower part of the Bishop in the Mosby Mountain-Lake Mountain area, and white tuffaceous sandstone is prominent on Diamond Mountain.

Glaciers descended into the valleys of Dry Gulch, Uinta River, Pole Creek, Whiterocks River, and Dry Fork of Ashley Creek, and occupied the headwaters of Farm Creek, East Fork of Dry Fork, Black Canyon, and Ashley Creek. Three ice advances, respectively termed the Earliest, Maximum, and Latest glaciation periods, are recognized; corresponding outwash gravels of these periods are also present.

The area is divided into two parts by Dry Fork of Ashley Creek and by a line trending S. 60° E. across Ashley Valley. Faulting is dominant south of this line, although sharp folds are also present. East and northeast of Dry Fork, faulting

is of minor importance and open folding is predominant. The strata dipping southward from the main Uinta Mountain axis are folded into sharp south-southeast plunging anticlinal noses. South of the principal Uinta Mountain axis and separated from it by the Island Park syncline, are two parallel westward-plunging anticlines, the Split Mountain anticline and the Section Ridge anticline. These anticlinal folds are separated by the shallow Daniels Draw syncline. To the west of Dry Fork of Ashley Creek, the northwest-trending faults, comprising the Deep Creek fault zone, intersect the South Flank fault zone that generally bounds the pre-Cambrian core of the mountains.

Three periods of deformation are indicated in the area. The first deformation involved the faulting of pre-Cambrian rocks and occurred prior to the deposition of the limestone unit of Mississippian age. The second deformation followed the deposition of the Moenkopi formation and included gentle westward tilting of the area prior to the deposition of the Shinarump conglomerate. The third and principal deformation of the area followed the deposition of the youngest Cretaceous rocks and continued during the deposition of the early Tertiary rocks. Deformation of the area had almost ceased by the time the Bishop conglomerate was deposited in Miocene (?) time.

Three widepread erosion surfaces, the Gilbert Peak surface, the Lake Mountain surface, and the Jensen surface, were developed during late Tertiary and Quaternary time. The Gilbert Peak surface underlies the Bishop conglomerate and bevels all older rocks. The Lake Mountain surface was cut on the Bishop conglomerate, and the Jensen surface was formed by coalescing pediments late in the erosion period of the Tertiary sedimentary rocks of the Uinta Basin. Two strath terraces, the Vernal and Thornburg surfaces, were formed along major streams during the glaciation of the Uinta Mountains in Pleistocene time.

Lenticular coal beds, 14 inches or more in thickness, occur in the upper part of the Frontier sandstone member of the Mancos shale. The coal is high-volatile C bituminous in grade. Coal is reported in the black shale unit of late Mississippian age, and lignite is present in the Mesaverde formation of Late Cretaceous age. Approximately 240,000 tons of coal has been mined from the Frontier sandstone member of the Mancos shale. Sixty million tons of coal under less than 1,000 feet of overburden, 54 million tons under 1,000 to 2,000 feet of overburden, and 29 million tons under 2,000 to 3,000 feet of overburden are considered as indicated reserves.

A number of oil and gas wells have been drilled in the area. Commercial gas was discovered on the Ashley Creek structure in 1925 and was produced from 1929 to 1940. The producing horizon was a sand in the lower part of the Morrison formation. Five hundred and thirty-six million cubic feet of gas were produced. Oil was discovered in the Weber sandstone on the Ashley Creek structure at a depth of 4,152 feet in September 1948. Twenty-eight commercially producing wells had been drilled by February 1950. One of the wells is producing from a sand in the Park City formation.

Small quantities of copper, lead, and iron have been produced from the Carbonate district (T. 1 S., R. 21 E.), which is located in the limestone unit of Mississippian age.

Low-grade phosphate rock occurs in the lower part of the Park City formation. The phosphate rock averages 20 percent of P_2O_5 for a thickness of 18 feet in the Ashley Creek-Brush Creek area. Two hundred and fifty million tons of phosphate rock under 43 feet or less of overburden, 650 million tons under 78 feet or less of overburden, 1,800 million tons to stream level, and 2,450 million tons to 1,000 feet below stream level are listed as indicated reserves in the Ashley Creek-Little Brush Creek area.

Sand and gravel for concrete and road construction occur in terrace deposits adjoining the major streams. Reserves are adequate for the normal demands of the area.

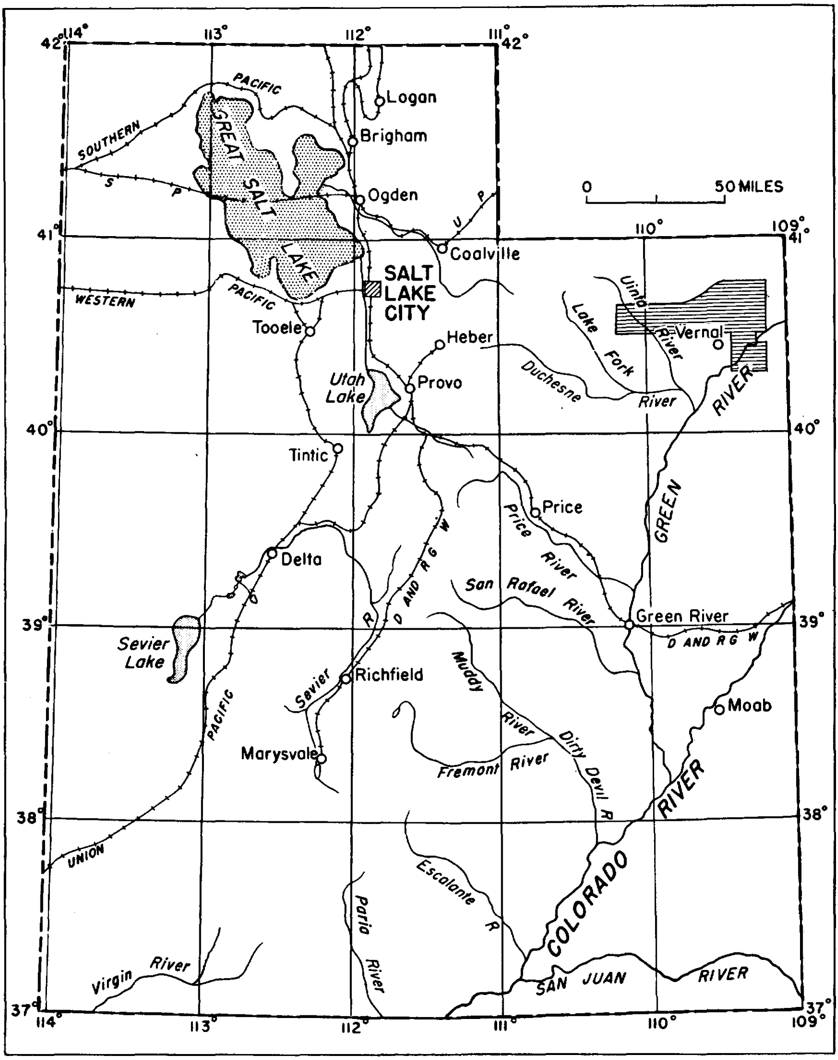

FIGURE 1.—Index map of Utah showing location of Uinta River–Brush Creek area.

INTRODUCTION

LOCATION AND EXTENT OF THE AREA

The Uinta River-Brush Creek area is in northeastern Duchesne County and northern Uintah County in the northeastern part of Utah. It lies on the south flank of the Uinta Mountains between longitude 109° 15′ and 110° 15′ and includes an area of about 870 square miles. The location and extent of the area are shown on figure 1.

The northern boundary of the area roughly corresponds to the northern limit of rocks of Paleozoic age, and the southern boundary of the area corresponds to the northern extent of the overlapping Tertiary rocks of the Uinta Basin. The eastern boundary of the area lies north and east of Vernal, the county seat and principal town in Uintah County, and the western boundary lies north and west of Roosevelt, the largest town in Duchesne County. The rectangular indentation on the eastern boundary of the area is the extreme western part of the Dinosaur National Monument, which lies partly in northwestern Colorado and partly in northeastern Utah. By agreement with G. E. Untermann and B. R. Untermann of Vernal, Utah, who have studied the geology of the monument for the U. S. Park Service, this rectangular area was excluded from the present investigation.

PURPOSE AND SCOPE OF THE WORK

The study of this area by the United States Geological Survey is part of a plan to portray the geologic setting of the great Uinta Basin, an irregularly shaped and structurally depressed area that underwent sedimentation throughout much of Tertiary time. The Uinta Basin is bounded on the north by the Uinta Mountains, on the south by the Book Cliffs, on the east by a structurally high area near the Rangely and Douglas Creek anticlines, and on the west by the Wasatch Mountains.

The geology of the Book Cliffs region has been published in United States Geological Survey Bulletin 852 by D. J. Fisher, Bulletin 819 by E. M. Spieker, and Bulletin 793 by F. R. Clark. These bulletins, which deal primarily with the coal resources, cover an area extending from the Colorado State line westward to longitude 111°. The western boundary of the Uinta Basin, the Wasatch Mountains, is being studied by A. A. Baker. The western portion of the south flank of the Uinta Mountains has been studied by John W. Huddle. Huddle's area bounds the Uinta River-Brush Creek area on the west along longitude 110° 15′. In 1943, impetus was given to the study of the south flank of the Uinta Mountains by the development of petroleum production in the Weber sandstone on the large Rangely anticline in northwestern Colorado. Increased prospecting activity in adjacent areas in northeastern Utah led to the discovery of oil deposits in the Weber sandstone (Pennsylvanian) at the Ashley Creek field in September 1948. Interest in the Uinta Basin as a petroliferous province has been further justified by the discovery of oil in the Green River formation, Eocene) in the northern part of the Uinta Basin, near Roosevelt, Utah.

FIELD WORK

Part of the area between 109° 30′ and 110° 00′ was mapped in 1945 by A. J. Crowley and Joseph M. Gorman of the Geological Survey.

Their field work was terminated in November 1945 before their study was complete. Their mapping has been incorporated, with modifications, in the field work carried on by the writer between April and November 1946. Joseph F. Rominger and Ralph S. Brown served as assistants between June and September, P. Verastegui M. from August to October, and Robert W. Blair in October 1946. The pre-Tertiary geology of the area between 109° 30′ and 110° 00′ was briefly described by the writer and J. F. Rominger in Preliminary Map 82, Oil and Gas Investigations, U. S. Geological Survey, December 1947. The areas between 110° 00′ and 110° 15′ and between 109° 15′ and 109° 30′ were studied from April to October, 1947, with Joseph Rominger as field assistant (June to September). This area was described in U. S. Geological Survey Oil and Gas Map 123, September 1951. The location and altitudes of many control points in the area between longitude 109° 30′ and 110° 00′ were established in 1945 by means of plane-table triangulation by Howard Clark and Wm. P. Clark of the Geological Survey. Additional locations and altitudes in the remaining areas were established by Joseph F. Rominger in 1947 by means of plane-table triangulation using primary triangulation stations of the United States Coast and Geodetic Survey. In 1946 and 1947, altitudes of key beds were obtained at many places by angles determined with the telescopic alidade from stations established by three-point intersection from control stations and by distances measured on the photographic mosaics.

That part of the area north of latitude 40° 30′ and between longitude 109° 30′ and 110° 15′ is shown on the topographic maps of the Marsh Peak and Gilbert Peak quadrangles of the U. S. Geological Survey at a scale of 1:125,000 (or approximately 2 miles to the inch). These maps, surveyed in 1904–1906, show the major features of the land surface, but they are not adequate as a base for detailed mapping of thin stratigraphic units.

Geologic mapping was done on aerial photographs, on a scale of 1:31,680 (or 1 mile to 2 inches), and later was compiled on photograph mosaics supplied by the Soil Conservation Service, U. S. Department of Agriculture. A small area north of 40° 37′ 30″ and west of 109° 45′ was assembled from photographs by the radial line method of compilation. The land net, shown on plate 1, is based on land plats of the General Land Office, on section corners identified on the photographs, and on section corners located by alidade and plane table, using three-point intersection from known triangulation stations and stadia traverses from triangulation stations. Three detailed stratigraphic sections at intervals across the area (see pl. 2) were measured by plane table and telescopic alidade. A few thin units were measured by hand level or Brunton clinometer.

As part of a coordinated study of the phosphate and associated minor metals in Idaho, Wyoming, Montana, and Utah, the Mineral Deposits Branch of the Geological Survey under V. E. McKelvey (geologist in charge of the northwest phosphate investigations) cooperated in the detailed study of the phosphate unit of the Park City formation. Following the bed-by-bed description of the phosphatic unit by J. F. Rominger and the author, R. P. Sheldon cut channel samples, Helmuth Wedow made numerous statigraphic-paleontologic collections, and L. E. Smith subdivided the formation into three members and mapped their distribution.

ACKNOWLEDGMENTS

The writer is indebted to his field assistants, Messrs. Rominger, Brown, Verastegui, and Blair for their capable aid in the field. To G. E. Untermann and B. R. Untermann, of the Utah Field House of Natural History; Charles Neal; Philip Williams, geologist for the Carter Oil Co.; and Harry Ratliffe, resident manager for the Humphreys Phosphate Co., all of Vernal, the writer is deeply indebted for geologic information and discussion of problems. James Steele Williams, Ralph Imlay, and Lloyd Henbest of the Paleontology and Stratigraphy Branch; V. E. McKelvey, L. E. Smith, Helmuth Wedow, and R. P. Sheldon of the Minerals Deposits Branch; and A. A. Baker, J. W. Huddle and N. W. Bass of the Fuels Branch, all members of the United States Geological Survey, visited the writer during the course of the field work and contributed valuable aid. Messrs. James Steele Williams, Ralph Imlay, William Hass, John B. Reeside, James M. Schopf, and Miss Helen Duncan, all of the Geological Survey; and Messrs. David H. Dunkle and G. Arthur Cooper, of the U. S. National Museum, identified fossils and made age determinations of collections from the area.

During the preparation of the report, the writer has been aided by criticism and suggestions from Jack E. Schoellhamer of the Geological Survey.

The writer wishes to express appreciation to the Director of the Geological Survey for his permission to submit a part of this report to Yale University as a dissertation in partial fulfillment of the requirements for the degree of doctor of philosophy. He also acknowledges with thanks the helpful criticism of Prof. C. R. Longwell and Prof. C. O. Dunbar of the department of geology at Yale University.

TOPOGRAPHY, DRAINAGE AND WATER SUPPLY

The Uinta River-Brush Creek area lies on the south flank of the elongate Uinta Mountain range, which trends eastward across northeastern Utah and southeastward in northwestern Colorado. To the west, the mountains are separated from the north-trending Wasatch Range by the narrow Heber Valley. To the east, they die out in Cross Mountain and the Danforth Hills, which extend to the White River uplift. The crest of the Uinta Mountains lies to the north of the median line and result in a relatively gentle south slope and a steep north slope. The crest slopes eastward and westward in a gradual manner from an average altitude of 13,000 feet near the central portion of the range. The higher peaks, Kings Peak and Mt. Emmons, lie slightly south of the crest and to the north and west of the northwestern corner of the area. The mountains do not give the impression of great height because they are smoothly contoured and rise from a high plateau-like surface which slopes gently away from the crest. This high surface, which on the south flank in large part defines the boundaries of the Uinta Mountains, not only slopes southward from the crest, but it also slopes eastward to the Green River and the eastern border of the area. The Uinta Basin lies south of the Uinta Mountains and extends in a southerly direction for 60 to 100 miles to the Book Cliffs.

The most important topographic feature in the area is the widespread gently rolling surface that forms the tops of Jefferson Park, Pole Mountain, Mosby Mountain, Lake Mountain, Dry Fork Mountain, the upland area between Ashley Creek and Brush Creek and Diamond Mountain. The crests of Little Mountain and Split Mountain, and the Yampa Plateau, which lies east of the Green River, also are remnants of this surface that have been isolated by erosion. The surface slopes at a rate of 120 to 180 feet to the mile southward from the crest and slopes 50 feet to the mile toward the east. It descends from an altitude of more than 10,000 feet at Jefferson Park, west of the Uinta River, to 7,300 feet at a few points on Diamond Mountain. On Mosby Mountain, the surface is at an altitude of about 9,400 feet; on Lake Mountain, it is at 9,050 feet, and on Little Mountain, at about 8,050 feet.

Limestone and quartzite hills rise above this widespread surface on Taylor Mountain, Brush Mountain, Little Brush Mountain, and in the line of peaks that extend east and southeast across the northern border of Diamond Mountain and separate Diamond Mountain from the valley of Pot Creek. These hills reach an altitude of 10,250 feet on Brush Mountain and an altitude of 8,500 feet on the peaks north of Diamond Mountain.

Split Mountain and Section Ridge enter the area on the eastern boundary. The maximum altitude of points on these features is only 500 to 600 feet above the level of the Green River, but to the east, Split Mountain and Section Ridge merge to form Blue Mountain whose upper surface, an altitude of 7,500 feet, forms the Yampa Plateau.

South of the termination of the high surface, the average altitude drops almost 2,000 feet in a distance of 3 or 4 miles. West of Little Mountain, from Little Mountain east to Diamond Mountain, and on the flanks of Split Mountain and Section Ridge, the more resistant sandstone strata form hogbacks rising 300 to 400 feet above the stream courses that have developed in the more easily eroded strata. Between Diamond Mountain and Split Mountain, west and south of Split Mountain, and south of Section Ridge, easily eroded gray shale forms low hills, some of which are capped by gravelly benches sloping away from the mountains. Northwest of Split Mountain, the barren, gray Buckskin Hills are capped with coarse gravel and rise to an altitude of 6,800 feet. South of Section Ridge and east of Green River, there is a low sandstone escarpment called The Rim Rock. This is a continuation of Asphalt Ridge, the north-facing escarpment that increases in altitude northwestward to merge into the gravel-capped surface sloping south from Little Mountain. This escarpment, and its continuation westward from Little Mountain to Mosby Mountain, marks the northern boundary of the Uinta Basin. West of Mosby Mountain, the flat-lying Uinta Basin sediments encroach farther north and the change from mountains to basin has no intervening belt of sandstone hogbacks and gray shale hills.

Green River, the master stream of the region, enters the eastern boundary of the area after it emerges from Split Mountain Gorge and flows southwesterward across the Uinta Basin to Desolation Canyon, where it passes through the Tavaputs Plateau and the Roan and Book Cliffs in a deep gorge. Below Jensen, the Green River lies about 4,700 feet above sea level; this is the lowest altitude in the area.

The rolling upland surface is cut by steep-walled gorges, which are 2,000 to 2,500 feet deep and trend south to southeast from the crest of the range. Uinta River, Whiterocks River, Ashley Creek, Brush Creek, and Little Brush Creek are perennial streams draining the central part of the range. These streams obtain their maximum discharge from melting snow in late spring. Dry Fork of Ashley Creek is perennial in its upper course, but after the flood stage of late spring the lower course of the boulder-covered streambed is dry. Whiterocks River and Deep Creek join the Uinta River south of Whiterocks settlement, and the Uinta River, in turn, joins the Duchesne River 10 miles above the junction of the Duchesne with the Green River. Neither the Uinta River nor the Whiterocks River has a clearly defined single channel after leaving the mountain front; each river separates into a series of distributary channels flowing over boulder-choked alluvial plains. Dry Fork of Ashley Creek joins Ashley Creek east of Little Mountain, and Ashley Creek flows southeastward through the broad Ashley Valley to join the Green River south of Jensen. Little Brush Creek joins Brush Creek in the east-central part of T. 3 S., R. 22 E., and the latter stream enters the Green River a few miles above Jensen. Diamond Mountain and the area to the north of Diamond Mountain are drained by Diamond Gulch and Pot Creek, which are tributary to Green River.

The perennial streams flowing southward from the crest of the Uinta Mountains have been partly diverted by irrigation canals, which carry the water southward by gravity flow into the arid, but potentially fertile, Uinta Basin. Water from Uinta River is diverted toward the southwest to irrigate the farmlands between Neola and Roosevelt. Water from Whiterocks River is diverted toward the southeast to irrigate the farmland from Whiterocks southeast to Tridell and Lapoint, and water from Ashley Creek irrigates the Ashley Valley around Vernal. The small flow of Brush Creek is used to irrigate land near Jensen. The Green River is used for irrigation by only one large farm that raises the water by pumps to irrigate the bottomland along the river northeast of Jensen. Small ranches that raise grass for hay and pasture use the water within the borders of the mountains; however, the amount of irrigated land is small. Water from Brush Creek, normally lost as surface flow by passing underground at Brush Creek Cave, is stored in the Oak Park Reservoir, and part of it is diverted westward into the Ashley Creek watershed by a canal that skirts Taylor Mountain. This water is then used to irrigate a portion of the Ashley Valley. Much of the water that goes underground at Brush Creek Cave probably reappears in the spring 5 miles downstream.

Hydroelectric power is produced at the mouth of Uinta Canyon by water diverted from Uinta River in sec. 4, T. 2 N., R. 2 W., and carried by open ditch and iron pipe to the generating station. Hydroelectric power is also generated at the mouth of Ashley Creek for use in Vernal.

Small springs are common a few hundred feet below the high surface that forms the tops of Jefferson Park, Pole Mountain, Mosby Mountain, Lake Mountain, Little Mountain, Dry Fork Mountain, and Diamond Mountain. Many of these springs run dry in late summer, but others provide a small flow of water suitable for livestock throughout the year. In addition to the springs that feed Brush Creek below Brush Creek Cave, a large spring is located in the E½ sec. 31, T. 2 S., R. 22 E., west of the mouth of Brush Creek Gorge. The principal water supply of the town of Vernal is brought by pipe from a large, covered spring, half a mile above the mouth of Ashley Canyon. A large spring is located on the east side of Uinta River at the end of the automobile road; a smaller spring, in SE¼SE¼ sec. 34, T. 3 N., R. 2 W., feeds Pole Creek.

CLIMATE

Because the amount of rainfall increases with an increase in altitude, the records of the U. S. Weather Bureau at Jensen and Elkhorn Ranger Station are supplemented by records taken at other stations in the Uinta Basin and on the south flank of the Uinta Mountains in the following table:

Average monthly and annual mean precipitation (in inches) at seven stations in the northern part of the Uinta Basin or on the south flank of the Uinta Mountains

Stations	Altitude	Length of record (years) [1]	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Jensen	4, 739	27	0. 52	0. 49	0. 59	0. 94	0. 75	0. 61	0. 40	0. 71	0. 92	0. 93	0. 36	0. 54	7. 96
Fort Duchesne	4, 951	61	. 45	. 40	. 54	. 62	. 69	. 43	. 97	. 68	1. 03	. 76	. 38	. 46	6. 99
Myton	5, 030	25	. 33	. 79	. 75	. 61	. 57	. 45	. 81	. 91	. 98	. 78	. 37	. 96	6. 93
Vernal	5, 280	51	. 63	. 58	. 78	. 90	. 91	. 43	. 62	. 71	1. 09	. 93	. 62	. 54	8. 74
Duchesne	5, 520	43	. 59	. 65	. 78	. 67	. 73	. 72	1. 01	1. 25	1. 13	. 97	. 50	. 53	9. 53
Elkhorn	6, 657	35	. 95	1. 08	2. 68	1. 28	1. 31	4. 03	1. 22	1. 17	1. 62	1. 98	. 78	2. 76	13. 63
Moon Lake	8, 150	13	1. 40	1. 74	1. 70	1. 48	1. 48	1. 63	1. 50	2. 08	1. 80	2. 15	1. 00	4. 50	19. 00

[1] Record ends in 1948.

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Most of the area below the 8,500-foot contour has a semiarid climate with a mean annual rainfall of 20 inches or less. Below the 5,600-foot contour the rainfall is 10 inches or less. Localities along the south flank of the Uinta Mountains at the same altitude should have similar precipitation, because prevailing storms come from the west, and no high mountains are sufficiently close to form a "rain shadow" on the western side of the Uinta Basin. No measurements of precipitation in the higher parts of the mountains have been made, although incomplete records from the Trout Creek Ranger Station, at an altitude of 9,200 feet northwest of the area, suggest that the precipitation at Elkhorn and Moon Lake may be relatively high because of their location in, or at, the mouths of canyons surrounded by high mountains. Rainfall usually accompanies thunderstorms and is heavier from the middle of July through October.

From the first of November, through March, most of the precipitation is in the form of snow. Both rainfall and snowfall tend to increase at greater altitude. The following table, compiled from records of the U. S. Weather Bureau, shows the average monthly and annual snowfall at stations in the general area.

Average monthly and annual snowfall (in inches) at five stations in the northern part of the Uinta Basin or on the south flank of the Uinta Mountains

Stations	Altitude	Length of record (years) [1]	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Fort Duchesne	4,739	30	4.2	3.9	2.6	1.0	0.1	0.0	0.0	0.0	0.0	1.0	2.1	4.1	19.0
Myton	5,030	13	5.1	2.2	2.8	.1	T	.0	.0	.0	.0	T	1.2	2.9	14.3
Vernal	5,280	28	5.1	5.3	3.7	.9	.2	.0	.0	.0	T	.8	2.7	4.4	23.1
Duchesne	5,520	24	6.2	6.6	5.0	.9	.4	.0	.0	.0	T	.8	3.3	5.3	28.5
Elkhorn	6,657	13	8.4	9.2	8.4	6.1	3.0	.0	.0	.0	.7	2.2	9.7	10.9	58.6

[1] Record ends in 1948.

The lesser amount of snowfall at Myton, as compared with that at Fort Duchesne, is due to the higher average and annual temperature at Myton.

The daily and annual variations in temperature show a wide range. At lower altitudes (5,000 to 7,000 feet) during the summer, the days usually are hot, but the nights invariably are cool. At higher altitudes, the direct midday sun is warm, but shady areas are relatively cool and nights are cold. At a lower level, a similar range in temperature exists during the winter months. July is the hottest month, and August is a few degrees cooler. January is the coldest month, and December averages almost 5° warmer. Extremes of temperature at Vernal ranged from a maximum of 103° F. in July to a minimum of −38° F. in January. The average date of the last killing spring frost at Jensen or Vernal is late in May, and the earliest date of killing frost in the fall is late in September, thus giving a minimum growing season of approximately 4 months. The U. S. Weather Bureau has furnished the following tables of temperature.

Mean monthly and annual temperatures (° F.) at four stations in the northern part of the Uinta Basin or on the south flank of the Uinta Mountains

Stations	Altitude	Length of record (years) [1]	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Jensen	4, 739	14	16. 1	18. 6	36. 0	46. 6	57. 7	65. 2	72. 7	71. 6	61. 3	49. 2	34. 6	22. 6	46. 4
Fort Duchesne	4, 951	57	13. 3	20. 6	35. 5	47. 9	55. 5	64. 1	72. 0	70. 0	61. 0	47. 8	33. 6	19. 9	44. 2
Myton	5, 030	33	15. 4	24. 4	37. 0	47. 6	57. 2	65. 5	72. 2	70. 4	61. 5	49. 4	33. 6	20. 9	46. 3
Vernal	5, 280	44	16. 8	23. 2	35. 3	46. 6	55. 3	63. 9	70. 2	67. 9	58. 8	46. 9	34. 1	19. 9	44. 9

[1] Record ends in 1948.

Highest and lowest monthly and annual temperature (° F.) recorded at three stations in the northern part of the Uinta Basin or on the south flank of the Uinta Mountains

Stations	Altitude	Length of record (years) [1]		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Fort Duchesne	4, 951	58	Max.	59	65	82	86	95	101	104	101	98	88	76	61	105
			Min.	−40	−36	−14	4	18	21	31	31	17	4	−19	−33	−40
Vernal	5, 280	48	Max.	54	62	79	85	93	99	103	99	94	86	72	61	103
			Min.	−38	−32	−16	0	12	24	25	32	17	11	−13	−32	−38
Duchesne	5, 528	43	Max.	57	60	74	83	92	95	99	98	93	84	72	60	99
			Min.	−43	−32	−16	9	18	25	35	26	16	4	−17	−39	−43

[1] Record ends in 1948.

The relatively higher monthly and annual temperatures for Jensen and Myton, in comparison with Fort Duchesne and Vernal, can be explained by the proximity of the two stations to large streams, Jensen is located near the Green River, and Myton is near the Duchesne River.

VEGETATION

The vegetation in the Uinta River-Brush Creek area is typical of the Rocky Mountain states. The lowlands are treeless except along watercourses and near springs, where cottonwoods and willows abound. Sagebrush and the commonly associated desert shrubs, rabbitbrush, shadscale, and salt sage are common at altitudes as high as 9,000 feet. Greasewood flourishes on the alluvial flats, particularly in areas that have been under cultivation. Piñon and juniper are common on the flanks of the higher mountains between 6,000 and 8,500 feet, and thick stands of juniper are present on well-drained rocky soils underlain by sandstone or slabby limestone. Above 8,000 feet, and particularly on the high surface that comprises the top of Mosby Mountain, Dry Fork Mountain, and parts of Diamond Mountain, aspen grow in thick clumps interspersed with grass-covered meadows or "parks." Mixed stands of pine and aspen appear on all exposures at 8,500 feet; these stands continue above 9,000 feet on south slopes. Above 9,500 feet, on the flanks and summits of mountains, and as low as 7,500 feet in canyons, pine and fir are the dominant types. The high plateau land, known as Diamond Mountain, has only a few clumps of aspen; the remaining area is covered with native grass and sagebrush. The mountain "parks" support a continuous sod cover, but the lowlands are so sparsely covered that they make poor grazing land. Diamond Mountain contains some of the best grassland in the area; it has been dry-farmed successfully for grain during the years of high grain prices following World Wars I and II.

POPULATION

The permanent population of the Uinta River-Brush Creek area is concentrated along perennial streams, where irrigable land is available. Except for temporary lumber camps maintained on Pole Mountain, Mosby Mountain, and Dry Fork Mountain, and occasional U. S. Forest Service cabins at protected locations, no permanent habitation is maintained at high altitudes. During the summer the high mountains within the Ashley National Forest are visited by itinerant sheep camps that are moved with the flocks toward the crest of the range in July and August and are returned to lower altitudes in early September. A few farms are located on the gently sloping land at the mouth of Whiterocks River and Farm Creek southwestward to Uinta River, in the valley of Mosby Creek and Deep Creek, along Dry Fork of Ashley Creek and Ashley Creek, in the lower part of Steinaker Draw, and in the valley of Brush Creek and Little Brush Creek. The largest community in the area is located on the rich bottomland of the Green River at Jensen, where two general stores, gasoline stations, and cafes are grouped at the western approach of the highway bridge over the river. The raised terraces of the Green River from Little Brush Creek southward for a distance of 4 miles to Ashley Creek, and the terraces of lower Ashley Creek, are the most highly cultivated areas. However, much of this land is used for pasture or the growing of hay.

Farming and stockraising are the principal occupations. Coal mining has been of considerable importance in the past, but only one mine in the Deep Creek area and one mine at Coal Mine Draw, west of Ashley Creek, were active during 1947. Oil is produced at the Ashley Creek oil field in T. 5 S., R. 22 E., and some oil from the Rangely field in northwestern Colorado is processed at a small refinery on the east side of the Green River at Jensen. Lumbering operations in the Ashley National Forest include cutting mine-prop timbers for the mines of Carbon County. Vernal, the county seat of Uintah County, is the shopping center for the eastern part of the area, and the town of Roosevelt is the shopping center for the area from Whiterocks River to Dry Gulch. The nearest railheads are at Heber and Helper, Utah, and at Craig, Colo.; therefore, all supplies must be brought into the area by truck.

ACCESSIBILITY AND ROUTES OF TRAVEL

Paved U. S. Highway 40 enters the area from the east, southeast of Jensen, and runs northwestward to Vernal, where it turns southeastward to Roosevelt. This highway provides the principal means of access to the area from Craig, Steamboat Springs, and Denver on the east, and from Duchesne, Heber, and Salt Lake City on the west. Utah State Highway 121 lies a short distance south of the area and leads west from Vernal. It connects Vernal, Lapoint, Hayden, and Neola, and then turns southward to join U. S. Highway 40 at Roosevelt. Utah State Highway 44 goes north from Vernal across the Uinta Mountains to Manila, Utah, and to Green River, Wyo. The route of access to Uinta River Canyon is northward on a graded road from Neola. From the mouth of Uinta Canyon, roads lead westward to Dry Gulch and southeastward down the northeast bank of the Uinta River to Whiterocks. Whiterocks and Whiterocks Canyon can also be reached by means of a graded road leading northward from U. S. Highway 40 and Utah State Highway 121.

An unimproved road, leading northward from Lapoint, supplies access to the coal mines on Deep Creek, which are also connected westward with the Whiterocks road by an unimproved, rocky road, and eastward with the settlement of Dry Fork on Dry Fork of Ashley Creek. From Vernal, an asphalt paved road leads northwestward to the community of Maeser and from there by unsurfaced roads northward to Taylor Mountain and northwestward up Dry Fork of Ashley Creek and East Fork of Dry Fork to Dry Fork Mountain. Access to Upper Brush Creek and Ashley Creek is gained by the graded Iron Springs road, which branches westward from Utah State Highway 44 after reaching the upland surface above Brush Creek. Two roads lead into the Diamond Mountain area; the first road branches toward the east from State Highway 44, 2 miles above the Little Brush Creek crossing, and the other road leads northeastward from Vernal to Brush Creek and then scales the west slope of Diamond Mountain by a series of switchbacks and dugways. Branch roads and trails lead from these roads to almost all parts of the area. No single point on the map is more than a few miles from a passable automobile road. All roads shown on plate 1 were passable for ordinary passenger car travel during 1946 and 1947.

PREVIOUS PUBLICATIONS

The earliest published description of the geology of the area is the report of J. W. Powell on the eastern Uinta Mountains, published in 1876. This report described the structure of the area, and named and described geologic formations with such accuracy that all units separated on the map are clearly identifiable with present-day stratigraphic nomenclature. Some formations still bear the names given by Powell, and (in the opinion of the author) others might better have been left with Powell's names than included in formations named and described in adjacent areas.

Geologists of the Fortieth Parallel Survey mapped the geology of the area in a reconnaissance in 1869 and 1871 (Emmons, 1877) but they added very little to the total knowledge of the area. In 1906, F. B. Weeks made a reconnaissance investigation of the geology of the Uinta Mountains and published a revised, but crude, map of the area.

The coal deposits of the area, extending as far westward as Little Mountain, were described by H. S. Gale and party in 1906, and more coal deposits in the Deep Creek area to the west of Little Mountain were described by C. T. Lupton in 1910. In 1915, A. R. Schultz made a reconnaissance examination of the phosphate deposits and adjacent rocks along the flanks of the Uinta Mountains.

Geologic investigations of the area and adjacent regions have been more intensive during the past 20 years, because the possibilities of the Uinta Basin as an oil-producing province have been realized.

The chronological list of publications included here consists of only those titles that specifically refer to the mapped area. Other publications dealing with the stratigraphy and structure of adjacent regions are cited at appropriate places in the report, and all cited publications are given in the principal bibliography.

Listed in chronological order, these pertinent publications are as follows:

1876. Powell, J. W., Report on the geology of the eastern portion of the Uinta Mountains: U. S. Geol. and Geog. Survey Terr., 2d div.

1877. Emmons, S. F., Green River Basin: Report of the Geological Exploration of the Fortieth Parallel, v. 2, p. 198–202; 291–300.

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

1910. Gale, H. S., Coal fields of northwestern Colorado and northeastern Utah: U. S. Geol. Survey Bull. 415, p. 204–219.

1912. Lupton, C. T., The Deep Creek district of the Vernal coal field, Uintah County, Utah: U. S. Geol. Survey Bull. 471, p. 579–594.

1919. Schultz, A. R., A geologic reconnaissance of the Uinta Mountains, northern Utah, with special reference to phosphate: U. S. Geol. Survey Bull. 690, p. 31–94.

1930. Spieker, E. M., Bituminous sandstone near Vernal, Utah: U. S. Geol. Survey Bull. 822, p. 77–98.

1933. Heaton, R. L., Ancestral Rockies and Mesozoic and late Paleozoic stratigraphy of Rocky Mountain region: Am. Assoc. Petroleum Geologists Bull., v. 17, p. 109–168.

1937. Forrester, J. D., Structure of the Uinta Mountains: Geol. Soc. America Bull., v. 48, p. 631–666.

1939. Williams, J. S., "Park City" beds on southwest flank of Uinta Mountains, Utah: Am. Assoc. Petroleum Geologists Bull., v. 23, p. 82–100.

1939. Williams, J. S., Phosphate in Utah: Utah Agr. Exper. Bull. 290, p. 1–44.

1943. Williams, J. S., Carboniferous formations of the Uinta and northern Wasatch Mountains, Utah; Geol. Soc. America Bull., v. 54, p. 591–624.

1944. Walton, P. T., Geology of the Cretaceous of the Uinta Basin, Utah: Geol. Soc. America Bull., v. 55, p. 91–130.

1945. Thomas, C. R., McCann, F. T., and Raman, N. D., Mesozoic and Paleozoic stratigraphy in northwestern Colorado and northeastern Utah: U. S. Geol. Survey, Oil and Gas Investigations, Prelim. Chart 16.

1946. Thomas, H. D., and Krueger, M. L., Late Paleozoic and early Mesozoic stratigraphy of Uinta Mountains, Utah: Am. Assoc. Petroleum Geologists Bull., v. 30, p. 1255–1293.

1947. Kinney, D. M., and Rominger, J. F., Geology of the Whiterocks River-Ashley Creek area, Uintah County, Utah: U. S. Geol. Survey, Oil and Gas Investigations, Prelim. Map 82.

1949. Untermann, G. E., and Untermann, B. R., Geology of Green and Yampa River Canyons and vicinity, Dinosaur National Monument, Utah and Colorado: Am. Assoc. Petroleum Geologists Bull., v. 33, p. 683–694.

STRATIGRAPHY

The sedimentary rocks exposed within the area range in age from Proterozoic to Cenozoic; the latter beds were studied only where they directly overlie the older formations. Three thousand to 4,000 feet of pre-Cambrian strata are present in the area shown on plate 1. Formations of Paleozoic and Mesozoic age total 14,000 feet and include beds of both marine and continental origin. The older rocks are located to the north, and progressively younger strata are exposed towards the south except in Split Mountain and in the area to the east of Jensen where folding brings older formations to the surface. Rocks of Paleozoic and Mesozoic age are well exposed in canyons of south-flowing streams which cross the general strike of the strata at right angles.

The lithologic characteristics, succession, and variation of thickness of the formations are summarized in tabular form on plate 6 (in pocket).

PRE-CAMBRIAN

UINTA MOUNTAIN GROUP

Definition.—The oldest rocks exposed in the area are massive quartzitic sandstones and interbedded shales of the Uinta Mountain group of Proterozoic age. J. W. Powell (1876, p. 141–145) named these rocks the Uinta sandstone or Uinta group, but because that name was preoccupied by Marsh (1871, p. 196) for lake beds of Eocene age, Burbank, Lovering, Goddard, and Eckel in the Geologic Map of Colorado (1935) adopted the present name, Uinta Mountain group, for the pre-Cambrian rocks formerly called "Uinta sandstone," "Uinta group," and "Uinta quartzite."

Distribution and character.—West of Ashley Creek, the pre-Cambrian rocks are limited to a small strip on the northern edge of the map area near the South Flank fault zone; to the east of Ashley Creek the pre-Cambrian rocks lie north of the escarpment formed by the limestone unit of Mississippian age. They form the central mass and higher peaks of the Uinta Mountain range. Large outcrops of the group are located in the upper canyons of the Uinta River, Whiterocks River, Dry Fork of Ashley Creek, Ashley Creek, Brush Creek, and in the higher peaks north of the exposures of the limestone unit of Mississippian age. The massive quartzitic sandstones yield large angular blocks and many bare rock exposures, but the sandstone areas are generally well forested with stands of pine and spruce. Interbedded shales are poorly exposed except along Whiterocks River and Ashley Creek.

Lithology and thickness.—Massive to thick-bedded sandstone, partly quartzitic, and ranging in color from light tan to dull red or purplish red, is the dominant lithology of the Uinta Mountain group. Some intervals are coarse grained and arkosic, with poorly rounded pebbles as much as one-half inch in diameter. The interbedded tan to dark-gray or greenish-gray sandy shale, which weathers to drab or tan, constitutes less than one-third of the group. Lenticular beds of coarse pebbly sandstone and beds of glauconitic sandstone are present in the shale. Ripple marks, cross-laminations, and rain-drop (?) impressions have been noted in the sandstone.

Powell's graphic section (1876, p. 141 and 143) shows more than 12,000 feet of the Uinta Mountain group in Red Canyon, of Green River, on the north flank of the mountains where the base of the group is not exposed. The shale in the upper part of the group on the south flank has been studied in more detail than the rest of the formation in an attempt to establish its age. At least 3,000 feet of beds are present south of the South Flank fault zone in Uinta Canyon, more than 1,800 feet in Whiterocks Canyon, 500 feet along Ashley Creek, and only 265 feet north of Diamond Mountain. At Lodore Canyon on the Green River, east of the area studied, no shale is present in an equivalent stratigraphic position. This eastward thinning is believed to be due to erosion that occurred prior to Upper Cambrian time, but it may be due to a facies change from shale to massive quartzite.

Stratigraphic relations and age.—The Uinta Mountain group rests unconformably upon a complex series of quartzites, schists, and intrusive rocks (the Red Creek quartzite) exposed in a small area north of Browns Park. Powell (1876, p. 140) records about 10,000 feet of red sandstone beds deposited against the Red Creek quartzite and obviously derived from the older rock. In the western part of the area, the Uinta Mountain group is overlain by the limestone unit of Mississippian age but east of Brush Creek it is succeeded by the Lodore formation of probable Late Cambrian age.

The interbedded shales, especially the well-exposed section along Whiterocks River, offer the best possibilities for the preservation of fossils but repeated searches have failed to reveal evidence of ancient life. In the absence of paleontologic evidence, the age of the Uinta

Mountain group is dependent upon its stratigraphic position beneath the Lodore formation of Late(?) Cambrian age and above highly metamorphosed Red Creek quartzite. The rocks of the Uinta Mountain group were originally assigned to the Devonian by Powell (1876, p. 70), but were later placed in the pre-Cambrian by Gale (1910, p. 47), Schultz (1920, p. 24), and Burbank, Lovering, Goddard, and Eckel (1935), and are so considered in the present report.

Conditions of deposition.—The great thickness and general coarse-grained character of the beds suggest rapid accumulation of sediments in a subsiding basin. The presence of ripple marks, cross-laminations, and rain-drop(?) impressions in the sandstones indicate that some of the beds were deposited in water subject to current action and sometimes were exposed to the air. Glauconitic sandstone beds in the thick shale unit on Whiterocks River are probably of marine origin, which suggests sea encroachment late in the deposition period of the Uinta Mountain group. Eardley (1940, p. 830–831) has suggested that rocks of similar stratigraphic position and appearance in the northern Wasatch Mountains accumulated between the highland of northern Utah (represented by the outcrops of the Red Creek quartzite), and the highland of central Utah (represented by the igneous and metamorphic rocks of the Uncompahgre Plateau 100 miles to the south).

CAMBRIAN SYSTEM

LODORE FORMATION

Definition.—The only Cambrian formation in the area was named by Powell (1876, p. 41, 147) for exposures in Lodore Canyon on the Green River about 15 miles east of the area mapped. At the type section in Dunn's Cliff (now known as Limestone Ridge), the formation is 460 feet thick and consists of soft sandstone and shale with conglomerate at the base. A section 1 mile north of Hells Half Mile on the Green River and 2 miles west of the type locality, is approximately 440 feet thick. At this locality, the lower 290 feet of tan to reddish sandstone is very feldspathic at the base, and grades upward into green micaceous sandy shale and sandstone 150 feet thick. The color of the upper sandy shale and sandstone is due to glauconite which is present in the shale and is extremely abundant in the interbedded sandstone.

Distribution and character of outcrop.—Within the mapped area the lower arkosic coarse-grained sandstone is well exposed beneath the limestone unit of Mississippian age on the peaks north of Diamond Mountain and east of State Highway 44. The upper green shale does not crop out but is believed to be present in a covered interval between the arkosic sandstone and the overlying limestone unit of Mississippian age. West of Highway 44 the Lodore formation is thin; it is not known to extend west of Brush Creek.

Lithology and thickness.—East of State Highway 44 the lower part of the Lodore formation is light gray to pink, coarse-grained arkosic sandstone. The bedding of the formation ranges from massive to thick bedded; cross-lamination is common. The feldspar fragments are salmon colored, one-half inch to 1 inch maximum diameter, and generally slightly rounded; some pieces represent only slightly worn euhedral crystals derived from a coarse-grained granite or pegmatite. Feldspar of similar appearance is present in the pegmatites intrusive into the Red Creek quartzite and in the coarser grained arkosic beds of the Uinta Mountain group. On Little Brush Mountain, a short distance west of State Highway 44, the basal arkosic sandstone was not noted in outcrop, but blocks of pink arkosic sandstone, probably representing the lower part of the Lodore, occur as float resting on shale of the Uinta Mountain group. From the size of these blocks it is probable that the lower sandstone has thinned to about 6 feet. Thin slabs of pink arkosic sandstone cemented by tan dolomitic limestone were noted on the west side of Brush Mountain.

At the Iron Springs road bridge on Brush Creek, beds of greenish micaceous sandstone, and coarse-grained to pebbly, cross-laminated, thick-bedded, light-gray quartz sandstone (which underly the limestone unit of Mississippian age) were first believed to correlate with the Lodore formation, but the absence of pink feldspar grains suggests that these beds belong to the Uinta Mountain group. Similarly, a 25- to 60-foot bed of massive, white, coarse-grained sandstone with well-rounded pebbles of vein quartz and quartzite (underlying the limestone unit of Mississippian age on Ashley Creek and in the headwaters of East Fork of Dry Fork), is interpreted as being part of a bed locally occurring at the top of the Uinta Mountain group.

The Lodore formation thins from 155 feet north of Diamond Mountain to a thickness of less than a foot on Dyer Mountain. The upper part of the formation is only 32 feet thick north of Diamond Mountain and wedges out a short distance east of Highway 44.

Fossils and age.—No fossils were found within this area, but G. E. Untermann and B. R. Untermann (1949, p. 690) report a fauna from the upper part of the Lodore formation within the Dinosaur National Monument that has been identified by G. Arthur Cooper and Christina Lockman Balk as of Late Cambrian age. To the west of the Uinta River-Brush Creek area, in the vicinity of Peterson's Sawmill north of Rock Creek, John Huddle (personal communication, 1948) has collected a poorly preserved Late Cambrian fauna from the sandy shales above the thick Pine Valley conglomerate, which was named and assigned to the Ordovician system by Forrester (1937, p. 638).

Stratigraphic relations and correlation.—Along the Green River, Powell (1876, p. 144–145) states that the Lodore formation rests on a very irregular erosional surface cut in massive quartzite of the Unita

Mountain group. A discordance of dip from 4° to 6° has been measured in the strata above and below the unconformity. In the area of this report, the boundary between the Lodore and the Uinta Mountain group appears regular, and no divergence of dip has been detected. It is only in the eastward thinning of the shale, at the top of the underlying group, that evidence is found for unconformable relations; this thinning may be due to facies change from shale to massive quartzite.

Without identifiable fossils, the Lodore formation cannot be definitely correlated with formations of Late Cambrian age in adjacent areas. The lower arkosic sandstone might be correlated with the Sawatch sandstone of central Colorado and the Ignacio quartzite of southwestern Colorado, and the upper glauconitic shale might correspond with the limestones of Late Cambrian age recorded from adjacent mountain ranges.

Conditions of deposition.—The lower arkosic sandstone is believed to have been derived from highlands to the north, which are represented by outcrops of Red Creek quartzite in the Browns Park area of northwestern Colorado. The feldspar closely resembles crystals in the pegmatites of the ancient metamorphic terrane, and the occasional fresh, unweathered euhedral crystals could not have been transported far. The lower sandstone was probably deposited by streams flowing from an area underlain by Red Creek quartzite. The abundant glauconite and the marine faunas in adjacent areas indicate occasional marine environment for some of the upper shale.

CARBONIFEROUS SYSTEM

The Carboniferous rocks offer pecular problems of subdivision and nomenclature in the eastern Uinta Mountains. In ascending order, they consist of (1) 900 to 1,200 feet of light- to dark-gray, cherty limestone and dolomitic limestone with intercalated beds of tan sandstone near the top; (2) 80 to 280 feet of black shale with thin beds of black argillaceous limestone; (3) 300 to 415 feet of light-gray cherty limestone; and (4) 735 to 960 feet of red sandstone, shale, and argillaceous limestone with intercalated beds of gray limestone, grading upwards into (5) 1,015 to 1,275 feet of fine- to medium-grained light-gray sandstone.

The basal part of the thick limestone unit has an early Mississippian fauna typical of the Madison limestone of Montana (Peale, 1893, p. 32–33), but the upper part, which has a fauna that is poorly preserved and, for the most part, undiagnostic, may be of early or, in part, of late Mississippian age. Because fossil evidence points to the early Mississippian age of the lower part of the limestone unit and to the possibility for a late Mississippian age for the upper part, the whole unit has been assigned to the lower and upper Mississippian in this report. The black shale unit overlying the thick basal limestone is poorly exposed and its upper boundary is not visible. It carries a late Mississippian fauna, and west of Whiterocks River it rests on red sandstone which may have been derived from the solution of the underlying sandy limestone during a period of subaerial erosion.

The light-gray cherty limestone overlying the black shale unit is remarkably consistent, in both thickness and lithology. It carries a fauna, which, although it includes many undiagnostic forms, has an early Pennsylvanian aspect. In this report, it is considered the basal member of the Morgan formation because it resembles the basal member of the Morgan formation of the central Wasatch Mountains (Calkins and Butler, 1943, p. 28–29) and may have a counterpart (Calkins, F. C., personal communication, 1949) in the type locality of the Morgan on Weber River (Blackwelder, 1910, p. 529–530). The overlying red sandstone, shale and argillaceous limestone appear to be conformable with the underlying limestone and grade upward into tan to light-gray, crossbedded sandstone, with thin beds of light-gray, cherty limestone. The upper boundary of the Morgan formation is drawn at the top of the highest limestone bed in the predominantly massive sandstone sequence.

The highest formation of the Carboniferous system, a massive, partly crossbedded, fine- to medium-grained, light-gray sandstone, is the Weber sandstone. The entire unit is probably Pennsylvanian in age and is overlain by the Park City formation of Permian age.

MISSISSIPPIAN SERIES

LIMESTONE UNIT

Definition.—In this area the limestone unit of Mississippian age includes probable equivalents of the Madison limestone, the Deseret limestone, and the Humbug formation, as recognized in the Wasatch Mountains (Calkins and Butler, 1943, p. 23–28) and in the western Uinta Mountains (Huddle and McCann, 1947). These subdivisions of the limestone unit of Mississippian age are tentatively recognized in the detailed section measured at Whiterocks River, but are not sufficiently distinctive in the rest of the area to make possible the mapping of the units at the scale of the aerial photograph contact prints, 2 inches equal 1 mile.

Distribution and topographic expression.—The limestone unit of Mississippian age is present at isolated exposures in the headwaters of Dry Gulch, on Uinta River, Pole Creek, and Farm Creek, and as an escarpment on the southwest side of Whiterocks River. East of Whiterocks River, the limestone is broken by the Deep Creek zone of faulting so that it occurs only in fault blocks, and farther to the east, in the tributaries of Dry Fork of Ashley Creek and in Black Canyon, the limestone is only incompletely exposed south of the South Flank fault zone. Virtually complete exposures are present from Ashley Creek (fig. 2) eastward across Brush Creek and Little Brush Creek to the peaks that separate the valley of Pot Creek from Diamond Mountain (the plateaulike area to the south). It also appears along the Green River in the center of Split Mountain within the Dinosaur National Monument.

The limestone makes almost vertical cliffs along streams in the western part of the area, but in interstream areas it is unconformably overlain for the most part by Bishop conglomerate or glacial debris. East of Ashley Creek, however, limestone ridges rise more than 1,000 feet above the upper surface of the Bishop and form the higher peaks in the area. Beds of cherty limestone form prominent dip slopes in this area.

Lithology and thickness.—The lower 215 feet of the limestone unit of Mississippian age on Whiterocks River is dark-gray, fine- to coarse-grained, massive to thin-bedded cherty limestone with some interbedded light-gray, fine- to medium-grained dolomitic limestone. The chert is light to dark gray, and occurs as small porous masses or as thin lenticular beds. To the east, in equivalent stratigraphic position, are light-gray to tan, fine- to medium-grained, massive to thin-bedded cherty limestone and dolomitic limestone. The chert is brown to light gray, and for a short distance east of Ashley Creek and in the SW¼ sec. 11, T. 1 S., R. 22 E., it forms a massive bed 20 to 40 feet thick. Beds of coarse-grained limestone in the lower part of the sequence on Whiterocks River are crinoidal and moderately fossiliferous; fossils also occur in finer grained rock eastward as far as Brush Creek. The dark-gray, coarse-grained cherty limestone on Whiterocks River is typical of the Madison limestone as recognized in the western Uinta Mountains and Wasatch Mountains, but eastward the lithologic similarity of the lower part of the unit disappears.

On Whiterocks River, the 750-foot limestone unit that overlies the probable Madison limestone equivalent is light-gray, fine- to medium-grained cherty limestone with thin beds of reddish sandy limestone and tan shale. The chert is light to dark gray and occurs as nodules or lenses. One 30-foot bed of coarse-grained crinoidal limestone is located 250 feet above the base. Beds of brecciated limestone are characteristic of the unit, and some of the breccias appear to have been formed in place because the stratification in adjacent fragments may be only slightly disturbed. The breccia beds grade upward into massive limestone and appear to have been cemented by material similar to the overlying bed. Evidence of disconformity in the sequence is found in the Whiterocks River section, 400 feet above the base, where dark-gray, fine- to medium-grained limestone with peb-

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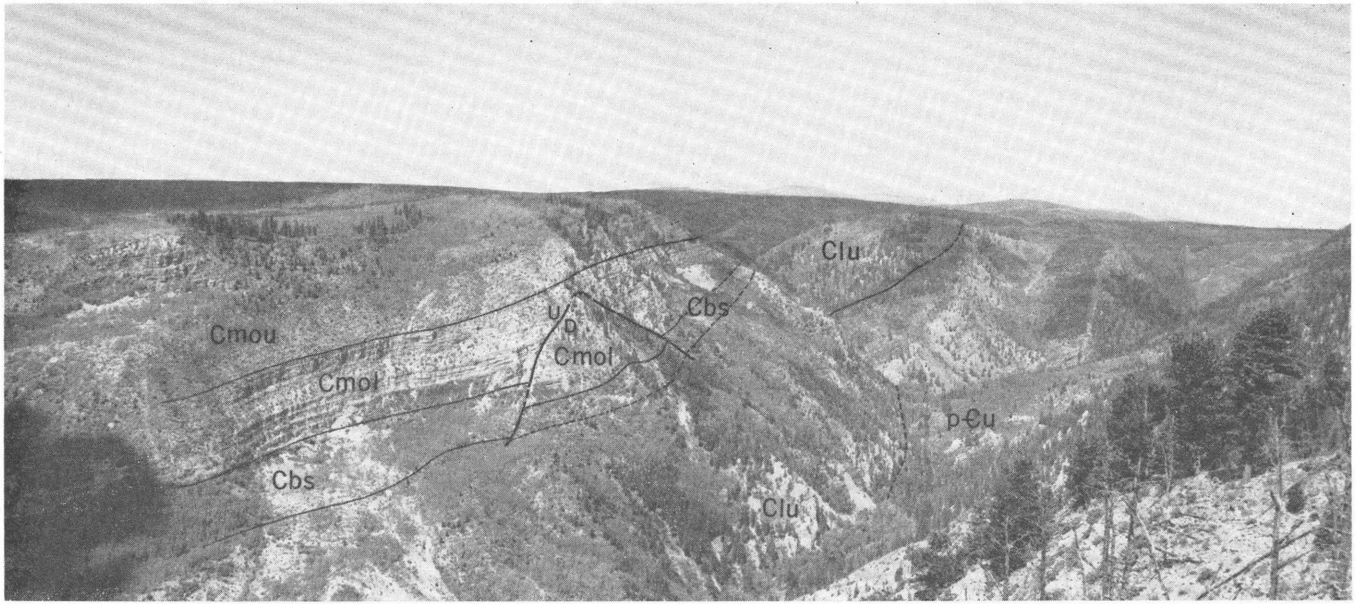

FIGURE 2.—West wall of upper Ashley Creek canyon from south of Red Pine Setting, showing the Uinta Mountain (*p€u*) limestone unit of Mississippian age (*Clu*), the black shale unit of Mississippian age (*Cbs*), and the Morgan formation [upper member (*Cmou*), lower member (*Cmol*)].

bles of chert, sandstone, and iron oxide rest on a slightly irregular surface. The entire unit is probably equivalent to the Deseret limestone of the Duchesne River area in the western Uinta Mountains.

The upper 250 feet of the limestone unit of Mississippian age on Whiterocks River consist of tan, fine- to medium-grained sandstone with beds of brecciated, light-gray, fine-grained limestone. For the most part, the unit is not as well exposed as the underlying gray cherty limestone, but just east of Brush Creek about 110 feet of interbedded, tan, fine- to medium-grained sandstone, light-gray fine-grained limestone, and some dark-gray to reddish shale are exposed along the road in NE¼SE¼ sec. 29, T. 1 S., R. 21 E. On Diamond Mountain, in SW¼ sec. 27, T. 1 S., R. 23 E., a massive red sandstone is located beneath the covered interval correlated with the black shale unit of Mississippian age. In the measured stratigraphic section in the W½ sec. 20, T. 1 S., R. 23 E., the sandstone unit is covered, but on the eastern border of the mapped area, in the NW¼ sec. 32, T. 1 S., R. 24 E., tan-weathering light-gray fine-grained sandstone forms good outcrops. The stratigraphic unit at Split Mountain, called "Beds of undetermined age" by McCann, Raman, and Henbest (1946, p. 3, 15–17), probably represents this sandstone facies of the limestone unit of Mississippian age. These sandstones are believed to be equivalent to the Humbug formation mapped by Huddle and McCann (1947) in the Duchesne River area of the western Uinta Mountains.

The detailed lithology and thickness of the limestone unit of Mississippian age, measured at intervals across the mapped area, is as follows:

Section of the limestone unit of Mississippian age on the west side of Whiterocks River in W½ sec. 7, T. 2 N., R. 1 E.

[Measured by D. M. Kinney, J. F. Rominger, R. S. Brown, and P. Verastegui M.]

Black shale unit: Fine- to medium-grained red sandstone and red shale.

Limestone unit:	*Feet*
Limestone, gray, coarse-grained	4
Shale, gray, platy	2
Limestone, gray, fine-grained	2
Sandstone, tan, fine- to medium-grained; and limestone, light-gray, fine-grained, brecciated	244
Limestone, light-gray, fine-grained, brecciated	152
Limestone, light-gray, fine-grained, thin-bedded	30
Limestone, light-gray, fine-grained, with rare solitary corals	83
Limestone, brecciated, light-gray, fine-grained, tan-weathering; chert, dark-gray; and shale, tan, contorted	46
Limestone, dark-gray, fine- to medium-grained; pebbles of chert, sandstone, and iron oxide pellets at base marking a possible disconformity	45
Limestone, light-gray, fine- to medium-grained, jointed	2
Limestone, light-gray, fine-grained, brecciated and recemented; grades upward into undisturbed limestone	112
Limestone, red, fine-grained	5

Section of the limestone unit of Mississippian age on the west side of Whiterocks River in W½ sec. 7, T. 2 N., R. 1 E.—Continued

	Feet
Limestone unit—Continued	
Limestone, light gray to tan, coarse-grained, crinoidal, with few reddish streaks	30
Limestone, light-gray, fine-grained, with lenses of chert, light-gray	56
Limestone, light-gray, fine-grained; nodules and lenses of light-gray chert; top 8 feet very cherty	97
Limestone, light-gray, fine-grained, with nodules of light-gray chert	30
Limestone, light-gray, medium-grained	36
Limestone, light- to medium-gray, brecciated; breccia fragments to 2 feet in diameter	28
Limestone, dark-gray, fine-grained, styliolitic, with lenses of dark-gray chert; breaks into angular blocks	25
Limestone, dolomitic, gray, fine- to medium-grained; forms cliffs	35
Limestone, light-gray, fine-grained; makes recess in cliff	3
Limestone, dolomitic, light-gray, fine- to medium-grained; contains small solutional cavities to ⅜ inch in diameter	25
Limestone, dark-gray, medium-grained; thinly banded on weathered surface	3
Limestone, light-gray, fine-grained, tan-weathering; with beds of limestone; dark-gray, coarse-grained, fossiliferous and thin beds of light-gray chert	72
Limestone, dark-gray, massive, fossiliferous, with white chert in small lace-like masses; contains solitary corals, coiled gastropods, and brachiopods	28
Limestone, dark-gray, massive, crystalline	14
Limestone, dark-gray, fine-grained	3
Limestone, gray, fine-grained, thin-bedded with unconformity at base	7
Sandstone, tan, fine- to medium-grained, calcareous; and shale, reddish-brown, sandy in thin streaks; contains vugs filled with calcite	2
Limestone, dark-gray, with calcite-filled fractures	3
Sandstone, tan to reddish, fine-grained, thin-bedded; interbedded with limestone, dark-gray, brecciated	11
	1,235

Section of the limestone unit of Mississippian age on Diamond Mountain north of Diamond Gulch from the SE¼ sec. 7 to the SE¼ sec. 19, T. 1 S., R. 23 E.

[Measured by D. M. Kinney and J. F. Rominger]

Black shale unit: Covered.	
Limestone unit:	
Limestone, light-gray to mottled tan, fine-grained hackly weathering	22
Covered; probably limestone and sandstone interbedded; Diamond Mountain road passes through swale made by this interval	198
Limestone, light-gray, fine-grained, with tan to reddish chert nodules	43
Sandstone, tan to gray, fine-grained, calcareous; forms ledge	5
Limestone, light-gray to pink, fine-grained; 0.5 foot of pink chert at base	13
Limestone, light-gray to tannish-gray, fine-grained, slightly cherty	110
Limestone, light-gray, fine-grained, cherty, with few thin beds of limestone, dark-gray, fine-grained; weathers brown; fossiliferous near top	77

Section of the limestone unit of Mississippian age on Diamond Mountain north of Diamond Gulch from the SE¼ sec. 7 to the SE¼ sec. 19, T. 1 S., R. 23 E.—Con.

	Feet
Limestone unit—Continued	
Limestone, light- to dark-gray, mottled, brecciated	30
Limestone, light-gray, fine-grained, slightly dolomitic, thin-bedded, fossiliferous, with tan to light-gray reticulated chert	72
Limestone, light-gray, medium- to coarse-grained, crinoidal and fossiliferous, thin-bedded with light-gray to tan chert concretions; forms ledge	52
Limestone, light-gray, fine- to medium-grained and limestone, coarse, crinoidal, thin-bedded; forms slope	73
Limestone, light-gray, fine- to coarse-grained, crinoidal, thin-bedded; forms slope	29
Limestone, light-gray, fine-grained, with lenses of tan chert	4
Limestone, light-gray, coarse-grained, fossiliferous	15
Limestone, light-gray, slightly porous; limestone, coarse-grained, crinoidal; and chert, tan, porous interbedded	29
Limestone, light-gray to brown, oölitic, fossiliferous; solitary horn corals abundant; forms ledge	5
Limestone, light-gray, fine-grained, in part dolomitic, massive; shows fine banding and crossbedding on weathered surface; vugs to 1 foot in diameter filled with calcite; fossils poorly preserved and probably fragmental. Some light-gray chert concretions	67
Limestone, light-gray, thin-bedded and brown chert concretions showing "liesegang ring" banding	90
Limestone, pink to gray, sandy, thin-bedded; poorly exposed	31
	965

Fossils and age.—The lower 50 to 100 feet of the limestone unit of Mississippian age in the western part of the area is abundantly fossiliferous at certain places. A collection (USGS 10,335) from the west side of Whiterocks River, submitted to James Steele Williams of the Geological Survey, was reported as follows: "This is a typical Madison limestone assemblage, containing *Spirifer centronatus* Winchell, *Chonetes loganensis* Hall and Whitfield and Schuchertellas? represented by brachial valves." Concerning a second collection (USGS 10,328) from the W½ sec. 36, T. 1 S., R. 20 E., east of Red Pine Setting, Mr. Williams states, "Though none of the species definitely recognized is restricted to the Madison limestone, the assemblage is typical of that formation." The upper part of the unit is only sparingly fossiliferous, although poorly preserved cup corals are present at a number of horizons, crinoidal columnals are locally present, and poorly preserved and mostly fragmental brachiopods are recognizable in cross section on weathered surfaces. In regard to a large collection (USGS 10,359) of brachiopods and corals from the small hill near the quarter-section corner between sections 30 and 31, T. 1 S., R. 24 E., close to the northeastern border of the map on Diamond Mountain and a short distance below the base of the interbedded sandstone and limestone at the top of the limestone unit of Mississippian age, Mr. Williams and Miss Helen Duncan report:

The *Spirifer* that is so abundant is, unfortunately, probably a new species. It has some affinities with types commonly found in upper Mississippian and lower Pennsylvanian rocks in the West but is also allied to a species *S. vernonensis* Swallow, which has also been reported in upper Mississippian rocks in the West but is typically in rocks in the midcontinent that would probably be correlated with the Madison limestone. The other brachiopods consist of a few incomplete specimens that are tentatively identified as immature individuals of *Punctospirifer subellipticus* (McChesney), a large but generically indeterminate shell tentatively referred to *Orthotetes* sp. indet., and two productids that preserve so little of the ornamentation that they cannot be generically identified. The assemblage looks more like an upper Mississippian one for this area than a typical Madison assemblage, but the age could be of Madison.

Several types of corals are present, but they are so much altered by recrystallization and replacement that it is difficult to interpret internal structures. What are believed to be two species of *Syringopora* are each represented by several specimens. They resemble, at least superficially, types that are common in the Madison but that have been reported from the upper Mississippian as well. There is one specimen of a lithostrotionid coral that has been partly silicified, partly dissolved, and much recrystallized. I rather think it is a *Lithostrotionella*, but I have not been able to demonstrate the presence of columellas, so it might be a *Thysanophyllum*. These lithostrotionids are not entirely unknown in the lower Mississippian but are much more characteristic of Meramecian and later rocks. There are also a number of specimens, mostly fragmentary, of zaphrentoid corals. Most of these are small forms, though a few are medium sized. Details of internal structure are not clear, and I do not wish to make even a tentative guess as to what genera may be represented.

No marine fossils were noted in the sandstone and interbedded limestone at the top of the limestone unit of Mississippian age, although a mold of a plant stem almost 5 inches in diameter, in fine-grained red sandstone, was collected from the NE¼SW¼ sec. 27, T. 1 S., R. 23 E. This specimen (USGS 10,341) was identified by James S. Schopf of the Geological Survey as a root stock of *Stigmaria ficoides* Brongniart. It suggests that continental, or very near shore conditions, were necessary for deposition of the upper part of the unit to the east. Commonly, *S. ficoides* ranges from late Mississippian to late Permian in age, but it could occur in rocks of early Mississippian age.

The age of the lower part of the thick limestone sequence is indicated as early Mississippian according to megafossil collections which were obtained 40 to 100 feet above the top of the shale of the Uinta Mountain group on Whiterocks River. Collection USGS 10,359 from the upper part of the unit on Diamond Mountain has conflicting elements, but it is probably of late Mississippian age. The black shale that overlies the limestone unit is definitely of late Mississippian age. The age of the entire limestone unit of Mississippian age, therefore, has been assigned as "early and late Mississippian."

Stratigraphic relations and correlations.—The limestone unit of Mississippian age rests unconformably upon the pre-Cambrian Uinta Mountain group from Dry Gulch eastward to Brush Creek, and upon the Lodore formation of Late(?) Cambrian age from Brush Creek to Diamond Mountain. The dip and strike of the underlying pre-Cambrian and Upper(?) Cambrian rocks and the limestone unit of Mississippian age are very similar except on the south and west side of Whiterocks River, where the limestone unit of Mississippian age overlaps and cuts out more than 300 feet of the shale at the top of the Uinta Mountain group. No other physical evidence of an unconformity was noticed, although the importance of the break is proved by the absence of Cambrian, Ordovician, Silurian, and Devonian rocks in the western part of the area, and by the lack of the Ordovician, Silurian, and Devonian rocks in the area where the Lodore formation of Late(?) Cambrian age is present. The pronounced thinning of the upper shale unit of the Uinta Mountain group eastward from Whiterocks River suggests that considerable erosion of the pre-Cambrian rocks occurred during the time represented by the hiatus, but, as has been pointed out in the discussion of the pre-Cambrian rocks, the thinning of the shale at the top of the Uinta Mountain group may be due to facies change from shale to red quartzitic sandstone.

Some evidence is present on the divide between Whiterocks River and Farm Creek that the red sandstone at the base of the overlying Mississippian black shale unit is an accumulation formed by the solution of lime from calcereous sandstone and sandy limestone, although karst topography, as reported by Henbest (McCann, Raman, and Henbest, 1946, p. 3) in northwestern Colorado, was not recognized. It is probable that the time break at the top of the limestone unit of Mississippian age is of small duration. The disconformity, 400 feet above the base of the limestone on Whiterocks River, and the abundance of limestone breccias at intervals throughout the upper two-thirds of the unit, suggest frequent temporary interruptions of sedimentation.

The limestone unit of Mississippian age includes probable equivalents of the Madison limestone, the Deseret limestone, and the Humbug formation of the western Uinta and Wasatch Mountains, and the Madison limestone in Wyoming, southeastern Idaho, and northwestern Colorado. A much thinner limestone in central and southwestern Colorado, the Leadville limestone, is equivalent to the lower 200 feet of the Mississippian strata on Whiterocks River. In the Grand Canyon area of Arizona, the correlative Mississippian unit is the Redwall limestone. No Mississippian rocks are present in the area directly south of the Book Cliffs, although Dane (1935, p. 24) reports a Madison fauna from boulders in a conglomerate of early Pennsylvanian (?) age in the Salt Valley area. These boulders could not have been transported far, so the Madison limestone equivalent must have been present in the area and must have been eroded prior to the deposition of the Pennsylvanian rocks.

Conditions of deposition.—The limestone unit of Mississippian age is predominantly of marine origin, although the tan to red sandstone (in which a mold of a rootstock of *Stigmaria ficoides* was found on Diamond Mountain) may be of continental origin. The crossbedding visible on weathered outcrops of limestone, the frequency of occurrence of broken or worn fossil fragments in the upper part of the unit, and the abundance of limestone breccia beds, suggest that much of the limestone accumulated under shallow water and conditions suggestive of deposition in an epeiric sea. Deposition was frequently interrupted by storms whose waves broke the already consolidated limestone, but did not disarrange or transport the fragments so that they were later recemented by deposition of calcium carbonate now represented by the overlying limestone and dolomitic limestone. No subaerial conditions are believed to have existed in the western part of the area; the only observed case of a surface of scour overlain by pebbles of chert, sandstone, and iron oxide is believed to be subaqueous.

BLACK SHALE UNIT

Definition.—The black shale unit as used in this report is a thin, topographically weak sequence of strata of late Mississippian age above the limestone unit of Mississippian age and below the lower member of the Morgan formation. At Split Mountain, the shale has been included in the Morgan formation by Brill (1944, p. 632), and by McCann, Raman and Henbest (1946, p. 2, 3, 13, 14). The shale at Split Mountain occupies the same stratigraphic position as the black shale unit to the west, but it may be slightly younger. The black shale unit is not given a formal formation name here because of the lack of a well-exposed section to serve as a type locality.

Distribution and topographic expression.—The black shale unit is present in a fault block in secs. 34 and 35, T. 3 N., R. 2 W., east of Pole Creek; in secs. 3, 10, 11, and 12, T. 2 N., R. 1 W., and secs. 7, 8 and 5, T. 2 N., R. 19 E., on Farm Creek and Whiterocks River; in T. 2 S., R. 19 E. (unsectionized), in the headwaters of tributaries of Dry Fork of Ashley Creek; in secs. 1, 2, 3, and 11, T. 2 S., R 20 E., on Ashley Creek at Red Pine Setting; and from sec. 32, T. 1 S., R. 21 E., eastward across Brush Creek and Little Brush Creek to Diamond Mountain.

The black shale unit is not completely exposed at any point in the area. The better exposures are along Farm Creek in sec. 11, T. 2 N., R. 1 W.; on the east fork of Dry Fork of Ashley Creek in sec. 10, T. 2 S., R. 19 E. (unsectionized); and on the Iron Springs Road, east of Brush Creek in sec. 29, T. 1 S., R. 21 E. Generally, a heavy dark soil mantles the area of outcrop, and blocks of limestone from the overlying Morgan formation litter the surface. In places, it has been necessary to map the black shale unit by using stratigraphic position and the lack of exposures as the only criteria. The shale forms swales or low places in ridges and underlies small subsequent streams. Along Ashley Creek, the shale was eroded more rapidly than the strata above and, as a result, massive limestone of the Morgan formation is undermined and retreats as an almost vertical wall. The retreat of the Morgan formation and the weathering of the shale has developed a ledge on top of the underlying limestone unit of Mississippian age that is almost covered by large angular blocks of Morgan limestone. Along Dry Fork of Ashley Creek, the black shale forms a similar narrow ledge which slopes gently southward with the dip of the strata.

Lithology and thickness.—On Farm Creek and on the divide between Farm Creek and Whiterocks River, the black shale unit consists of 14 feet of red sandstone and shale overlain by 6 feet of light-gray to pink limestone and 259 feet of dark-gray to black highly organic and pyritiferous shale with beds of greenish sandstone, green to tan sandy limestone, and black fossiliferous limestone. Some lignitic shale is present in the upper part of the unit, and analyses of bituminous coal samples, reportedly collected from Carboniferous strata on Farm Creek, are given in the section on Economic Geology. Eastward, a black to dark-gray shale is the most abundant lithologic constituent, however, beds of tan-weathering, coquinalike limestone, black chert, and thin beds of dark-greenish sandstone are commonly the only lithologic criteria present in outcrop because the shale disintegrates to a black clay soil. Black shale fragments have been definitely identified east of State Highway 44 near the bridge over Little Brush Creek.

The detailed lithology of the black shale unit at one of the better exposures, where the formation is of maximum thickness, is given in the following section.

Section of black shale unit in the NW¼ sec. 12, T. 2 N., R. 1 W., on the divide between Farm Creek and Whiterocks River

[Measured by D. M. Kinney and J. F. Rominger]

	Feet
Morgan formation:	
Lower member:	
Limestone, light-gray, fine- to coarse-grained, fossiliferous, with nodules of light-gray chert	50
Black shale unit:	
Shale, dark-gray to black, pyritiferous; lignitic shale or lignite beds near the top. Streaks of argillaceous, fossiliferous limestone and 0.5 feet of greenish sandstone at base	162
Shale, dark-gray to black, pyritiferous, with thin bed of green to tan sandy limestone near the middle	36
Shale, dark-gray to black, thin beds of greenish sandstone	30
Sandstone, gray-green, medium-grained	12
Covered, probably black to dark-gray shale	19
Limestone, light-gray to pink, fine-grained	6
Sandstone, red, fine- to medium-grained, and shale, red, sandy	14
	279

The black shale unit decreases in thickness from 279 feet (as measured in the above section) to not more than 25 feet in the N½ sec. 36, T. 1 S., R. 23 E., on Diamond Mountain. The eastward thinning appears to be gradual because 125 feet of black shale was measured in the SE¼ sec. 29, T. 1 S., R. 22 E., and 80 feet of shale was measured in the SE¼ sec. 19, T. 1 S., R. 23 E. The unit seems to thicken south of Diamond Mountain because a thickness of 165 feet of shale was measured at Split Mountain (Thomas, McCann, and Raman, 1945); however, part of this shale may be of Pennsylvanian age (McCann, Raman, and Henbest, 1946, p. 3). The Tidewater Associated Oil Co.-Mohawk Oil Co. well 1–58–7, located in the SW¼SW¼SE¼ of sec. 7, T. 3 S., R. 20 E., passed through 147 feet of black shale between 2,588 feet and 2,735 feet depth.

Fossils and age.—Fossil collections from two localities of the black shale unit were made in the course of the field work. Because of their importance, both localities were visited twice to obtain large, diagnostic collections. The first locality is on the east side of Farm Creek near the center of sec. 11, T. 2 N., R. 1 W., Uintah County, Utah. The original collection (USGS 10,321) from this locality was submitted to James Steele Williams of the Geological Survey, who made the following report in 1949:

The most common form and only identifiable species in this collection is *Dictyoclostus inflatus* (McChesney). The genus *Chonetes* is represented by immature or incomplete individuals that cannot be specifically identified. Other genera that have been tentatively identified include: *Composita?*, *Diaphragmus?*, *Ambocoelia?*, and *Leiorhynchus?*. The *Leiorhynchus?*, if it is a *Leiorhynchus*, is of about the same size as *L. carboniferum Girty.* Several unidentified aviculopectenoid pelecypods are also in the collection. The age cannot be given with certainty because so many of the elements in it are not determinable. The resemblances are more with Mississippian faunules of nearby areas than with nearby Pennsylvanian faunules.

The second group of collections, obtained from the same locality in August of 1947, was made by Williams, Mendes, Rominger, and Kinney. Mr. Williams made the following report in 1949 on material in Collections USGS 10,350, 10,351 and 10,352:

These lots contain good brachial valves of *Diaphragmus* that show the internal characters that typify that genus. The collections also contain *Dictyoclostus inflatus* (McChesney), a *Schizophoria* cf. *S. swallowi* (Hall), probably two species of *Chonetes*, both of the general type of *C. illinoisensis* Worthern, at least one species of *Lingula* or of a closely related genus, a small linoproductid, at least two genera of aviculopectenoids and a few other pelecypods, and two pieces of fish remains.

The fish remains were examined by Dr. David H. Dunkle of the U. S. National Museum who reports:

Specimen No. 1—An unassociated operculum of a palaeoniscoid fish. The specimen is not generically and specifically identifiable, but its general habit is strongly reminiscent of the corresponding part in members of the Carboniferous family Rhadinichthyidae.

Specimen No. 2—A typical crossopterygian scale of the cycloid type. In all observable characters this specimen suggests identification as the late Devonian *Holoptychius giganteus*. The same attributes, however, permit the assumption that the specimen might pertain to either of the Carboniferous rhizodont genera *Strepsodus* or *Rhizodopsis*. *Strepsodus* is confined to Mississippian strata in various parts of the world. One species, *arenosus*, has been described from near the base of the lower Mississippian in north-central Pennsylvania. It differs from the present specimen in being much smaller and having a greater length than breadth. *Rhizodopsis* is an exclusively Pennsylvanian genus and differing similarly in small size and greater length than breadth has been reported in the United States from the Allegheny group in Illinois and Ohio. The only other published occurrence of a Mississippian crossopterygian is a mandible from the St. Louis limestone in Missouri. In the absence of associated scales, this single specimen has been referred to the osteolepid *Megalichthys*.

Of the age of Collections USGS 10,350, 10,351, and 10,352, Mr. Williams commented, "There is little, if any, doubt that this collection is of late Mississippian age, probably Chester, but it may be slightly older."

The second locality from which a black shale fauna was collected is in the swale in the NE¼SE¼ sec. 29, T. 1 S., R. 21 E., one-half mile east of Brush Creek. Collection USGS 10,348, obtained from a thin, brown limestone in the black shale, was submitted to Mr. Williams who reported as follows: "It contains fragments of brachiopods, possibly representing Spirifers, Punctospirifers, and Compositas, but nothing determinable. No age significance. Mr. Haas examined material from this collection for conodonts and obtained an indeterminate species of the genus *Cavusgnathus*, which genus ranges from Mississippian into Pennsylvanian."

On a second collection from the same locality, Mr. Williams reports,

Collection USGS 10,358. This collection contains nothing that is determinable except possibly some immature Cleiothyridinas. Fragments of brachiopods resembling dictyoclostids of the *Dictyoclostus inflatus* type, and possibly Compositas are present, as are crinoid columnals and a few very small and incomplete horn corals that are not determinable. No age data of value are provided by the collection, but nothing was seen that conflicts with a late Mississippian age. Mr. Hass found several fragments of conodonts belonging to the genera *Cavusgnathus* and *Ligonodina* and one specimen that may be *Gnathodus*.

Stratigraphic relations and correlation.—The stratigraphic relations of the black shale unit to the underlying limestone unit of Mississippian age and overlying lower member of the Morgan formation are poorly known because of the lack of exposures. On the divide between Whiterocks River and Farm Creek, the red sandstone included in the black shale appears to rest conformably upon the underlying gray limestone of Mississippian age and to be overlain conformably by light-gray to pink fine-grained limestone which is succeeded by a covered interval presumed to be black shale. The boundary between the limestone unit and the black shale unit might have been drawn equally well at the top of the light-gray to pink fine-grained limestone, because some tan to red sandstone is characteristic of the upper part of the limestone unit. To the east, the boundary of the limestone unit of Mississippian age and the black shale unit is on a dip slope of limestone; the stratigraphic relations are not exposed. The upper boundary of the black shale is covered throughout the area.

The black shale has been recognized in all sections that were measured along the south flank of the Uinta Mountains. From the faunal evidence derived from study of the collections made by Huddle in the Duchesne River area, there seems little doubt that the entire unit is of uniform age. A black limestone and black shale unit occupying a similar stratigraphic interval in the Cottonwood-American Fork area of the Wasatch Mountains was included in the Humbug formation by Calkins and Butler (1943, p. 27). Fossils collected from the black limestone-shale unit in Big Cottonwood Canyon were assigned to the upper Mississippian by G. H. Girty (Baker, Huddle, and Kinney, 1949, p. 1177). It is probable that this unit in the central Wasatch Mountains is continuous with the black shale unit on the south flank of the Uinta Mountains. Lithologically, the post-Humbug rocks north of the thrust fault, which passes through Heber Valley, closely resemble the basal part of the Great Blue limestone south of the fault and these units have been tentatively correlated by Baker. It is possible, nevertheless, that the black shale unit of the Uinta Mountains is to be correlated with the lower part of the Manning Canyon shale (upper Mississippian, lower Pennsylvanian) which overlies the Great Blue limestone.

Conditions of deposition.—The presence of a normal marine fauna, in the black shale unit on Farm Creek and east of Brush Creek, indicates that marine conditions existed over the major portion of the area during most of the period of shale deposition. Swamp conditions during the deposition of the upper part of the shale are suggested by streaks of lignitic shale and the reported occurrence of a coal prospect along Farm Creek. The source of the black muds and the calcareous muds, which formed the shale unit, was probably somewhere west of the Wasatch Mountains because the formation thickens in that direction. The attenuated black shale unit along the south flank of the Uinta Mountains probably represents a foreland facies of the thicker sections to the west.

PENNSYLVANIAN SERIES

MORGAN FORMATION

Definition.—The name "Morgan formation" was originally given to exposures of red sandstone and shale with intercalated limestone in the upper canyon of the Weber River, near the town of Morgan in the Wasatch Mountains (Blackwelder, 1910, p. 529). At that location, it rests on the cavernous weathered surface of a gray limestone, whose fauna was assigned by Girty to the early Pennsylvanian (Blackwelder, 1910, p. 530), and it grades upward through alternate gray shale, limestone, and sandstone into the Weber quartzite. A fauna from the intercalated limestone is also early Pennsylvanian in age (Blackwelder, 1910, p. 530). A formation, tentatively correlated with the Morgan in the central Wasatch Mountains, 35 miles south of the type locality (Calkins and Butler, 1943, p. 28–29, and Baker, 1947), consists of 250 feet of cliff-forming blue-gray cherty limestone overlain by 100 feet of thin-bedded maroon limestone and calcareous shale, and some gray limestone. It is separated from the underlying limestone unit of late Mississippian age by an erosional unconformity. The Morgan formation is also identified in the Duchesne River area of the western Uinta Mountains, where 240 feet of gray cherty limestone is overlain by 210 feet of red sandstone (Huddle and McCann, 1947). In the Uinta River-Brush Creek area, the formation includes 300 to 415 feet of light-gray cherty limestone overlain by 250 to 440 feet of red sandstone, shale, and argillaceous limestone with intercalated beds of gray limestone.

Distribution and topographic expressions.—The Morgan formation is well exposed in the cliffs on the west side of Whiterocks River (fig. 3), along Ashley Creek (fig. 2), along Dry Fork of Ashley Creek, and at isolated places in the northern part of Diamond Mountain.

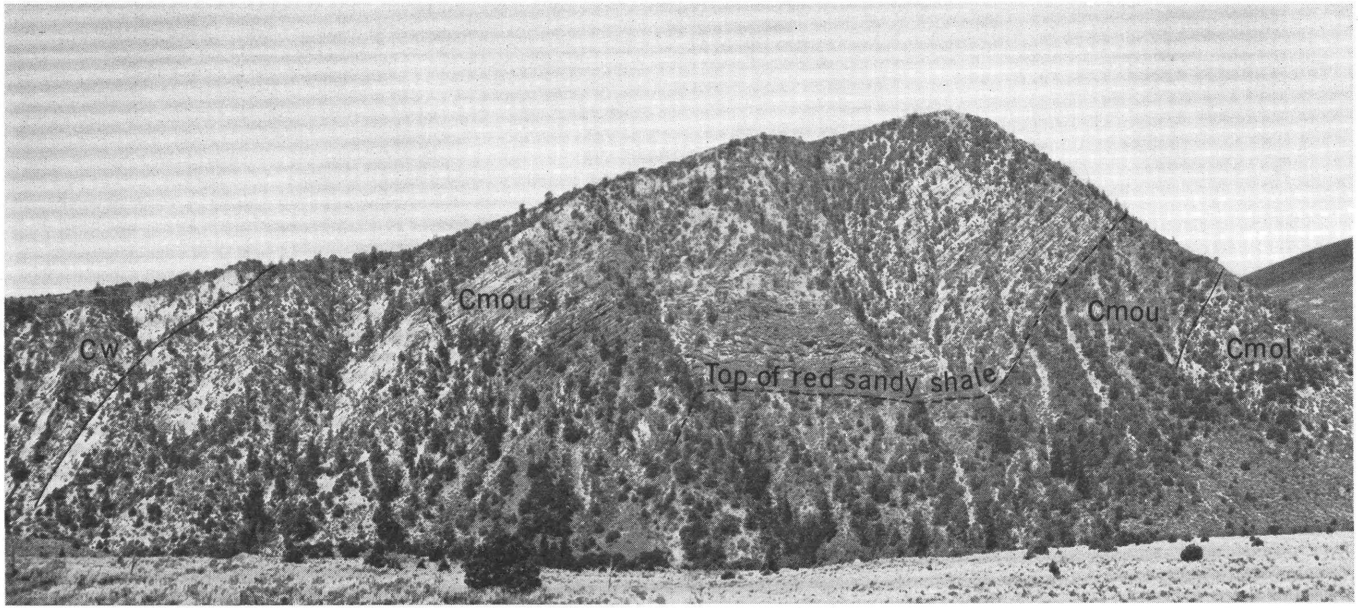

FIGURE 3.—Small anticlinal fold in the upper member of the Morgan formation (*Cmou*) on the west side of Whiterocks River. Upper member of Morgan formation overlain by Weber sandstone (*Cw*) and underlain by lower member of Morgan formation (*Cmol*).

The lower gray cherty limestone member forms cliffs or steep slopes and is generally well exposed throughout the area. The overlying red sandstone, shale, and argillaceous limestone member is relatively soft, disintegrates into a red sandy soil, and rarely forms good exposures.

Lithology and thickness.—The lower member of the Morgan formation includes beds of light- to dark-gray, fine- to coarse-grained, thin- to thick-bedded, cherty limestone. The chert is generally light gray, but in certain beds it is red to orange red. The base of the upper member is soft, red sandy shale, fine-grained sandstone, and argillaceous limestone with intercalated beds of light-gray to pink coarse-grained fossiliferous limestone. It grades upward into calcareous, fine- to medium-grained, crossbedded or massive, tan to red sandstone with occasional thin beds of light-gray to pink, medium- to coarse-grained limestone. The sandstone is similar to that in the overlying Weber sandstone, but it contains more calcareous cement, is slightly darker in color, and is crossbedded in thinner beds.

The lower member of the Morgan formation thins from 415 feet on Whiterocks River to 296 feet on Split Mountain. The upper member is remarkably constant in thickness, ranging from 960 feet in the west to 900 feet on Diamond Mountain. However, in the section at Split Mountain measured by McCann, Raman, and Henbest (1946, p. 5–13), it is only 711 feet thick.

The following sections measured on Whiterocks River, Ashley Creek, and Diamond Mountain show the detailed lithologic variation in the Morgan formation.

Section of Morgan formation in cliff on west side of Whiterocks River SW¼ sec. 7 and NW¼ sec. 18, T. 2 N., R. 1 E., Uintah County, Utah

[Measured by D. M. Kinney, J. F. Rominger, P. Verastegui M., and R. S. Brown]

Weber sandstone:	
Sandstone, light-gray, fine-grained, massive, crossbedded, slightly calcareous.	
Morgan formation:	*Feet*
Sandstone, red to tan, fine-grained, in part calcareous, with a few sandy limestone beds and lenses of red chert	517
Breccia, sandstone, tan and limestone, light-gray	4
Sandstone, red, shaly and shale, red, sandy, interbedded with a few thin beds of sandy red limestone	378
Limestone, light-gray with lenses of light-gray chert	9
Sandstone, tan, fine- to medium-grained	6
Sandstone, red, shaly with beds of limestone, reddish-gray, fine-grained	49
Limestone, gray, with lenses of light-gray chert	109
Limestone, white, cherty, rough-weathering	10
Shale, reddish-brown	2
	1,084

Section of the limestone unit of Mississippian age on the west side of Whiterocks cliff on east side of Ashley Creek 1½ miles west of the west boundary of sec. 8, T. 2 S., R. 21 E. Upper part of section measured in cliff on west side of Ashley Creek in the SE¼ sec. 2 and NE¼ sec. 11, T. 2 S., R. 20 E. (unsectionized), Uintah County, Utah

[Measured by D. M. Kinney, J. F. Rominger, P. Verastegui M., and R. S. Brown]

	Feet
Weber sandstone:	
Sandstone, light-gray, tan-weathering, crossbedded, thick-bedded to massive, fine-grained, calcareous.	
Morgan formation:	
Limestone, gray, medium-grained, with fossils and a few chert concretions	16
Limestone, light-gray, sandy, rough-weathering	6
Sandstone, tan, calcareous, slabby	22
Limestone, light-gray, massive, thick-bedded, fine-grained, with poorly preserved fossils	14
Sandstone, tan, fine-grained, crossbedded, with streaks of crinoidal limestone	190
Sandstone, red to tan, fine-grained, crossbedded with thin beds of fossiliferous crinoidal limestone	301
Sandstone, tan, fine- to medium-grained, crossbedded, calcareous	191
Shale, red, sandy, with a few thin beds of fossiliferous limestone	134
Sandstone, light-gray to pink, quartzitic, thin-bedded	5
Shale, red, sandy, with a few thin beds of fossiliferous limestone	44
	923

Section of Morgan formation on north side of Diamond Gulch, Diamond Mountain. SE¼ sec. 29, to NW¼ sec. 32, T. 1 S., R. 23 E.

[Measured by D. M. Kinney and J. F. Rominger]

	Feet
Weber sandstone:	
Sandstone, light-gray, tan-weathering, fine-grained, crossbedded, thick-bedded.	
Morgan formation:	
Limestone, sandy, light-gray to pink, fine-grained, thin-bedded, cherty; weathers to slabs	18
Limestone, light-gray, fine-grained, fossiliferous, with ovoid tan to red chert concretions to 6 inches in diameter	8
Sandstone, tan, calcareous, crossbedded, fine-grained	115
Limestone, light-gray to pink at top, fine- to medium-grained crinoidal and fossiliferous at base, with lenses of tan chert to 2 feet in length	6
Sandstone, tan, fine-grained, crossbedded, calcareous	35
Limestone, fine- to coarse-grained, light-gray, crinoidal, with abundant light-gray ovoid chert nodules	27
Sandstone, light-gray, tan-weathering, fine-grained	51
Limestone, light-gray, coarse-grained, fossiliferous	10
Sandstone, light-gray, tan-weathering, fine-grained, crossbedded, calcareous	40
Sandstone, red, fine-grained	20
Limestone, gray, coarse-grained, with nodules of red chert	6
Sandstone, light-gray to tan, fine-grained	119
Limestone, dark-gray, with concretions of red chert	3
Sandstone, light-gray, fine-grained	90

Section of Morgan formation on north side of Diamond Gulch, Diamond Mountain. SE¼ sec. 29, to NW¼ sec. 32, T. 1 S., R. 23 E.—Continued

Morgan formation—Continued	*Feet*
Sandstone, light-gray, fine-grained, calcareous, with some pink to white chert	10
Limestone, gray to red, coarse-grained	66
Sandstone, tan and red interbedded, fine-grained	30
Shale, red and sandstone, thin-bedded, red, interbedded	59
Limestone, red and purple to gray, argillaceous	194
Standstone, light-gray, tan-weathering, fine-grained, cherty	1
	908

Fossils and age.—Certain limestone beds in the Morgan formation are abundantly fossiliferous. Collections made at a number of places and at different stratigraphic positions were submitted to James Steele Williams of the Geological Survey. Collection USGS 10,332, which was obtained near the base of the lower limestone member on the west side of Whiterocks River, and collection USGS 10,338, from about the middle of the lower limestone member at the same locality, were reported as follows:

Collection USGS 10,332.—This collection contains a horn coral tentatively identified by Miss Duncan as *Caninia* cf. *C. flaccida* Easton, *Dictyoclostus* cf. *D. inflatus* (McChesney), a linoproductid represented by fragments, a small *Juresania?*, Spirifers of the *S. occidentalis* type, Compositas, and unidentified fragments of other brachiopods. *Caninia flaccida* is so far known only from the Mississippian, but the identification is not certain and the range of the species has not been adequately tested. The *Juresania?* suggests Pennsylvanian age, whereas the other fossils are types that occur in both Mississippian and Pennsylvanian rocks. The evidence is perhaps slightly stronger for a Pennsylvanian age than for a reference to Mississippian.

Collection USGS 10,338.—This collection is a large one, but it is not varied, as only a small number of species are represented. Included in it are *Spirifer occidentalis* (Girty) ; a species of the *Spirifer opimus* type; a productid that probably represents the form commonly identified in this region as *Juresania nebrascensis* (Owen), but I cannot be sure that it actually belongs to that genus: a *Composita*; and a *Myalina*. That is very probably Pennsylvanian in age, but the possibility that it might be Mississippian cannot be ruled out.

These determinations are the basis for separating the limestone from the underlying black shale unit which carries an upper Mississippian fauna.

Collections USGS 10,329, 10,330, and 10,331, from limestone beds near the top of the Morgan formation in sec. 1, T. 3 S., R 20 E., on the west side of Ashley Creek, and collection USGS 10,337, from near the base of the upper member on the west side of Whiterocks River, were reported as follows:

Collection USGS 10,329.—This collection consists of Spirifers of the *S. opimus* type and some crinoid stems. The collection is of Des Moines or older Pennsylvanian age.

Collection USGS 10,330.—This collection contains bryozoans tentatively identified as belonging to the genera *Tabulipora, Polypora, Fenestella,* and *Meekopora.* There is also a rhomboporoid form. (Identified by Miss Helen Duncan). The brachiopods include species close to *Productus* (*Dictyoclostus*) *hermosanus* Girty and one that is probably a *Productus* (*Linoproductus*) *coloradoensis* Girty. There are also Spirifers of the *S. opimus* type. The age is Des Moines or older Pennsylvanian.

Collection USGS 10,331.—This collection contains Bryozoa belonging to the genera *Septopora, Fenestella,* and *Polypora* as well as a rhomboporoid form. The brachiopods are referable to the genera *Composita, Spirifer,* and *Productus* s. l. The Spirifers are of the *S. occidentalis* type. One of the productid species is probably P. (*Dictyoclostus*) *hermosanus* Girty, and the other is a linoproductid of larger size. The assemblage suggests Pennsylvanian age.

Collection USGS 10,337.—The fossils include crinoid columnals, stenoporoid(?) bryozoans, a *Spirifer* cf. *S. occidentalis* (Girty), a part of a brachial valve of a *Derbya*?, and many immature compositids. A fragment of a trilobite pygidium was referred to Dr. J. Marvin Weller, of the Universeity of Chicago, who identified it as *Paladin*? sp. indet. This collection has a Pennsylvanian aspect.

From these determinations, it is evident that the lower member of the Morgan formation may be early Pennsylvanian or late Mississippian, but that Mr. Williams favors an early Pennsylvanian age. The limestone, therefore, has been considered as the lower member of the Morgan formation and separated from the underlying black shale unit that definitely is of late Mississippian age.

A fusulinid collection from 50 feet below the top of the upper member of the Morgan formation in the NW$\frac{1}{4}$ sec. 18, T. 2 N., R. 1 E., on Whiterocks River collected by M. N. Bramlette in 1949 was reported by L. G. Henbest as follows:

The following fusulinidae are identifiable: *Wedekindellina* aff. *W. euthysepta* and a species of *Fusulina.* The early half of the Des Moines epoch is indicated. The preservation is poor, but the identifications seem rather secure.

A second fusulinid collection from 50 feet below the top of the upper member of the Morgan formation near the E$\frac{1}{4}$ corner of sec. 6, T. 3 S., R. 20 E., on Dry Fork of Ashley Creek, made by M. N. Bramlette in 1948, was submitted to L. G. Henbest of the Geological Survey. Mr. Henbest reports as follows:

Textularians, *Tetrataxis* sp., and a species of fusulinid that belongs to the series represented by *Fusulina girtyi* and *F. distenta* were identified in this sample. Also present are two sections rather definitely identifiable as *Prismopora.* Middle Des Moines age is definitely indicated and approximately the middle or slightly lower part of that epoch is strongly suggested.

These age assignments are consistent with the fusulinid faunas collected by Henbest (McCann, Raman and Henbest, 1946, p. 5–9) from the upper part of the Morgan formation in Split Mountain canyon. Mr. Henbest reports that all of these faunas are of "early Des Moines forms," except for one that was located 32 to 57 feet from the top of the upper Morgan, which he classified as "upper or possibly middle Des Moines form."

The upper member of the Morgan is herein considered of Pennsylvanian age, probably Des Moines.

Stratigraphic relations and correlation.—The contact of the limestone member of the Morgan with the underlying black shale unit is not exposed in the area. However, both at Split Mountain (Thomas, McCann, and Raman, 1945) and in the Duchesne River area (Huddle and McCann, 1947), the limestone is conformable with the shale. The limestone grades upward into the soft red sandstone, shale, and argillaceous limestone, with thin stringers of red sandy shale occurring some distance below the top of the limestone, and thin beds of fossiliferous limestone occurring in the red unit. Similar conditions exist at Split Mountain, but in the Duchesne River area an erosional break is suggested by "a relief of 1 to 2 feet in a horizontal distance of 4 feet" and "large masses of chert in the lower member projecting into the overlying red sandstone" (Huddle and McCann, 1947). In the upper part of the formation, the deposition appears to be continuous except at Whiterocks River where a breccia bed, 4 feet thick and 857 feet above the base, includes angular pieces of sandstone and gray limestone. The upper boundary of the Morgan formation is arbitrarily taken at the top of the highest limestone and the overlying Weber sandstone is conformable upon this bed. From the above fusulinid determinations, all from a stratigraphic horizon approximately 50 feet below the top of the upper member of the Morgan formation, it appears that the upper part of the Morgan formation is progressively younger as it is traced eastward. In other words, the Morgan formation at Split Mountain is in part equivalent in age to the Weber sandstone at Whiterocks River.

The Morgan formation is correlated with part of the Tensleep sandstone of central Wyoming, the Hermosa formation of western Colorado, and the lower part of the Oquirrh formation in the Provo area of the Wasatch Mountains (Baker, Huddle, and Kinney, 1949, p. 1185).

Conditions of deposition and origin.—The basal limestone member of the Morgan formation is of marine origin, as shown by its abundant invertebrate fauna. The lower part of the upper member, however, was formed partly under marine conditions (as shown by the interbedded fossiliferous limestone), and partly under conditions approaching modern offshore deltas (shown by the well-bedded, fine-grained red sandstone, and shale). From the recurrent character of the fossiliferous limestones, it is probable that the area of deposition was close to sea level, which allowed the sea to enroach over considerable areas with a slight change of sea level. The fine- to medium-grained light-gray calcareous sandstone, which (with the intercalated limestones) make up most of the upper member of the Morgan, are believed to be beach sands or dune sands that grew behind the beach and were reworked into thick massive beds of crossbedded sand with the succeeding marine encroachment. The calcareous cementing material probably came from shell fragments incorporated in the beach and dune sands.

The pronounced red color in the lower part of the upper member of the Morgan formation is believed to be due to the original red color of the sediment; it is not believed to be caused by environmental conditions during, or since, deposition. The great preponderance of uniform-sized sand grains, and a lack of finer gained sediments in the general area, suggest a source area in which the erosion of preexisting quartzites and sandstones provided the bulk of the material. The probable equivalence of the upper part of the upper member of the Morgan formation at Split Mountain to the lower part of the Weber sandstone at Whiterocks River to the west suggests that the source of the red sediments included in the upper member of the Morgan formation was to the east or southeast, probably in the Uncompahgre Plateau and other areas in central and western Colorado, which are underlain by pre-Cambrian, or younger, crystalline rocks emergent during Pennsylvanian time. As indicated by the great thickening of the Pennsylvanian rocks in the Provo area of the Wasatch Mountains (Baker, 1947), it is probable that there was a western source for at least some of the sediment.

WEBER SANDSTONE

Definition.—The Weber sandstone (originally defined as a quartzite at the type locality, the formation throughout the Uinta Mountains and most of the Wasatch Mountains is more correctly referred to as a sandstone) was named by Clarence King (1876, p. 480–481) and geologists of the Fortieth Parallel Survey in 1876, for exposures in Weber Canyon in the Wasatch Mountains. It was defined as including the strata that were later differentiated by Blackwelder (1910, p. 529) as the Morgan formation. In the Uinta Mountains, geologists of the Fortieth Parallel Survey mistakenly applied the name to the great thickness of pre-Cambrian rocks, now known as the Uinta Mountain group, instead of the less extensive sandstone of Pennsylvanian age. J. W. Powell (1876, p. 149), in his report on the eastern Uinta Mountains, named the massive sandstone of Pennsylvanian age the Yampa sandstone for the Yampa River which enters the Green River from the east in northwestern Colorado. The Yampa sandstone was correlated with the more widely used Weber standstone by A. R. Schultz (1920, p. 24) in his report on the Rock Springs uplift. Since 1920, the name "Weber sandstone" has been used instead of the name "Yampa sandstone," which has been rejected by the U. S. Geological Survey (Wilmarth, 1938, p. 2381).

Distribution and topographic expression.—The Weber sandstone crops out at intervals between the valley of Pole Creek east of Uinta River and Diamond Mountain. Good exposures can be seen in the canyon of Whiterocks River, where the steeply dipping white sandstone of the formation forms the "gates," that give rise to the name "Whiterocks" in the canyon walls of Dry Fork of Ashley Creek, Ashley Canyon, Brush Creek (fig. 4), Little Brush Creek, and in discontinuous outcrops on Diamond Mountain. The spectacular scenery of Split Mountain and Green River Gorge within the Dinosaur National Monument has also been carved from this sandstone.

Because of its calcareous cement and massive character, the Weber sandstone is a very resistant formation that forms almost vertical walls in defilelike canyons on Dry Fork, Ashley Creek (fig. 9), Brush Creek, and Little Brush Creek. The deep canyons and steep walls, however, may be due as much to the rapid cutting by proglacial streams during Pleistocene time as to the resistance of the sandstone. The Weber sandstone, veneered with the Bishop conglomerate of late Cenozoic age, forms the southern boundary of the topographically high area included in the Uinta Mountains; the area to the south is marked by a drop of 1,500 to 2,000 feet in elevation.

Lithology and thickness.—The Weber sandstone is a uniform, massive, fine- to medium-grained, light-gray, slightly calcareous, quartzose sandstone. Individual grains are not well rounded except in the upper 300 to 400 feet of the formation in the Brush Creek area, where well-rounded, medium-to-coarse grains are concentrated along planes of crossbedding. In this area (fig. 4), the crossbedding extends between bedding planes 30 to 50 feet apart. However, such crossbedding is relatively rare in the main mass of the sandstone exposed on Ashley Creek. The massive character of the Weber makes it very difficult for the investigator to detect dips and to accurately measure the thickness of the formation. The sandstone possesses relatively small amounts of heavy minerals. Quartz grains are clear, and feldspar is rare. Although the Weber sandstone has a calcareous cement, no beds of limestone are present.

The Weber sandstone ranges in thickness from 1,015 to 1,275 feet in this area, with an average of 1,150 feet. The thicker sections (in Ashley Creek and on Diamond Mountain) are adjacent and are located in the area in which the upper 300 to 400 feet of the Weber is particularly crossbedded.

Fossils and age.—No fossils have been found in the Weber sandstone and, therefore, the age of the formation is open to question. The apparent absence of depositional breaks from the upper part of the Morgan formation to the top of the Weber sandstone, and the Des Moines (Pennsylvanian) age of the upper part of the Morgan formation (reported by Bramlette and based on fusulinid determina-

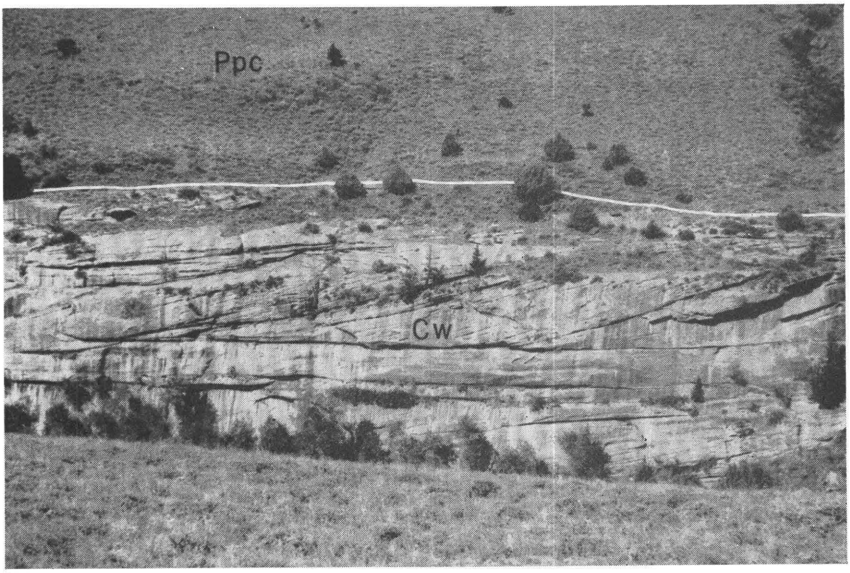

FIGURE 4.—Crossbedding in the upper part of the Weber sandstone (*Cw*) at The Seeps, *Ppc,* Park City formation.

tions by Henbest) strongly suggest that the Weber is entirely of Pennsylvanian age.

Stratigraphic relations and correlation.—The Weber sandstone is believed to correlate with part of the Tensleep sandstone of central Wyoming, the Hermosa formation of central Utah, the lower part of the Oquirrh formation of the Wasatch Mountains (Baker, 1947), the Wells formation in southeastern Idaho, and the Quadrant formation in Montana. The Weber sandstone of this area has been recognized on Yellowstone Creek, Rock Creek, the Duchesne River in the western Uinta Mountains, and in the Big Cottonwood-Park City district of the Wasatch Mountains (where it is thicker and more calcareous, but otherwise identical).

Conditions of deposition and origin.—The low percentage of heavy minerals, the scarcity of clay and micaceous minerals, and the great thickness and widespread distribution of the Weber sandstone, suggest that erosion of preexisting sandstone was the source of the formation. The Weber is believed to have been deposited under shallow marine waters, where currents winnowed out fine-grained constituents and formed tangential crossbedding in certain beds.

The principal source area of sediments of the Weber sandstone in the eastern Uinta Mountains is believed to have been the highlands of eastern Nevada which provided the clastics for the thick sequence of Pennsylvanian and Permian rocks assigned to the Oquirrh formation in the Oquirrh (Gilluly, 1932, p. 34) and Wasatch Mountains (Baker, 1947). Other sources, however, may have been the Algonkian type strata and crystalline rocks of the Uncompahgre Plateau and a westward extension of the Front Range highlands in western Colorado, and the sedimentary rocks of earlier Paleozoic age exposed in adjacent land areas.

PERMIAN SYSTEM

PARK CITY FORMATION

Definition.—The Park City formation was named for exposures in the Park City mining district (Boutwell, 1912, p. 443–444) in the central Wasatch Mountains, Utah. It consists of three divisions in that area, an upper and a lower member of cherty limestone and interbedded limy sandstone, separated by a middle member consisting of black phosphatic shale. Fossils collected from the lower member of the formation were referred to the upper Pennsylvanian by G. H. Girty and the fauna of the middle and upper members to the Permian. In the course of detailed mapping and stratigraphic studies in the southeastern Idaho phosphate district, Richards and Mansfield (1912, p. 684–689) defined the Phosphoria formation to include only those beds equivalent to the middle and upper members of the type Park City formation; that is, the part assigned to the Permian. Subsequently, Williams (1939, p. 85–86) suggested abandoning the Park City formation or restricting it to the lower, presumably Pennsylvanian, member of the original formation. However, recent work in the Provo area of the Wasatch Mountains, south of the type section, proved that the lower member of the Park City formation is also of Permian age because it can be correlated with the Kaibab limestone, thus reestablishing the Park City formation as an acceptable stratigraphic unit (Baker and Williams, 1940, p. 625).

Park City formation has been used in the western Uinta Mountains in preference to Phosphoria formation (Huddle and McCann, 1947) because the type section of the Park City is only a few miles to the west, the formation in both areas is tripartite, and the rocks are lithologically similar. The formation is exposed at intervals along the south flank of the Uinta Mountains, but east of Lake Fork, the lower sandstone and limestone member is not present. The first use of Park City formation in the Uinta Mountains was by Schultz (1919, p. 46–53) and the present definition conforms to his usage.

Distribution and topographic expression.—The Park City formation is exposed along the Whiterocks River, at two localities near the head of Mosby Creek, in a fault block in the Deep Creek area, and almost continuously eastward from north of Little Mountain to Diamond Mountain where rocks of Paleozoic and Mesozoic age are covered by the Bishop conglomerate. The phosphatic shale member of the Park City formation overlies the Weber sandstone and generally forms a poorly exposed bench mantled with pieces of chert and fragments of phosphate rock. The upper member of the Park City formation, in part correlative with the Rex member of the Phosphoria formation of southeastern Idaho, is well exposed in the Ashley Creek-Little Brush Creek area where the soft red and gray sandstone of the Moenkopi formation has been stripped away.

Lithology and thickness.—East of Lake Fork, the Park City formation consists of a lower light gray-green to olive-green phosphatic shale and rock phosphate member, overlain by an upper member of slabby-weathering light-gray cherty limestone, dolomite, limy sandstone and light-gray shale. A considerable proportion of the phosphate occurs as pellets or other small irregular phosphate particles. The color of the phosphatic member varies from light gray-green on Whiterocks River to dark olive-green in the vicinity of Brush Creek. The darker color is probably due to the higher organic content of the beds in the Brush Creek area which contain the highest grade phosphate rock in the eastern Uinta Mountains. The phosphatic member ranges from 20 to 30 feet in thickness; the maximum thickness is found in the vicinity of Brush Creek (fig. 5). The phosphatic shale is discussed in detail in the section on Economic Geology. The upper, interbedded light-gray, cherty limestone and shale member ranges in thickness from 175 feet on Whiterocks River to 80 to 100 feet between Red Mountain and Little Brush Creek. Some of the cherty limestone beds are very sandy; in some places, they are almost

FIGURE 5.—Lower part of the Park City formation at Brush Creek Gorge.

a limy sandstone. One such locality, in SW¼ sec. 12, T. 2 S., R. 21 E., carries a well-preserved Phosphoria fauna. A thin band of red siltstone or very fine grained sandstone is present near the middle of the Park City formation. Its occurrence in the southwestern Uinta Mountains was named the Mackentire "red beds" tongue of the Phosphoria formation by Williams (1939, p. 93). The tongue appears to thin toward the east in the Red Mountain-Brush Creek area and it seems to be split into two tongues by a limestone bed in the Whiterocks River section.

The detailed lithology of the Park City formation is shown in the following sections:

Section of the Park City formation on west side of Whiterocks River SW¼ sec. 18, T. 2 N., R. 1 E., Uinta Special Base and Meridian

[Measured by D. M. Kinney and J. F. Rominger]

	Feet
Moenkopi formation:	
Sandstone, reddish-brown, very fine grained, poorly exposed.	
Park City formation:	
Limestone, light-gray, cherty and light-gray bedded chert	60
Siltstone, red, sandy, and red, very fine grained sandstone	8
Limestone, light-gray to pink, fine-grained, cherty	17
Siltstone, red	15
Covered, probably light-gray shale	38
Sandstone, tan, fine-grained, with calcareous vugs	3
Limestone, light-gray, tan-weathering, very cherty; fossiliferous at top	34
Shale, greenish-gray, siliceous, and olive-gray phosphate rock with light-gray chert. One and one-half feet of limestone, tan, sandy with vugs of light-gray chert, at top	20
	195

Section of Park City formation on north side of Red Mountain NE¼ sec. 34, T. 2 S., R. 21 E., Salt Lake Base and Meridian

[Measured by D. M. Kinney, J. F. Rominger, R. S. Brown, and P. Verastegui M.]

	Feet
Moenkopi formation:	
Shale, light-gray, sandy.	
Park City formation:	
Limestone, light-gray, sandy, slabby	14
Sandstone, red, fine-grained	27
Sandstone, light-gray, speckled; contains angular medium- to coarse-grained sand grains. One-half foot chert conglomerate at top	11.5
Limestone, lightly-gray with thin streaks of light-gray chert	18
Limestone, light-gray, fine-grained, with calcite-filled vugs	6
Shale, light-gray, concretionary	2
Limestone, light-gray, fine-grained with calcite-filled vugs	1.5
Shale and phosphate rock, greenish-gray to olive-gray oölitic, fossiliferous	17
	97

Section of Park City formation in canyon 1 mile west of Little Brush Creek. NE¼ sec. 22, T. 2 S., R. 22 E. (unsectionized)

[Measured by D. M. Kinney and J. F. Rominger]

Moenkopi formation:	
Siltstone, light-gray, with thin streaks (0.1 to 2.0 feet) of light-gray, calcareous siltstone.	
Park City formation:	*Feet*
Limestone, light-gray, thin-bedded, sandy	22
Shale, light-gray and thin beds of light-gray, sandy limestone	6
Limestone, light-gray, thin-bedded, cherty, in part porous	7
Shale light-gray and thin beds of light-gray, sandy limestone	20
Sandstone, red, very fine-grained	2
Sandstone, light-tan, fine-grained	10
Limestone, light-gray, sandy (covered)	6
Limestone, light-gray, thin-bedded, slabby	6.5
Sandstone, light-tan, very fine grained, calcareous, fossiliferous (Phosphoria fauna)	4
Limestone, light-gray, with uneven bedding, vugs, nodules of white to purplish calcite, and angular particles of dark-brown chert	12
Limestone, tan, massive, with vugs, and nodules of light-gray chert	3.5
Chert, gray, nodular in matrix of gray-shale	1.0
Shale, gray-green to olive-green, and olive-green, oölitic phosphate rock with chert	19
	119

Fossils and age.—The phosphatic member of the Park City formation, especially in the Brush Creek area, carries an abundant phosphatized fauna limited to a few genera. The phosphate replacing the shell material adds considerably to the phosphate content of the rock but since it does not preserve shell ornamentation, specific identification is difficult.

A collection made by J. Steele Williams of the Geological Survey was reported as follows:

No conodonts were found. Quite a few immature gastropods that preserved no ornamentation and could not be identified were present. One or two individuals that might be ostracodes and fragments possibly of very small pelecypods or brachiopods were also present. No data of worth-while age significance have been found.

Large collections made by Helmuth Wedow of the Geological Survey were submitted to Kenneth McLaughlin for identification. Mr. McLaughlin reported two ostracodes, *Geisina* sp. and *Hollinella?* sp., and a conodont referred to *Gondolella*. Mr. McLaughlin reports in a letter dated January 1950:

It is difficult to place any age significance on the specimens in question. The probable taxonomic affinities of the ostracodes, as well as the nature of their occurrence in the Brush Creek samples, suggest that they are reworked specimens. *Geisina* is closely similar to species reported from both lower and middle Pennsylvanian; the genus is not a particularly diagnostic one, but is generally considered to be strictly Pennsylvanian. *Hollinella*? is a prominently nodose form which, according to Betty Kellet Nadeau, is characteristic of lower Pennsylvanian and Mississippian time. It is also similar to those which occur in the Des Moinesian Glen Eyrie formation of Colorado.

The single conodont specimen was not identified except as belonging to the gondolellid group, which are considered to become abundant at about middle Pennsylvanian.

More impressive than the above possible relationships, however, is the following:

(1) Out of a sizable sample only three single specimens were found.

(2) All three show evidence of physical wear.

(3) The ostracodes are casts composed of the same material as clastic grains making up a large part of the sample in which they occurred.

(4) The abundance of fossil fragments of this material among the clastic grains.

In short, these three specimens are nondiagnostic, but suggest that the Park City formation may have a rather complex stratigraphic-tectonic history.

Schultz (1919, p. 53), in his reconnaissance of the Uinta Mountains, made two fossil collections from the phosphate interval in the NE¼ sec. 8, T. 3 S., R. 19 E., Salt Lake meridian. The first collection from the "upper phosphate bed" was submitted to G. H. Girty who reported, *Yoldia macchensneyana* and small undetermined gastropod. In the second collection from the "lower phosphate bed," Mr. Girty identified *Lingulidiscina utahensis*.

From these fossil and stratigraphic age determinations, it is evident that no definite age can be assigned to the phosphatic member from fossils. McLaughlin's suggestion of middle or early Pennsylvanian or even Mississippian age for the recognized micro-fauna, and the evident abrasion by transport, implies that the source of the phosphatic sediments was some earlier formed Carboniferous rock.

The correlation of the upper part of the Park City formation with the Phosphoria formation of southeastern Idaho is based on a fauna present in the section 35 to 50 feet above the base of the formation. J. Steele Williams reports on the silicified fauna collected in the SW¼ sec. 12, T. 2 S., R. 21 E., as follows: "This is a typical Permian fauna of this region, containing Plagioglyptas, Euphemites, Ledas."

Considerable difference of opinion has been shown by investigators in regard to the time element that is represented by the Phosphoria formation and its general equivalent, the Park City formation. In southwestern Wyoming (Sublette Range), a cephalopod fauna from a horizon 60 feet below the Rex chert member of the Phosphoria formation, is characteristic of the Word formation (middle Permian) and certain elements suggest possible correlation with the Leonard series (Miller and Cline, 1934, p. 283–285). Fusulinids from limestone strata overlying the Quadrant formation (Frenzel and Mundorff, 1942, p. 675–684) in Montana, classified as Phosphoria, suggest an age as old as Wolfcamp (lower Permian?), but Thompson and Wheeler (1946, p. 8) believe that these strata are younger than the type section of the Wolfcamp formation. The physical-chemical aspects of the problem of precipitation of the phosphate (McKelvey, V. E., personal communication) require a very long period of time for an accumulation of great thicknesses of phosphate rock, which substantiates, in part, the above fusulinid determinations. However, recent work by A. A. Baker (1947) in the Provo area of the Wasatch Mountains shows that almost 3,000 feet of the Oquirrh formation, as well as the Kirkman limestone and the Diamond Creek sandstone, intervene between the horizon of the fusulinid collections of middle or late Wolfcamp age and the basal beds of the Park City formation, which are highly phosphatic. Considerable time must have been required for the deposition of more than 5,500 feet of strata (Baker, 1947), therefore only a relatively short period of time is available for the deposition of the phosphatic shale of the Park City formation.

Stratigraphic relations and correlation.—The lower boundary of the Park City formation is easily recognized in the area; the easily eroded phosphatic shale weathers backward, leaving a bench at the top of the Weber sandstone. However, many problems have been encountered in choosing the boundary between the Park City and the overlying Moenkopi formation. From Whiterocks River eastward to Red Mountain the boundary originally was taken at the base of the red beds which correspond to the top of the light-gray limy sandstone and interbedded shale. This boundary, easily recognizable in the field, appeared to be remarkably consistent across the area. Mapping between Red Mountain and Utah State Highway 44 at Brush Creek, however, showed that the lower part of the red beds grade into light greenish-gray sandy shale and thin-bedded sandstone, and the base of the red beds rises more than 150 feet stratigraphically in 3 miles. This rising color contact is believed to continue in a northeasterly direction beyond Split Mountain, for more of the rocks at the base of the Moenkopi are gray at Skull Creek in northwestern Colorado than at Split Mountain, and at Vermilion Creek the entire unit is gray. In order to use a consistent boundary throughout the area, the top of the highest slabby, light-gray cherty limestone or limy sandstone was taken as the top of the Park City formation. As the upper limestone beds thin and grade into light-gray sandy shale towards the east, the boundary probably descends stratigraphically in that direction.

Although the boundary that was adopted is believed to be best for the purposes of mapping in the area, the possibility remains that, in the absence of evidence of erosion at this horizon, the boundary should be taken somewhat lower, at the base of the coarse-grained, angular, in places conglomeratic, tan sandstone that lies 54 feet above the base of the Park City formation on Whiterocks River, 44.5 feet above the base at Red Mountain, and 35.5 feet above the base at Little Brush

Creek. Permian fossils have not been found above this sandstone and the sandstone is the only demonstrable physical evidence of erosion found between the top of the Weber sandstone and the base of the Shinarump conglomerate. If this sandstone bed marked the base of the overlying Moenkopi formation, some of the slabby white-weathering limestone, heretofore considered typical of the Park City formation, would be included in the overlying Moenkopi, and the boundary between the two formations would be lowered 138 feet on Whiterocks River, 55.5 feet at Red Mountain, and 83 feet on Little Brush Creek.

The lower member of the Park City formation (Williams, 1939, p. 93–94), as represented on Duchesne River in the western Uinta Mountains, is not recognized within this area. The absence of the lower member of the Park City formation in the eastern part of the area can be interpreted in either of two ways: (1) The member has been removed by erosion and is now represented by an unconformity at the top of the Weber sandstone in the area from Whiterocks River eastward (Thomas and Krueger, 1946, p. 1264), or (2) the lower member of the Park City formation grades laterally into the upper part of the Weber sandstone (Williams, 1939, p. 96). The upper 300 feet of the Weber strata on Whiterocks River is more thinly bedded and calcareous than the underlying massive sandstone, and it weathers to shades of tan. A similar thickness at the top of the Weber sandstone in the Brush Creek area is more strongly crossbedded than the underlying sandstone, and this unit may be correlative with the thin-bedded, tan-weathering calcareous sandstone on Whiterocks River and the lower member of the Park City formation of the Duchesne River section. However, no physical evidence is known to exist that would indicate interruption of sedimentation within the mapped boundaries of the Weber sandstone.

The Park City formation of this area is correlated with the Phosphoria formation and with the middle and upper members of the Park City formation in the section at Park City, Utah. Thin tongues of cherty limestone have been recognized in northwestern Colorado (Thomas, McCann, and Raman, 1945). The Kaibab limestone in the San Rafael Swell carries a mixture of the Kaibab fauna as represented in southern Utah and certain forms characteristic of the Phosphoria (Gilluly and Reeside, 1928, p. 64). The Park City formation above the phosphatic shale member in the Uinta Mountains probably represents deposits younger than the Kaibab limestone of the San Rafael Swell area.

Conditions of deposition.—Marine fossils in the sandy limestones of the upper member of the Park City formation indicate a marine origin for the enclosing sediments. The limited fauna in the lower (phosphatic) member and the abrasion to which the forms were subjected prior to incorporation in the beds suggest that the phosphate pellets are not a primary marine deposit. From the evidence presented by McLaughlin (see p. 51–52), it seems probable that the phosphate pellets were concentrated from a much greater thickness of marine Pennsylvanian rocks. This concentration might have been caused by wave action or by subaerial weathering with later deposition on the sea floor. However, due to the absence of ripple marks and crossbedding, it seems probable that the sea floor below the level of current action was the final place of deposition. The concentration of huge quantities of phosphate in a relatively thin interval is more easily explained by mechanical concentration than by chemical precipitation from sea water, for the latter action requires a very perfect balance of physical-chemical conditions, a great length of time, and an almost total absence of clastic sediments. On the other hand, mechanical concentration more easily explains the sharp boundaries of the phosphate ocurrence, because phosphate pellets are rare on the north side of Split Mountain 6 to 8 miles southeast of Brush Creek, which has the thickest and richest deposits in the eastern Uinta Mountains.

The great extent of the Park City formation and its equivalents, which reach from central Montana to northern Utah and from eastern Idaho almost to the Utah-Colorado border and northward into Wyoming, indicates that the sea was widespread and that the peculiar conditions necessary for the precipitation of phosphate were not local. It is possible that the phosphate deposits in the eastern Uinta Mountains may represent only a part of the time when phosphate was being deposited farther west in Idaho and southwestern Wyoming. Faunal evidence in southeastern Idaho suggests that the Phosphoria sea had connections southward into Texas, westward into California, and northward to Alaska and Russia (Mansfield, 1927, p. 185).

According to evidence accumulated by McKelvey (1946, p. 88), the sea floor in western Wyoming, southeastern Idaho, and northern Utah was essentially flat with only minor irregularities. Similar conditions appear to have prevailed in the Uinta River-Brush Creek area because the top of the Weber sandstone forms a smooth surface. High organic content of the phosphate rock, suggesting anaerobic and fetid conditions, is characteristic of the Park City and Phosphoria formations farther west, but the organic content is comparatively minor in the area covered in this report. This fact is evident from the olive-green to gray-green color of the phosphate rock in the Brush Creek area.

TRIASSIC SYSTEM

In his pioneer work in the eastern Uinta Mountains, J. W. Powell (1876, p. 41, 53) included in the Shinarump group, named for the Shinarump Cliffs in southern Utah, all the red beds now referred to the Triassic. He recognized three units, a Lower Shinarump sandstone and an Upper Shinarump sandstone separated by the Shinarump conglomerate. The use of a name both for a group and for a formation within the group being contrary to good stratigraphic nomenclature, the "Lower Shinarump" was renamed the Moenkopi formation, the "Upper Shinarump" was renamed the Chinle formation, and the Shinarump was retained for the conglomerate.

LOWER TRIASSIC SERIES

MOENKOPI FORMATION

Definition.—The Moenkopi formation was named by Ward (1905, p. 18–19) for Moenkopi Wash in northeastern Arizona, and the name has subsequently been carried northward into central Utah by the work of Gilluly and Reeside (1928, p. 65–66), Baker (1933, p. 34–37; 1936, p. 40–44), Dane (1935, p. 42–54), and McKnight (1940, p. 52–61). The reasoning for the extension of the nomenclature of northern Arizona into central Utah has been based on the stratigraphic position of the Moenkopi formation below the Shinarump conglomerate and the lithologic similarities with the type section. The Early Triassic age of the Moenkopi formation has been confirmed by vertebrate remains and tracks (Welles, 1947, p. 285–286; Peabody, 1948, p. 413) and by invertebrate faunas from the Sinbad limestone member of the Moenkopi (Gilluly and Reeside, 1928, p. 66) 200 feet above the base of the formation in the San Rafael Swell and by the interfingering of the Moenkopi formation with its marine Virgin limestone member (Reeside and Bassler, 1922, p. 67–68) in southern Utah and with the Thaynes limestone in northern Utah.

The Woodside shale, Thaynes limestone, and Ankareh shale, originally described by Boutwell (1912, p. 52–59) from the Park City district in the Wasatch Mountains, are recognized in the Duchesne River area (Thomas and Krueger, 1946, p. 1284–1285; Huddle and McCann, 1947) of the western Uinta Mountains. However, in the area between Duchesne River and Whiterocks River, the Thaynes limestone thins from a maximum of 650 feet to less than 20 feet; east of Whiterocks River, it is represented only by calcareous fine-grained red sandstone. With the disappearance of the tongue of the Thaynes limestone, the separation of the Woodside shale from the overlying shaly equivalent of the Thaynes limestone becomes more difficult and Moenkopi formation is substituted for Woodside, Thaynes, and Ankareh formations. Gypsum beds on Red Mountain at approximately the same horizon as the limestone farther west are believed to have been deposited on tidelands during the maximum extent of the Thaynes sea. The upper part of the Moenkopi is equivalent to the Ankareh and the lower part to the Woodside. The rocks between the Park City formation and the Shinarump conglomerate occupy the same interval and have the same lithology as the Moenkopi formation in the San Rafael Swell.

Distribution and topographic expression.—In the area shown on plate 1, the Moenkopi formation crops out at Whiterocks River, in fragmentary sections in the faulted area between Mosby Creek and Deep Creek, on the north side of Little Mountain south and west of the community of Dry Fork, and in continuous outcrop from east of Dry Fork, across the north side of Red Mountain eastward to Diamond Mountain. The Moenkopi is also exposed on the flanks and nose of Split Mountain anticline within the Dinosaur National Monument and along the westward plunging Section Ridge anticline, but these exposures are only partially shown on the accompanying map (pl. 1). The finest outcrops of the complete section of Moenkopi are on the north side of Red Mountain and along Little Brush Creek. Excellent exposures are also present in Dinosaur National Monument and on Cliff Creek (fig. 6) on the extreme eastern border of the mapped area.

The Moenkopi formation is a thin-bedded, easily eroded sequence of interbedded red sandstone, siltstone, and shale which would generally make poor outcrops except for protection afforded by the overlying resistant Shinarump conglomerate. The upper part of the formation is generally better exposed than the lower part, which forms strike valleys near Dry Fork and on both sides of Ashley Creek. The more massive and resistant sandstone beds, and especially the thin interval of gypsum and gypsiferous sandstone near the middle of the formation on Red Mountain, form steep cliffs, and the thin-bedded,

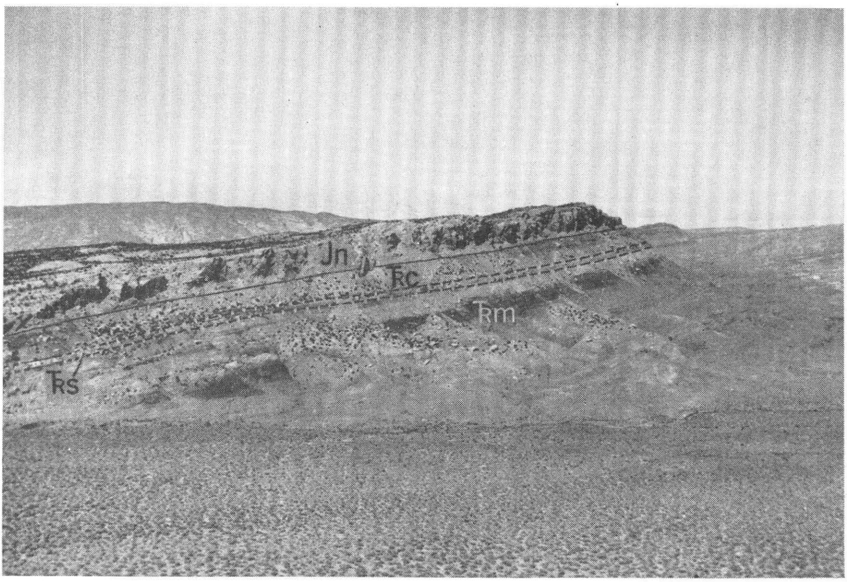

FIGURE 6—Moenkopi formation (*Trm*), Shinarump conglomerate (*Trs*), Chinle formation (*Trc*), and Navajo sandstone (*Jn*) on the north side of Cocklebur Wash.

fine-grained sandstones and interbedded shales form gentle slopes. At the head of Deep Creek the limy interval, which marks the maximum incursion of the Lower Triassic sea from the west, makes a slight escarpment.

Lithology and thickness.—In this area the Moenkopi formation consists of thin-bedded reddish-brown siltstone or very fine-grained sandstone with thin partings of weak-red, sandy shale and thin beds of light greenish-gray, fine-grained sandstone. The basal 100 to 150 feet, as mapped in the area from Red Mountain to Diamond Mountain, is light-gray to light greenish-gray, sandy shale and thin-bedded, micaceous sandstone. Eastward, the light-gray facies increases in thickness at the expense of the red facies of the Moenkopi and at Irish Canyon (Sears, 1924, p. 281) on Vermilion Creek, 37 miles to the northeast, the Lower Triassic sedimentary rocks are all light-gray, sandy shale and fine-grained sandstone.

The section of the Moenkopi formation on the north side of Red Mountain is the best exposed section in the area. It is given here to illustrate the general character of the formation in the western two-thirds of the area.

Section of Moenkopi formation on the north side of Red Mountain in SW¼ sec. 34, T. 2 S., R. 21 E.

[Measured by D. M. Kinney, J. F. Rominger, and R. S. Brown]

	Feet
Shinarump conglomerate:	
Sandstone, conglomeratic, yellowish-gray, weak yellowish-orange weathering, massive, crossbedded, very resistant, with light-brown streaks, pebbles up to 2 inches in diameter, and silicified wood; basal contact shows channels in the Moenkopi formation.	
Unconformity	
Moenkopi formation:	
Sandstone, weak-red, very fine grained, thin-bedded, intercalated with weak-red sandy shale and light-gray, fine-grained, thin-bedded (0.05 foot thick) sandstone; few thin (0.01 foot) lenses of gypsum. Forms steep slope below the cuesta formed by the Shinarump	126
Sandstone, pale reddish-brown, very fine grained, thin-bedded (0.05 to 0.2 foot) intercalated with light greenish-gray, fine-grained sandstone. Thin beds of gypsum 25 feet and 75 feet below top	269
Sandstone, reddish-brown, very fine grained	110
Sandstone, reddish-brown, fine-grained, gypsiferous, with three 1 foot beds of gypsum; forms cliff	10
Sandstone, reddish-brown, fine-grained, with thin band of light-gray sandstone at top	150
Sandstone, interbedded reddish-brown and light-gray, fine-grained	195
Sandstone, light-gray, very fine grained	25
Sandstone, red, very fine grained	12
Shale, light-gray, sandy	7
Sandstone, light-gray, very fine grained, calcareous, slabby	1
Shale, light-gray, sandy	60
	965

The section measured on Little Brush Creek illustrates the thickening section of gray sandy shale and thin-bedded sandstone at the base of the Moenkopi formation along the tributaries of Brush Creek and Little Brush Creek in the eastern part of the area. The thickness of the Moenkopi formation in the mapped area, as shown by the detailed measured sections, ranges from 1,120 feet in the west to 725 feet on the east. The thinning is believed to have been caused by erosion of the top, which has cut out beds in exposures 1 mile west of Dry Fork; some thinning may occur in individual beds.

Section of Moenkopi formation along west side of Little Brush Creek from the SW¼SW¼ sec. 24 to the SW¼ sec. 25, T. 2 S., R. 22 E.

[Measured by D. M. Kinney and J. F. Rominger]

Shinarump conglomerate:

Sandstone, light-gray to tan, coarse-grained, crossbedded, with pebbles to 2 inches in diameter; abundant fossil wood near base.

Unconformity

Moenkopi formation:	*Feet*
Sandstone, red, very fine grained	17
Sandstone, red, fine-grained, well-bedded and ripple-marked, with interbeds of shaly micaceous sandstone, and red sandy shale	35
Sandstone, red, very fine grained	255
Gypsum, white to pink, thinly laminated, contorted	7
Sandstone, red, fine-grained, ripple-marked, gypsiferous; forms ledge	72
Sandstone, red, fine-grained	26
Sandstone, red and white interbedded, fine-grained thinly laminated; basal 1 foot slightly calcareous	6
Siltstone, red, and red very fine grained sandstone, with streaks of sandstone, greenish-gray, fine-grained, crossbedded, micaceous, laminated (0.2 to 0.5 foot thick)	46
Siltstone, red and red very fine-grained sandstone	93
Shale, light-tan to gray, with 0.5 foot beds sandstone, light-gray, fine-grained, calcareous, slabby	36
Sandstone, light-gray, fine-grained, crossbedded, slabby; selenite crystals common	2
Siltstone, light-gray	31
Siltstone, light-gray, with 0.5- to 0.8-foot beds sandstone, light-gray, micaceous, ripple-marked, slabby	24
Sandstone, light-gray, fine-grained, with angular to semirounded grains	15
Siltstone, light-gray, with thin streaks (0.1 to 2.0 feet), siltstone, light-gray, calcareous	60
	725

Fossils and age.—A small collection of poorly preserved fossils from the limestone unit 520 feet above the base of the Moenkopi formation in the SW¼ sec. 18, T. 2 N., R. 1 E., on the west side of Whiterocks River was submitted to John B. Reeside, Jr., of the Geological Survey who reports:

295163—55——5

This material has obviously been a coquina, but I am unable to get out enough of any single specimen to warrant an identification. Fragments of several gastropods, one probably a bellerophontid, and fragments of several sorts of pelecypods are present. I have seen similar material at a number of places in Lower Triassic deposits in Utah and believe the material well placed as Triassic.

The light gray-green sandy shales and interbedded sandstones at the base of the Moenkopi formation in the section on Brush Creek are comparable to the sections described from the San Rafael Swell region where they have been attributed to deposition on a delta in stagnant, muddy pools (Gilluly, 1929, p. 86). No vertebrate fossils are known with the exception of the footprints of certain reptiles found in the upper part of the Moenkopi formation in the SE¼ sec. 32, T. 2 S., R. 22 E. The trackways are "too distorted for diagnosis," according to Dr. Frank E. Peabody (personal communication, 1948), who has studied the reptilian and amphibian trackways in the Moenkopi formation of northern Arizona and southern and central Utah. Dr. Charles L. Camp (personal communication, 1948) suggests that the tracts are "impression of *Chirotherium* made in soft mud."

Stratigraphic relations and correlations.—The Moenkopi formation, as mapped, rests with apparent conformity on the Park City formation of Permian age. In the discussion of the stratigraphic relations of the Park City formation, it has been suggested that in the absence of evidence of erosion at this horizon, the boundary might be taken somewhat lower, at the base of the coarse-grained, angular, in places conglomeratic tan sandstone that lies 54 to 35 feet above the base of the Park City formation. No evaluation of a time break, indicated by the coarse sandstone, can be made because of the lack of marine fossils in the overlying slabby, sandy limestones.

The upper boundary of the Moenkopi formation is clearly unconformable; it shows scour and fill by the streams that deposited the basal beds of the Shinarump conglomerate. The Shinarump rests in channels 40 to 50 feet wide and cuts out as much as 20 feet of red siltstone and shale within that distance. Excellent exposures of the channel fillings are present near Brush Creek on Utah Highway 44 (fig. 7) and on the west side of Red Mountain. Although the unconformity is evident over much of the area, very few beds of the Moenkopi have been removed in the area from Red Mountain eastward to Diamond Mountain. However, in sections 6, 7, and 8, T. 3 S., R. 20 E., 1 mile west of the community of Dry Fork, the Shinarump clearly truncates resistant sandstone beds in the upper part of the Moenkopi formation. The thinning of the Moenkopi, from 1,120 feet on Whiterocks to 725 feet on Little Brush Creek, is believed due to erosion by streams whose ancient channels are filled with the basal beds of the Shinarump conglomerate.

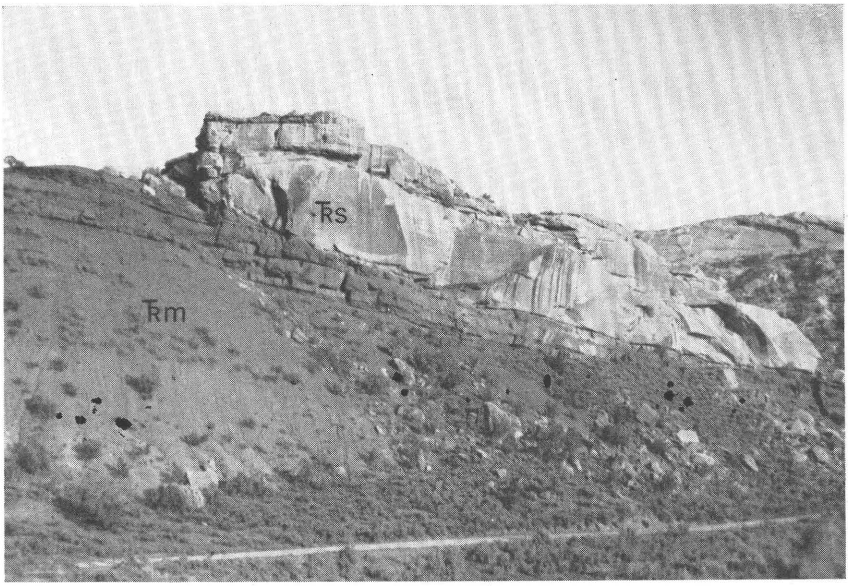

FIGURE 7.—Shinarump conglomerate (*Trs*) filling channel in the top of the Moenkopi formation *Trm*), on the West side of Brush Creek.

The Moenkopi formation of this region is correlated, at least in part, with the Moenkopi formation of the San Rafael Swell-Moab region to the south, and with the Woodside and Thaynes formations of the western Uinta Mountains and their type sections in the Wasatch Mountains. The Dinwoody formation of central Wyoming and the tongue of the Dinwoody at the base of the red beds in the Chugwater formation of southeastern Wyoming closely resemble the lower part of the Moenkopi formation east of Red Mountain and are correlated with it. To the east of the Green River, the Moenkopi formation extends practically unchanged in lithology for almost 100 miles (Thomas, McCann, and Raman, 1945).

Conditions of deposition.—The well-sorted, fine-grained sandstone, siltstone, and shale, the preponderance of uniform bedding, the abundance of mica on the bedding planes, and the scarcity of ripplemarks, mud cracks and crossbedding, point toward deposition of the Moenkopi formation in water generally free from strong currents. Such conditions might prevail near the center of a large intermontane basin or on a wide coastal plain. In Salt Valley south of the Uinta Basin, Dane (1935, p. 52) has demonstrated that the source of the sediments that formed the Moenkopi formation in that area was the old crystalline highlands now represented by the Uncompahgre Plateau. Such a source for the Moenkopi formation in the Vernal area is in harmony with what is known of the paleogeography of Early Triassic time and the character of the sediments on the North Douglas Creek anticline (Thomas, McCann, and Raman, 1945) in Rio Blanco County, Colo., 70 miles to the southeast, where coarse-grained sandstone and conglomerate are interbedded with red sandy shale and sandstone. The coarsening of the Moenkopi deposits to the southeast suggests that the Uncompahgre Plateau area was the source for at least part of the Moenkopi formation in the Uinta Mountains. Additional sediments might have been derived from crystalline rocks of the ancestral Rocky Mountains to the east, but the general thinning of the formation eastward suggests that this source was not important. With this interpretation, the Moenkopi deposits in the Vernal area represent the basinward or coastal-plain equivalents of coarse alluvial fans originating in highlands to the south and east.

The tongue of marine Thaynes limestone, and its eastward continuation as a gypsiferous interval in the middle of the Moenkopi formation, suggests deposition of this thin unit as normal marine sediments at Whiterocks River and as lagoonal deposits east of Deep Creek. The incursion of the sea from the west, bringing marine organisms, and the deposition of marine limestone at Whiterocks River, can be explained by temporary dominance of subsidence over deposition in the area, thus allowing the sea to transgress far to the east. The gypsiferous interval at the horizon of the tongue of the Thaynes limestone suggests lagoonal conditions where sea water evaporated until the calcium sulfate was precipitated. The salinity of the water is not known, although the lack of marine fossils, so prevalent to the west, suggests a brackish or very saline environment.

The red color of the sediments may be due to oxidizing conditions in the transporting medium or, more probably, it is due to the original red color of the sediments which were formed under humid subaerial conditions. The greenish-gray, sandy shale and fine-grained sandstone at the base of the Moenkopi formation in the Brush Creek area, and the increase of this facies to the east until the entire formation is gray on Vermilion Creek (Sears, 1924, p. 281) in northwestern Colorado, have their counterpart in the San Rafael Swell area, where Gilluly has attributed the color change to bleaching of sediments under reducing conditions (water high in sulfur) in stagnant, muddy pools on a delta (Gilluly, 1928, p. 65). Similar conditions prevail in lagoons along low-lying coasts. However, the west-to-east color change of the Moenkopi formation from red to gray may be due to groundwater conditions existing after deposition of the sediments, which allowed the red iron oxide in the sediments to the east to be reduced to the green ferrous state while the red facies of the Moenkopi to the west remained red or became gray only in the lower beds.

The presence of the amphibian tracks (thought to be *Chirotherium*) in the upper part of the Moenkopi formation near Brush Creek suggests a low-lying, poorly drained deltaic area with pools of shallow water and broad mud flats.

UPPER TRIASSIC SERIES

SHINARUMP CONGLOMERATE

Definition.—In 1876, Powell included the Triassic red beds and the thin but topographically prominent unit lying between them on the flanks of the Uinta Mountains in the Shinarump group, and named the conglomerate the Shinarump conglomerate. More than 40 years later a Triassic terminology borrowed from the Wasatch Mountains was extended east along the flanks of the Uinta Mountains (Schultz, 1919, p. 54; 1920, pl. 1) and Woodside, Thaynes, and Ankareh formations were commonly recognized as the names of Triassic formations in the eastern Uinta Mountains (Sears, 1924, p. 280–281 and 284). The extension of these names beyond their geographic limits created confusion in regard to stratigraphic nomenclature in the Upper Triassic or Ankareh formation equivalents. Thomas and Krueger (1946, p. 1270) tried to solve the problem by substituting the new name "Stanaker formation" for the beds Sears referred to the Ankareh (?) formation, and by naming its thin lower member the "Gartra grit." The Gartra grit is the same unit which Powell, 70 years before, had called the Shinarump conglomerate. The use of a single formation name for a thin unit of essentially uniform appearance over the entire Colorado Plateau region provides a point of reference to those familiar with the formation in adjacent areas, and, as the Shinarump conglomerate has priority in the eastern Uinta Mountains, it is retained in the Uinta River-Brush Creek area.

Topographic expression and distribution.—The Shinarump conglomerate, although not inherently a resistant formation, crops out as narrow sharp pointed ridges, or caps long dip slopes because of the ease of erosion of the underlying thin-bedded Moenkopi formation and the overlying soft clays and shales of the Chinle formation. The Shinarump conglomerate is present throughout the area shown on the map (pl. 1), although from west of Little Brush Creek eastward to Diamond Mountain it thins noticeably and at places is represented by only a few grains of sand separating typical Moenkopi from the shale of the Chinle formation.

The Shinarump conglomerate crops out on both sides of Whiterocks River, as discontinuous strike ridges in the valley of Deep Creek and Mosby Creek, and crops out continuously from north of Little Mountain eastward to Diamond Mountain. The ridges formed by the Shinarump conglomerate permit solution of the badly faulted zone between Mosby Mountain and Little Mountain. The formation makes consistently good outcrops; some of the best exposures are on the north and west sides of Red Mountain where the Shinarump has a calcareous cement and forms almost vertical ciffs and long dip slopes that are covered with cedar trees.

Lithology and thickness.—The Shinarump conglomerate is a light-gray, medium- to coarse-grained, in part conglomeratic, sandstone. The quartz is glassy, pink to light-gray, and the individual grains are angular to subrounded. Quartz grains comprise more than 95 percent of the rock; the remaining 5 percent is chert and feldspar. On weathered surfaces, the larger and more resistant quartz grains weather in relief, thus emphasizing the pebbly, conglomeratic or coarse-grained features of the rock. The larger pebbles in the Shinarump conglomerate are predominantly light-pink quartzite similar to the dreikanter found at two places in the area at the top of the Navajo sandstone. The clasts [clast (Woodford, Moran, and Shelton, 1946, p. 525) is used for clastic fragment. It does not have size limits as do granules, pebble, boulder, and cobble in the Wentworth (1922, p. 381) scale] are as large as 6 inches in diameter and usually are more rounded than the smaller grains. The relative proportion and general appearance of the pink, white, and gray quartz grains in the sandstone is much the same as the grains in the Navajo sandstone (Jurassic?) and the Entrada standstone (Jurassic), which suggests a common source area of pre-Cambrian rocks. Dark, ferromagnesian minerals are relatively rare.

The Shinarump conglomerate ranges from a knife-edge thickness at certain points in the Little Brush Creek area to a maximum of over 90 feet on Whiterocks River; it averages between 40 and 60 feet thick. The variation in thickness is not uniform; thicker sections may be adjacent to average or thin sections. On the whole, the lower half of the formation has a greater concentration of pebbles than the upper part. The finer grained upper half is characteristically crossbedded, and without close examination it might be taken for beds in the Navajo sandstone.

The following sections measured on Red Mountain and Little Brush Creek give the variation and general characteristics of the formation:

Section of the Shinarump conglomerate on the west side of Red Mountain SE¼ sec. 17, T. 3 S., R. 21 E.

[Measured by D. M. Kinney and J. F. Rominger]

	Feet
Chinle formation:	
Sandstone, reddish-gray to weak red-purple, shaly, with thin layers of shale, reddish-gray, sandy; silicified wood, manganese and iron-stained nodules in Shinarump-type sandstone lenses occur in basal 10 feet.	
Shinarump conglomerate:	
Sandstone, light-gray, fine- to medium-grained, thin-bedded (0.01 to 1.0 feet), crossbedded, calcareous; less resistant than underlying unit	22
Sandstone, coarse to very coarse grained, conglomeratic, yellowish-gray, weak yellowish-orange weathering, massive, crossbedded, with light-brown streaks; pebbles to 2 inches in diameter and silicified wood generally present. Caps cuestas. Basal contact locally disconformable with channels extending 25 feet into the underlying Moenkopi formation	44
	66

Section of the Shinarump conglomerate on the west side of Red Mountain SE¼ sec. 17, T. 3 S., R. 21 E.—Continued

Unconformity.
Moenkopi formation:
Sandstone, red, very fine grained.

Section of the Shinarump conglomerate on the west side of Little Brush Creek, SW¼ sec. 25, T. 2 S., R. 22 E.

[Measured by D. M. Kinney and J. F. Rominger]

Chinle formation:	
Shale, gray to purple.	
Shinarump conglomerate:	*Feet*
Sandstone, light-gray to tan, coarse-grained, crossbedded with pebbles to 2 inches in diameter and abundant fossil wood near the base	28
Unconformity.	
Moenkopi formation:	
Sandstone, red, very fine grained.	

Section of Shinarump conglomerate on the west side of Whiterocks River, SW¼ sec. 18, T. 2 N., R. 1 E., Uinta Special Base and Meridian

[Measured by D. M. Kinney, J. F. Rominger, R. S. Brown, and P. Verastegui M.]

Chinle formation:	
Shale, tan to red.	
Shinarump conglomerate:	*Feet*
Sandstone, gray to tan, medium-grained, crossbedded to massive	53
Sandstone, tan, medium- to coarse-grained, conglomeratic, with quartz pebbles	40
Unconformity.	93
Moenkopi formation:	
Sandstone, red, very fine grained.	

Fossils.—The Shinarump conglomerate throughout the area of outcrop is unfossiliferous except for the presence of silicified wood. Fragments and logs of silicified wood as large as 8 inches in diameter and a few feet long are concentrated in the basal part of the formation. The wood is especially abundant near Brush Creek, but generally can be found in almost any large outcrop. The petrified wood is usually some shade of gray in marked contrast to the warmer colored specimens in the overlying Chinle formation, although the wood in other particulars appears similar. In the type area of the Shinarump conglomerate the wood is believed to have affinities with that found in the overlying Chinle (Gregory, 1913, p. 41).

Stratigraphic relations, age, and correlation.—The contact of the Shinarump conglomerate and the underlying Moenkopi formation clearly shows erosion of the Moenkopi before deposition of the conglomerate (fig. 7). Upwards, however, the Shinarump appears to grade into the Chinle formation. At places, it is difficult to place the exact contact between the two formations because lenses of coarse-grained sandstone and pebbles appear in the lower few feet of the Chinle formation. For mapping purposes, the contact has been drawn at the top of the massive coarse-grained sandstone. In the area south of the Book Cliffs, where the Shinarump is thin and rocks flat lying, the Shinarump conglomerate has been considered the basal member of the Chinle formation (Dane, 1935, p. 55–56) and of Late Triassic age.

Recently, Stokes (1948, p. 1383), in an attempt to explain the lack of Middle Triassic sediments in the Plateau region, has suggested that the Shinarump conglomerate is the gravel cover of a coalescing pediment surface and the unconformity and basal beds represent most, if not all, of Middle Triassic time. Such an interpretation permits an explanation of the widespread distribution of the Shinarump conglomerate, its local variation in rock types making up the pebbles, the channel-type deposits in the top of the Moenkopi formation, and the total lack of Middle Triassic sediments in the area. However, the suggestion is based entirely upon deductive reasoning, and in view of the close relationship of the Shinarump to the overlying Chinle and the unquestioned Late Triassic age of the Chinle in southern Utah and northern Arizona, it seems prudent to continue classifying the Shinarump conglomerate as Late Triassic in age.

The Shinarump conglomerate is believed to thin eastward into northwestern Colorado, where it maintains much the same lithologic character as in the Uinta Mountains (Thomas, McCann, and Raman, 1945). It also extends southward to northwestern New Mexico, northern Arizona, and southeastern Nevada. It has been recognized on Weber River in the extreme western end of the Uinta Mountains (Thomas and Krueger, 1946, p. 1272 and 1283), and in the Park City district the equivalent of the Shinarump is probably represented in the basal part of the Nugget sandstone as mapped by Boutwell (1912, pl. 5). In the central Wasatch Mountains, south of the Park City district, it is represented by a conglomeratic sandstone unit at the base of the upper part of the Ankareh shale (Baker, 1947). On the north flank of the Uinta Mountains, the basal part of the Shinarump conglomerate contains scattered pebbles of limestone. In this respect, it resembles the conglomerates at the base of the Jelm formation in the Sierra Madre and Medicine Bow Mountains (Thomas and Krueger, 1946, p. 1273). Limestone pebble conglomerates are characteristic of the Chinle formation south of the Uinta Basin. No definite equivalent of the Shinarump is present in the Wind River Range of central Wyoming, although the sandstone above the Alcova limestone member of the Chugwater formation (Lower Triassic) contains fragments of limestone and comparatively large, rounded and frosted sand grains (Love, Johnson, Nace, Sharkey, Thompson, Tourtelot, and Zapp, 1945). Mansfield (1927, p. 192) has suggested the correlation of the Higham grit of southeastern Idaho with the Shinarump conglomerate in the eastern Uinta Mountains.

Conditions of deposition or origin.—Any explanation of the depositional conditions and origin of the Shinarump conglomerate must take into consideration (1) the widespread occurrence of the formation, (2) the relative thinness of the unit in comparison with its great areal distribution, (3) the high degree of rounding in the large pebbles, (4) the angularity of the smaller grains, (5) the diversity of rock types, and (6) the erosional surface at the top of the underlying Moenkopi formation.

The suggestion of Stokes that the Shinarump represents a coalescing pediment cover has already been discussed in connection with the age of the formation. The suggestion of Mansfield (1927, p. 192) that the Higham grit, a probable equivalent of the Shinarump in southeastern Idaho, is a series of overlapping fans also answers satisfactorily most of the field relations observed in the Uinta Mountains. The Shinarump is thicker than the normal pediment cover; therefore, in this particular case, origin as a series of coalescing fans appears to be more probable. The great expanse of the Shinarump conglomerate and its equivalents is difficult to explain by coalescing fans or by coalescing pediments.

CHINLE FORMATION

Name and Definition.—The name "Chinle", for the Chinle Valley, northeastern Arizona, was applied by Gregory (1913, p. 42) to the Upper Shinarump of Powell. It has been traced from the type area eastward into northwestern New Mexico, westward into the Spring and Muddy Mountains of southeastern Nevada, and northward into central Utah, by a series of workers (Longwell, 1921, p. 51; Gilluly and Reeside, 1928, p. 67–68; Baker, 1936, p. 47–48; Baker, 1933, p. 38–41; Dane, 1935, p. 54–65; and McKnight, 1940, p. 66–70) mapping in contiguous areas. Throughout the Colorado Plateau region, the formation maintains similar lithology, stratigraphic relationships, and included fossils.

The use of the name "Chinle formation" on the south flank of the Uinta Mountains cannot be based on lateral tracing of beds, for the Tertiary rocks of the Uinta Basin completely cover the area north of the Book Cliffs and south of the Uinta Mountains. The use of the Colorado Plateau stratigraphic terminology for the Triassic rocks in the eastern Uinta Mountains, however, was suggested by A. A. Baker, who has studied the Shinarump conglomerate and Chinle formation in the Plateau Region from the Monument Valley-Navajo Mountain area in southern Utah northward to the Moab-Green River Desert country, and the Ankareh shale in the Provo-Park City area of the Wasatch Mountains. The use of Colorado Plateau terminology in the eastern Uinta Mountains is based on stratigraphic position and, in part, on lithologic similarity of the Triassic rocks in the two areas.

Lithology and topographic expression.—The Chinle formation is divided into two members—a lower member of interbedded mudstone, fine-grained sandstone, and shale, in shades of red, purple and brown, and an upper member of fine-grained, light-gray to weak yellowish-orange sandstone with thin partings of weak-red shale (pl. 2 and fig. 8). The lower member is remarkably consistent in lithology from Mosby Creek eastward to Diamond Mountain. Fine-grained, reddish-gray to weak red-purple, shaly sandstone and siltstone are interbedded with dark reddish-gray to weak-red shale. The finer grained beds, those with the greater percentage of shale, are darker in color. Lenticular beds of coarse-grained, gray to dark purple sandstone with occasional pebbles of pink and gray quartzite, nodules of manganiferous iron oxide, and fragments of silicified wood are common in the basal 10 feet. A 23-to 36-foot bed of moderate yellowish-brown mudstone or siltstone, containing botryoidal concretions of calcite, lies 70 to 80 feet above the base of the Chinle in the Brush Creek-Ashley Creek area. The upper member is red

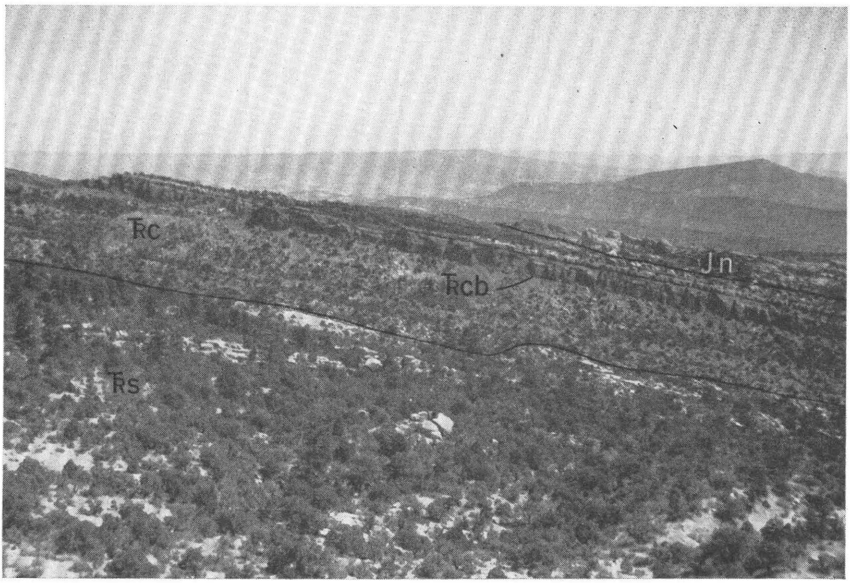

FIGURE 8.—Chinle formation (*Trc*) resting on Shinarump conglomerate (*Trs*) and overlain by Navajo sandstone (*Jn*) on Red Mountain.

to white, fine- to medium-grained sandstone with occasional thin beds of red to purple siltstone. Some sandstone beds are cemented with calcite and show irregular solution pits. Others are crossbedded in beds 0.5 to 1.0 foot in thickness. The lower member forms smooth slopes mantled by a thin crust of weathered red sandy shale and clay. Outcrops are usually good because of the protection afforded by the more resistant upper part of the Chinle formation. The upper member generally forms vertical cliffs which retreat by spalling large blocks of sandstone.

Distribution and thickness.—The Chinle formation crops out on Whiterocks River, in the faulted area between Mosby Mountain and Dry Fork of Ashley Creek, and on the north flank of Little Mountain. It appears at the crest of the Neal dome at the intersection of Dry Fork and Ashley Creek and crops out from the community of Dry Fork eastward to Diamond Mountain. It also is present on the north side of Split Mountain and along Cliff Creek in the southeastern part of the area.

The lower member ranges in thickness from 120 feet to 175 feet, and averages 145 feet. The upper member ranges in thickness from 85 feet to 130 feet, and averages 105 feet.

The detailed lithology and thickness of the Chinle formation is shown in the following sections taken at well-exposed intervals across the area:

Section of the Chinle formation on west side of Little Brush Creek SW¼ sec. 25, and NW¼ sec. 36, T. 2 S., R. 22 E.

[Measured by D. M. Kinney and J. F. Rominger]

Navajo sandstone:	
Sandstone, light-gray, fine-grained, crossbedded.	
Chinle formation:	*Feet*
Sandstone, red, fine-grained, friable	8
Sandstone, white, fine- to medium-grained, ripple-marked	3
Siltstone, red to purple with thin beds of sandstone, light-gray, fine-grained	13
Sandstone, red, fine-grained, massive, slightly calcareous, cavernous weathering	63
Sandstone, mottled red and white, fine-grained, slightly calcareous	3
Siltstone, red	48
Shale, moderate yellowish-brown, with botryoidal concretions of calcite	23
Sandstone, red to purple, very fine-grained, with streaks of purple shale	56
Sandstone, red, coarse-grained, crossbedded, with occasional small pebbles	5
Shale, gray to purple	12
	234

Shinarump conglomerate:

Section of the Chinle formation measured on southwest side of Red Mountain, SE¼ sec. 17, T. 3 S., R. 21 E., Salt Lake Base and Meridian

[Measured by D. M. Kinney and J. F. Rominger]

Navajo sandstone:

Sandstone, yellowish-gray, fine- to medium-grained, crossbedded. Weathers in turrets and spires.

Chinle formation:	Feet
Sandstone, yellowish-gray, fine- to coarse-grained, massive, crossbedded within 0.5 foot layers, calcareous, with spherical calcareous nodules 5 to 10 mm. in diameter. Thin beds of weak-red shale in upper 2 feet	13
Sandstone, weak yellowish-orange, fine-grained, friable, thin-bedded (0.2 to 1.0 foot), with harder 1-foot beds of sandstone, light-gray, fine-grained, slightly calcareous. Weak-red shale beds 36 to 40 feet and 56 to 60 feet above base	79
Sandstone, light-gray, fine- to medium-grained, massive crossbedded; forms ledge	8
Sandstone, light-brown, fine-grained, friable	14
Sandstone, light-brown with streaks of light-gray to greenish-gray, fine-grained, thin-bedded (0.1 to 1.0 foot), slightly crossbedded; forms cliff. Bed of shale, sandy, pale reddish-brown, 8 to 11 feet above base	22
Shale, weak-red	22
Siltstone, moderate yellowish-brown	36
Shale, dark reddish-gray to weak-red	58
Sandstone, shaly, reddish-gray, to weak red-purple, with thin layers of reddish-gray, sandy shale; silicified wood, manganese and iron-stained nodules, and Shinarump-like sandstone lenses in basal 10 feet. Thin bed (0.5 foot) of sandstone, very coarse grained, pebbly, weak orange-pink, lenticular, with few fragments of silicified wood at top	24
	276

Shinarump conglomerate:

Section of the Chinle formation on the west side of Mosby Creek SW¼ sec. 8, T. 3 S., R. 19 E., Salt Lake Base and Meridian

[Measured by D. M. Kinney, J. F. Rominger, R. S. Brown, and P. Verastegui M.]

Navajo sandstone:

Sandstone, light-gray, tan-weathering, fine-grained, crossbedded, with rounded grains of sand.

Chinle formation:	Feet
Sandstone, red to tan, thin-bedded, with partings of reddish-brown shale	85
Shale, tan to red, sandy	175
	260

Shinarump conglomerate:

Sandstone, light-gray, crossbedded, medium- to coarse-grained, pebbly.

Fossils and age.—The only recognized fossils in the Chinle formation in this area are fragments of silicified wood found near the base of the lower member, although Untermann (personal communication) reports finding fragments of phytosaurian bone in the same unit on Red Mountain. The wood probably belongs to the genus *Araucarioxylon*, the characteristic conifer of the Shinarump conglomerate and Chinle formation in northern Arizona. Evidence from vertebrate paleontology (phytosaurian bones) and paleobotany (Camp, 1930, p. 1–23; Baker, 1933, p. 38; McKnight, 1940, p. 66–71; and Daugherty, 1941) (leaf impressions and silicified wood) indicate a Late Triassic age for the Chinle in northeastern Arizona and as far north as Moab, Utah. On the south flank of the Uinta Mountains, the Chinle is not dated by vertebrate or botanical remains.

Stratigraphic relations and correlations.—Small lenses of coarse-grained pebbly sandstone in the basal few feet of the Chinle suggest a gradational boundary with the underlying Shinarump conglomerate. A similar relationship has been observed in the Salt Valley-Green River Desert region south of the Uinta Basin where the basal conglomerate of the Chinle formation "has much of the same stratigraphic significance as the Shinarump and may be regarded as the eastern equivalent of the Shinarump" (Dane, 1935, p. 55–56). The boundary between the lower and upper members of the Chinle in the Deep Creek-Brush Creek area is very sharp, and in the NE¼ sec. 20, T. 3 S., R. 21 E., the upper member appears to truncate the more steeply dipping red sandy shale of the lower member. This relationship was not observed elsewhere in the area, and an additional section measured in an exposure one-fourth mile to the north shows no change in thickness for the lower member. The truncated beds of the lower member are interpreted as foreset bedding in a deltaic deposit. The upper boundary of the Chinle is taken at the top of the highest reddish shale beneath the massive crossbedded Navajo sandstone of Jurassic(?) age. The upper boundary may not always have been drawn at the same horizon in measuring sections and in mapping. On Split Mountain, beds of reddish sandstone and red shale occur at intervals throughout the Navajo sandstone, making the choice of the upper boundary difficult. The arbitrary choice of the highest red shale as the top of the Chinle seems most reasonable in the area from Mosby Mountain east to Diamond Mountain, for it groups together the eolian-type crossbedding of the Navajo sandstone and the dominantly water-laid sandstone and shale of the Chinle. No evidence of erosion of the Chinle prior to the deposition of the Navajo was found, and additional study of the Chinle formation east of the Green River may make it more logical to group the upper member with the overlying Navajo sandstone.

The correlation of the Chinle formation in the eastern Uinta Mountains with the type section is made on the basis of lithologic similarity and stratigraphic position above the Shinarump conglomerate and below the crossbedded Jurassic(?) sandstone, here assigned to the Navajo sandstone. The lithology of the Chinle in the eastern Uinta Mountains, however, has changed slightly from that south of the Uinta Basin, for the crossbedding and lenticular bedding, characteristic of subaerial fluvial deposition, has been replaced by even-bedded siltstone and fine-grained sandstone, which are more characteristic of playa deposition. This change probably denotes greater distance from the source area. Ripplemarks and other evidence of current action are comparatively rare, except in the upper member of the Chinle where it is believed to be transitional to the overlying Navajo sandstone.

In northwestern Colorado, to the east of the Uinta Mountains, the Chinle formation is believed to continue relatively unchanged for at least 100 miles (Thomas, McCann, and Raman, 1945). To the west in the Wasatch Mountains, the Chinle is correlated with the upper part of the Ankareh shale of the Park City district. The type Ankareh includes a bed of coarse-grained sandstone near the middle of the section which has been correlated with the Shinarump conglomerate. In the Provo area (Baker, 1947), the twofold division of the Chinle into a lower fine-grained shaly member and an upper sandstone member persists, although the formation is almost twice as thick as in the eastern Uinta Mountains. In the Wind River Mountains of central Wyoming, the Popo Agie member of the Chugwater formation probably correlates with some part of the Chinle (Gregory, J. T., personal communication), although Branson and Camp have suggested a Middle Triassic age for the vertebrate fauna of the Popo Agie. The Popo Agie has a very characteristic lithology of ocher-colored, oölitic, siliceous, dolomitic claystone, limestone pellet-conglomerate, purple and red shale, and red silty sandstone. Certain beds in the lower member of the Chinle of the Red Mountain-Little Brush Creek area closely resemble the descriptions of the Popo Agie. The Deadman limestone and Wood shale (200 to 250 feet thick) in southeastern Idaho, now assigned questionably to the Triassic, may correspond to the Chinle formation of the eastern Uinta Mountains.

Conditions of deposition.—The prevailing thin-bedded, fine-grained micaceous character of the lower member of the Chinle formation together with the lack of mud cracks, raindrop impressions, and other evidence of subaerial conditions point to deposition in a body of standing water. The absence of gypsum, anhydrite, and beds of limestone associated with the shales and siltstones, together with the presence of fresh-water pelecypods and swamp-living vertebrate reptiles and amphibians in correlative strata in the Wind River Mountains to the north and the San Rafael Swell-Moab region to the south, suggest deposition in fresh water.

The lower member of the Chinle formation is in sharp contrast to the Chinle formation in the Salt Valley anticline and San Rafael Swell areas, where the beds of the Chinle are lenticular in shape, the bedding is discontinuous and irregular, and ripple marks are common. These conditions are characteristic of fluvial deposits. The upper member of the Chinle, however, is dominantly thick-bedded, fine- to medium-grained sandstone; crossbedding and ripple marks are common, which suggests fluvial deposition, perhaps on an advancing delta.

The Chinle and its equivalents become finer grained toward the north, suggesting a southern source, perhaps in highlands in central Arizona. Additional sediments probably were derived from rocks of other areas, such as the crystalline rocks of the Uncompahgre Plateau area which was a local source for the Chinle in the Salt Valley-Green River Desert area south of the Book Cliffs.

JURASSIC(?) SYSTEM

NAVAJO SANDSTONE

Name and definition.—The Navajo sandstone, a fine- to medium-grained, light-gray to buff, crossbedded sandstone was named for exposures in the "Navajo country" of northern Arizona (Gregory, 1913, p. 57). The name has been used for rocks of similar appearance and stratigraphic position in central Utah. In central and southern Utah and northern Arizona, the Navajo sandstone is the upper formation in the Glen Canyon group, which also includes the Wingate sandstone and the Kayenta formation. The Wingate and Kayenta cannot be differentiated in the eastern Uinta Mountains, although equivalent beds may be present in the upper member of the Chinle formation and in the lower beds of the Navajo. For many years, the rocks here included in the Navajo sandstone have been identified as the Nugget sandstone, whose type section is in southwestern Wyoming. As used by Schultz (1920, p. 78); Sears (1924, p. 284); and Hancock (1925, p. 8, 10) in the eastern Uinta Mountains, and especially in northwestern Colorado, the Nugget sandstone included equivalents of the Navajo sandstone, the Carmel formation, the Entrada sandstone, and the basal sandstone of the Curtis formation of the present report.

Lithology and thickness.—The Navajo is a light-gray to buff, fine- to medium-grained sandstone composed of subrounded to rounded quartz grains. The larger particles are concentrated along planes of crossbedding and are generally better rounded than the average-sized grains. The sand is dominantly clear quartz, but a minor portion is pink and dark-gray quartz resembling the minor constituents of the Shinarump conglomerate and the Entrada sandstone. The crossbedding in the Navajo dips in a southerly direction between true bedding planes 10 to 30 feet apart. Dreikanter of light-pink quartzite exhibiting fluted carving and frosted surfaces, as much as 6 inches in diameter, have been found at two localities in the Steinaker Draw area; one locality is in the SE¼ sec. 27, T. 3 S., R. 21 E., west of Utah State Highway 44, and the other is located 4 miles to the northeast in the SE¼ sec. 5, T. 3 S., R. 22 E. In both localities, the dreikanter are found in the top bed of the formation. They may have been concentrated from a great thickness of sandstone by the encroaching Carmel sea during late Jurassic time or by wind ablation prior to submergence of the area.

A thin, lenticular bed of fine-grained, rough- to hackly-weathering, gray, sandy limestone, 6 to 8 feet thick, is present in the middle of the Navajo sandstone on a sharp-pointed hill in the NW¼ sec. 36, T. 2 S., R. 22 E., a short distance west of Little Brush Creek. In the San Rafael Swell region similar beds in the Navajo have been interpreted as deposits of ephemeral lakes among the dunes (Gilluly and Reeside, 1928, p. 72; Baker, 1946, p. 69). A bed of tan-weathering, highly calcareous sandstone is present on Neal dome, east of Ashley Creek. This resistant calcareous bed appears to have been deposited at a single horizon and probably under conditions similar to those under which the lenticular limestone bed was deposited. The tracing of this calcareous bed has made possible the structural contouring of Neal dome.

The Navajo sandstone thins from 1,028 feet on the west side of Whiterocks River to a little over 700 feet at Split Mountain; between Steinaker Draw, Little Brush Creek, and Split Mountain it is remarkably constant and averages between 750 and 800 feet thick. The highly crossbedded nature of the Navajo and the obscurity of true bedding made it difficult to obtain detailed measurement of the thickness of the sandstone. The above thicknesses are calculated from sections wherein the strike and dip of the underlying well-bedded Chinle formation and of the overlying Carmel formation are in close accord.

Distribution and topographic expression.—The Navajo sandstone is present on the east and west sides of Whiterocks River where it is heavily impregnated with petroleum residue, in the valleys of Mosby Creek and Deep Creek where it is only incompletely exposed because of the faulted condition of the rocks, on the north side of Little Mountain, and in continuous outcrop from west of Ashley Creek (fig. 9), eastward to Diamond Mountain. It is again exposed on the north flank of Split Mountain and in the vicinity of Cliff Creek on the eastern border of the area under study. Some of the finest exposures of the formation are between Ashley Creek and Steinaker Draw, where the "tangential" crossbedded sandstone weathers into smoothly rounded domes and sharp turrets, and is cut by steep-walled box

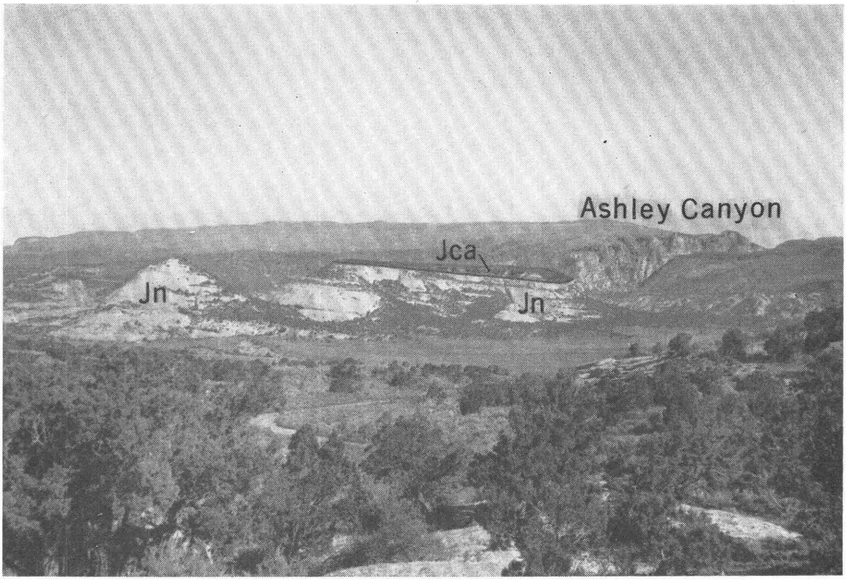

FIGURE 9.—Carmel formation (*Jca*) on massive crossbedded Navajo sandstone (*Jn*) preserved in small syncline north of Neal dome.

canyons eroded along northwest-southeast striking joints or faults of slight displacement. It is not a particularly resistant formation except in the walls of Dry Fork of Ashley Creek and Ashley Creek where its massive, basal part forms cliffs 100 to 200 feet high. Elsewhere the sandstone forms smoothly rounded slopes covered with dunes of wind-drifted, fine-grained sand.

Stratigraphic relations and age.—The lower boundary of the Navajo sandstone has been chosen arbitrarily at the base of the massive, light-gray, crossbedded sandstone. No erosion of the Chinle formation prior to the deposition of the Navajo has been observed and the boundary is believed to be gradational. Sand derived from the upper beds of the Navajo or from dunes lying on the surface of the consolidated Navajo were reworked into a bed of light-gray, fine-grained sandstone by the advancing Carmel sea during Middle and late Jurassic time. Except for this thin bed of reworked sand, the sharp change from crossbedded Navajo to the overlying red sandy shale, pink to white sandstone, gypsum and interbedded marine fossiliferous limestone that make up the Carmel formation, suggests unconformity. The upper surface of the Navajo shows no channeling or other irregularities which might have been caused by subaerial erosion. Of course, unconformity is shown most clearly by truncation of the underlying beds; this could not readily be recognized because the Navajo sandstone is highly crossbedded. The eastward thinning of the Navajo is not believed to be due to thinning by truncation of beds.

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The age of the Navajo sandstone is entirely dependent upon its stratigraphic position below the fossiliferous Carmel formation which carries a diagnostic Middle and Upper Jurassic fauna and above the Chinle formation which, in the Uinta Mountains, is itself correlated by lithology and stratigraphic position with the Chinle formation south of the Book Cliffs. The Chinle formation, in turn, is dated as Late Triassic by amphibian remains found near Moab, Utah. It has been suggested by Heaton (1939, p. 1176) that the Wingate and Kayenta formations in the San Rafael Swell were deposited in Late Triassic or Middle(?) Jurassic time and that the Navajo sandstone was deposited in Middle(?) Jurassic time. More recently, however, Imlay (1945, p. 1026), on the basis of ammonites, has suggested that the Carmel formation of the San Rafael Swell region is separated from the Navajo sandstone by an unconformity representing most of Middle Jurassic time. No fossil evidence favoring either of these suggestions is available in the Uinta River-Brush Creek area because the Navajo is unfossiliferous.

Correlation.—The Navajo sandstone in the eastern Uinta Mountains is believed to correlate with the typical Nugget sandstone of southwestern Wyoming and the Wasatch Mountains (Baker, Dane, and Reeside, 1936, p. 5). Eastward from the Uinta River-Brush Creek area, the Navajo has been traced for more than 100 miles (Thomas, McCann, and Raman, 1945) by surface sections and drill cuttings. To the south, the sandstone is believed to be continuous with the Navajo of the San Rafael Swell, the region between the Green and San Juan Rivers, and the Moab area.

Conditions of deposition.—It is agreed by all investigators working in the highly crossbedded, fine- to medium-grained Navajo sandstone that the formation is predominantly of eolian origin. Water played a minor part in its deposition, as is shown by thin lenticular beds of fine-grained, sandy limestone and occasional horizontally bedded, shaly, red sandstone.

An isopachous map of the Navajo sandstone in southern and central Utah prepared by Baker, Dane, and Reeside (1936, p. 47) strongly suggests a western source. Recent additional information in regard to the thickness of the Navajo sandstone in the Uinta Mountains coupled with the more prevalent belief that it is correlative with the Nugget sandstone of the Wasatch Mountains and southwestern Wyoming has justified an isopachous map which shows eastward thinning of the formation from the latitude of central Wyoming southward to central Arizona. This thinning towards the east suggests that the principal source was in the mountains of central and eastern Nevada. It is possible that additional sediments were derived from central Colorado. However, the predominant southern dips of the crossbedding in the Uinta River-Brush Creek area indicate that the prevailing winds advanced the local dunes towards the south.

JURASSIC SYSTEM

MIDDLE AND UPPER JURASSIC SERIES

SAN RAFAEL GROUP

The San Rafael group (Middle and Upper Jurassic), named for exposures in the San Rafael Swell (Gilluly and Reeside, 1928, p. 73), includes four formations in the type area, which, in ascending order, are the Carmel formation, the Entrada sandstone, the Curtis formation, and the Summerville formation. In the eastern Uinta Mountains, however, the Summerville formation is not recognized, and the Morrison formation of Late Jurassic age overlies the Curtis formation.

CARMEL FORMATION

Name.—The Carmel formation, the lowest in the San Rafael group, was proposed by Gregory and Moore (1931, p. 73) for exposures near Mount Carmel in southwestern Utah. Informally published by W. T. Thom (1926, p. 3) in summarizing field investigations of W. T. Lee, W. W. Boyer, and James Gilluly, it was first published formally by Gilluly and Reeside (1928, p. 73) in their study of the San Rafael region. Dane (1935, p. 90) has suggested that only the lower marine part of the Carmel formation in central and east central Utah may be equivalent to the type Carmel. The name "Carmel" was introduced into the eastern Uinta Mountains by Baker, Dane, and Reeside (1936, p. 14). Previously, these strata were considered a part of the Nugget sandstone.

Lithology and thickness.—Within the area mapped, the Carmel formation consists of soft red sandy shale, fine-grained sandstone, a few thin beds of platy, light-gray, calcareous mudstone, and fossiliferous light-gray limestone. Beds of pinkish gypsum or gypsiferous fine-grained sandstone are present locally in the lower part of the formation. Limestone is more abundant on Whiterocks River in the western part of the Uinta River-Brush Creek area than to the east; it disappears at the head of Steinaker Draw.

The Carmel formation thins from 390 feet on the west side of Whiterocks River to 244 feet in Steinaker Draw, 170 feet between Little Brush Creek and Brush Creek, and 124 feet on the south side of Split Mountain. This thinning is uniform from west to east, and near Skull Creek in northwestern Colorado the Carmel is present only as thin lenses beneath the Entrada sandstone.

The following detailed sections, measured by stadia, show the pronounced thinning and change of character of the formation from west to east:

Section of the Carmel formation on west side of Whiterocks River NW¼ sec. 19, T. 2 N., R. 1 E., Uinta Special Base and Meridian

[Measured by D. M. Kinney and J. F. Rominger]

Entrada sandstone:
Sandstone, light-gray, fine- to medium-grained, with rounded and frosted grains.

Carmel formation:	Feet
Covered, probably sandstone, reddish-brown, fine-grained and shale, reddish-brown, and sandy	113
Sandstone, weak yellowish-gray, very fine grained	20
Covered, probably shale, reddish-brown to light-gray, sandy	76
Mudstone, yellowish-gray	10
Sandstone, light reddish-brown, with veinlets of gypsum	6
Gypsum, light-gray, lenticular	2
Sandstone, reddish-brown, fine-grained, with gypsum veins	3
Gypsum (60 percent) and sandstone (40 percent), yellowish-gray, interbedded	2
Mudstone, yellowish-gray	2
Sandstone, yellowish-gray, very fine grained	4
Gypsum	1
Mudstone, reddish-brown, gypsiferous, slightly sandy, with veinlets of gypsum	13
Gypsum, white to greenish, lenticular	1
Mudstone, yellowish-gray, thin-bedded	40
Covered	29
Sandstone, reddish-brown, very fine grained	15
Limestone, light-gray, very thin bedded, slabby, brittle, and ripple-marked	3
Sandstone, moderate reddish-brown, fine-grained	17
Shale, light-gray, fissile, with thin beds (to 0.4 foot) of limestone, gray, tan-weathering, abundantly fossiliferous	26
	383

Navajo sandstone:
Sandstone, dark-brown, petroleum impregnated, fine- to medium-grained.

Section of Carmel formation on west side of Steinaker Draw E¼ sec. 27 and W¼ sec. 26, T. 3 S., R. 21 E.

[Measured by D. M. Kinney, J. F. Rominger, P. Verastegui M., and R. S. Brown]

Entrada sandstone:
Sandstone, light-gray, fine-grained, massive, with rounded grains.

Carmel formation:	Feet
Covered, sandstone, red, very fine grained	54
Mudstone, gray, with streaks of silty sandstone	22
Sandstone, red, fine-grained	27
Gypsum, light-pink to white. Bed thickens to 4 feet in 300 feet southwest	2
Mudstone, gray	17
Sandstone, red, fine-grained	8
Shale, gray, crinkly-bedded	3

Section of Carmel formation on west side of Steinaker Draw E¼ sec. 27 and W¼ sec. 26, T. 3 S., R. 21 E.—Continued

	Feet
Carmel formation—Continued	
Sandstone, gray, fine-grained, platy, calcareous, fossiliferous	6.5
Shale, gray, platy	6.5
Sandstone, red, fine-grained	31
Shale, light-gray, conchoidally fracturing, with 4 inches of limestone, light-gray, fine-grained, at base. *Trigonia* replaced by red chert in the limestone bed	7
Sandstone, red, fine-grained, with three 1- to 2-foot beds of sandstone, gray, fine-grained	39
Sandstone, light-gray, fine-grained, turbulent-bedded, with calcareous cement near top. Probably reworked Navajo sandstone	8
	231

Section of the Carmel formation south of road between Brush Creek and Little Brush Creek, NW¼ sec. 2, T. 3 S., R. 22 E.

[Measured by D. M. Kinney and J. F. Rominger]

Entrada sandstone:
Sandstone, white fine- to medium-grained, with rounded and polished grains.

	Feet
Carmel formation:	
Siltstone, red	22
Shale, greenish-gray, and sandstone, fine-grained, interbedded	10
Siltstone, red	22
Sandstone, light-gray, fine-grained	9
Shale, gray, conchoidally fracturing, in part calcareous	24
Sandstone, gray, fine- to medium-grained, with rounded and polished grains	1
Sandstone, red, fine to very fine grained and shale, red	82
	170

Distribution and topographic expression.—The Carmel formation is present along Whiterocks River, in the faulted area between Mosby Mountain and Ashley Creek, and eastward from Ashley Creek along the west side of Steinaker Draw and across the valleys of Brush Creek and Little Brush Creek to Diamond Mountain. It is present also on the north flank of Split Mountain and on the westward plunging Section Ridge anticline in the eastern part of the mapped area. Good exposures can be found on the north side of Little Mountain, along Steinaker Draw, and between Brush Creek and Little Brush Creek.

The Carmel formation is easily eroded, and forms strike valleys between the Navajo sandstone and the Curtis formation, or between the Navajo sandstone and the massive crossbedded sandstone which comprises the Entrada sandstone in the eastern part of the area. At some places, as in the faulted area between Mosby Creek and Little Mountain, or in Steinaker Draw, the light-gray, conchoidally weathering, calcareous shale and thinbedded, fossiliferous limestone in the basal 50 feet of the Carmel will form strike ridges.

Fossils.—Fossil collections from the limestone beds in the basal 50 feet of the Carmel formation in Steinaker Draw were submitted to Ralph W. Imlay of the Geological Survey. Mr. Imlay reports as follows:

> The collections from the Jurassic of the Uinta Mountains do not allow exact age determinations. Collection U–4 from the Carmel or Twin Creek in sec. 26, T. 3 S., R. 21 E., contains *Trigonia quadrangularis* Hall and Whitfield which has been found previously only in the Carmel, Gypsum Spring, Twin Creek and lower part of the Sundance. Collection U–5 from the Carmel or Twin Creek in sec. 12, T. 3 S., R. 21 E., contains fragmentary *Camptonectes*. . . .

Stratigraphic relations and correlation.—The contact between the Carmel formation and the Navajo sandstone is sharp (fig. 9). Except for a thin reworked sandstone bed at the base of the Carmel, no gradational beds appear between the light-gray to tan, fine-grained sandstone of the Navajo and the overlying red sandy shale. The boundary of the Carmel with the overlying Entrada sandstone appears gradational, particularly in the western two-thirds of the area. From Whiterocks River eastward to the measured section in Steinaker Draw, the boundary is generally poorly exposed. Even in the better exposures in this area, the change from red siltstone and fine-grained sandstone of the Carmel to the fine-grained light-gray sandstone of the Entrada takes place over an interval of 10 or 15 feet. In the area from Brush Creek southward to Section Ridge anticline, the boundary between the two formations is sharp, but no evidence points to erosion of the Carmel formation prior to the deposition of the overlying Entrada sandstone. The two formations appear conformable throughout the area.

The limestone beds in the basal 50 feet of the Carmel formation are tongues of the Twin Creek limestone, which progressively thickens to 700 or 800 feet east of the Duchesne River (Huddle and McCann, 1947) to 1,100 feet in the Wasatch Mountains (Baker, 1947), and finally reaches a thickness of 3,500 to 3,800 feet in the type section in southwestern Wyoming (Veatch, 1907, p. 56). The amount of Twin Creek limestone that is represented in these thin limestone beds is not known, but from analogy with the section in the San Rafael Swell, where the limestones near the base of the Carmel formation are early Middle Jurassic (Imlay, 1948, pl. 4), it is probable that the Carmel formation in the eastern Uinta Mountains is, for the most part, Middle Jurassic in age.

Conditions of deposition.—The fossiliferous limestone at the base of the Carmel formation in the western three-quarters of the area is certainly of marine origin. Thin beds of gypsum, which occur in the lower 150 feet of the Whiterocks River section, also suggest deposition from sea water in shallow land-locked lagoons. The upper part of the Carmel formation probably was deposited from water in lakes or ponds, on a river flood plain, or on a coastal plain near the sea as the Jurassic sea withdrew northward and westward into the central trough of the geosyncline. The gradational contact between the Carmel and the overlying Entrada sandstone marks the change from subaqueous to prevailing eolian deposition. Some of the rock showing evidence of subaqueous deposition at the top of the Carmel was probably wind transported before final deposition. The source of the clastic sediments, fine-grained sandstone and silt, in the Carmel formation was probably to the east and southeast where Triassic and Permian red beds were being eroded from a low-lying land area. Some of the Carmel formation, as mapped in the western and central parts of the Uinta River-Brush Creek area, may be equivalent to the red, silty sandstone facies of the Entrada which is present to the west of the "white sand" facies in the San Rafael Swell region.

ENTRADA SANDSTONE

Name.—The Entrada sandstone was defined by Gilluly and Reeside (1928, p. 76) as a thick series of earthy sandstones and subordinate shale overlying the Carmel formation and underlying the Curtis formation in the northern part of the San Rafael Swell. Two lithologic facies of the formation are present in central Utah, the westerly facies is red, silty, and fine-grained, but eastward the sandstone is light-gray, "clean," and fine- to medium-grained. The Entrada sandstone has been recognized in the eastern Uinta Mountains since the work of Baker, Dane, and Reeside (1936, p. 27, 41).

Lithology and thickness.—The Entrada sandstone, as typically developed in the eastern Uinta Mountains, is a fine- to medium-grained, light-gray, poorly cemented sandstone. This facies of the formation has also been decribed from east of the San Rafael Swell (McKnight, 1940, p. 91–93; Baker, 1933, p. 49–50; Dane, 1935, p. 92–98). To the west, the clean, light-gray sandstone is interbedded with light-gray to red, very fine grained sandstone or siltstone. The fine-grained silty phase of the Entrada fingers out into the light-gray, fine- to medium-grained phase near the head of Steinaker Draw. Some of the strata included in the upper, covered portion of the Carmel formation in Whiterocks Canyon and west of Steinaker Draw also may be the fine-grained red silty facies of the Entrada sandstone.

The sand grains in the Entrada are sorted into two very definite sizes—fine and coarse. This double sorting distinguishes the Entrada sandstone from the Navajo sandstone (which it superficially resembles), because the coarse grains are not concentrated along planes of crossbedding; instead, they occur as isolated grains surrounded by finer grained sand. The coarser grains are well rounded and their surfaces have a matte or frosted appearance. The majority of the sand grains are transparent or colorless quartz, but minor percentages of pink and dark-gray grains give the sandstone a characteristic appearance. This mixture of clear quartz with gray and pink grains also has been noted in the Navajo sandstone and in the Shinarump conglomerate, which suggests a common source area for these three formations. Dane (1935, p. 93) also records similar minor mineral constituents in the Entrada sandstone of the Salt Valley anticline area of west central Utah.

The bedding in the Entrada sandstone in the eastern part of the area is massive and faintly crossbedded. Individual beds more than 25 feet thick and displaying no horizontal bedding, are common. The crossbedding is in marked contrast to the promient "tangential" bedding which characterizes the Navajo sandstone. The cross-lamination in the Entrada may be subordinant because it is not highly developed or because differential solution does not emphasize the long sweeping false bedding as is done in the calcareous-cemented Navajo sandstone.

The Entrada sandstone thins from 240 feet on Whiterocks River to 215 feet at Steinaker Draw, 163 feet between Brush Creek and Little Brush Creek, and to 104 feet at Split Mountain. Heaton (1939, p. 1175) records only a little more than 100 feet of Entrada on Whiterocks River, but this discrepancy is due to the choice of the lower boundary of the sandstone in an area where the red silty sandstone facies is interbedded with the "clean" sand facies (Thomas and Krueger, 1946, p. 1287).

The following detailed sections of the Entrada sandstone give the lithology and thickness of the different units in more detail:

Section of the Entrada sandstone on the west side of Whiterocks River, NW¼ sec. 19, T. 2 N., R. 1 E.

[Measured by D. M. Kinney and J. F. Rominger]

Curtis formation:	
Sandstone, light-gray, fine- to medium-grained, glauconitic, crossbedded.	
Entrada sandstone:	*Feet*
Sandstone, moderate reddish-brown, fine-grained	45
Sandstone, yellowish, very fine grained	34
Sandstone, light-gray, fine- to medium-grained	28
Covered, probably sandstone, reddish-brown, fine-grained	113
Sandstone, weak yellowish-gray, very fine grained	20
	240
Carmel formation:	
Covered.	

Section of the Entrada sandstone on the west side of Steinaker Draw SW¼ sec. 26, T. 3 S., R. 21 E.

[Measured by D. M. Kinney, J. F. Rominger, P. Verastegui M., and R. S. Brown]

	Feet
Curtis formation:	
Sandstone, light-gray, fossiliferous, conglomeratic with pebbles of quartz and shale.	
Entrada sandstone:	
Sandstone, red, fine-grained	10
Sandstone, light-gray, fine-grained, with large, rounded and frosted sand grains	55
Sandstone, light-gray, fine-grained, with rounded and frosted grains	101
Sandstone, light gray, fine-grained, massive, with rounded and frosted grains	49
	215

Section of the Entrada sandstone between Brush Creek and Little Brush Creek, SW¼NW¼ sec. 2, T. 3 S., R. 22 E.

[Measured by D. M. Kinney and J. F. Rominger]

	Feet
Curtis formation:	
Sandstone, light greenish-gray, glauconitic, fine- to medium-grained, poorly sorted, calcareous, with pebbles to ½ inch in diameter, partings of reddish shale, and dark greenish-gray shale.	
Entrada sandstone:	
Sandstone, white, fine-grained, crossbedded with rounded and polished sand grains. Basal 2 feet poorly sorted	64
Sandstone, red, fine- to medium-grained, poorly sorted, with rounded and polished grains	4
Sandstone, white, fine- to medium-grained, with rounded and polished sand grains	95
	163
Carmel formation:	
Siltstone, red.	

Distribution and topographic expression.—The Entrada sandstone is present on Whiterocks River, in the faulted area between Mosby Mountain and Ashley Creek, and eastward from Ashley Creek to Diamond Mountain. Also, it is present on the north flank of Split Mountain and on the Section Ridge anticline. In the western half of the mapped area, both the Carmel formation and the Entrada are poorly exposed; it is difficult to draw a boundary between the two formations because the boundary frequently lies at the bottom of a strike valley. Only the upper part of the Entrada is well exposed near the base of the escarpment, which is topped by the oölitic sandy limestone that is present at the top of the Curtis formation. East of Steinaker Draw, the Entrada commonly forms 25- to 35-foot cliffs topped by the basal, thin-bedded, coarse-grained, glauconitic sandstone of the Curtis formation.

Fossils and age.—The Entrada sandstone is unfossiliferous in the eastern Uinta Mountains and therefore its exact age is unknown. In the San Rafael Swell area, Imlay (1948, pl. 4) considers the Entrada to be upper Callovian (low Upper Jurassic) and a similar age is probable for the Entrada in the eastern Uinta Mountains.

Stratigraphic relations and correlation.—The Entrada sandstone is apparently gradational with the underlying Carmel formation in the western three-quarters of the Uinta River-Brush Creek area. To the east, it is separated from the Carmel by a sharp lithologic boundary, but there is no evidence of erosion. The upper boundary of the Entrada is sharp, especially in those sections where the basal bed of the unconformably overlying Curtis formation is a coarse-grained to pebbly, glauconitic sandstone. The upper surface of the Entrada is channeled and irregular east of Steinaker Draw. Fragments of shale and pebbles as much as one half inch in diameter are incorporated in the basal bed. Between Mosby Mountain and a mile west of Steinaker Draw, the basal bed of the Curtis formation is shale and there is no evidence of interruption in sedimentation in exposed sections. A marked change in the depositing medium is evident in this area between the Entrada sandstone and the overlying Curtis formation because the massive Entrada sandstone is succeeded by thin-bedded, in part crossbedded, highly glauconitic sandstone of the Curtis formation.

The Entrada sandstone is believed to be continuous with the type area on the east side of the San Rafael Swell and in the Green River Desert to the south of the Uinta Basin. It has been traced westward into the Preuss sandstone (Heaton, 1939, p. 1173; Thomas and Krueger, 1946, p. 1277), which is widely recognized in the western Uinta Mountains, the Wasatch Mountain, and in southeastern Idaho and southwestern Wyoming. In northwestern Colorado, the underlying Carmel formation wedges out, and the Entrada has been included with the Navajo sandstone in the Nugget formation. The Entrada is also recognized on the north side of the Uinta Mountains, where 201 feet of the section was measured at Manila, Utah (Thomas and Krueger, 1946, p. 1292). In central Wyoming, equivalents of the Entrada are probably present in the "lower Sundance."

Conditions of deposition.—As mapped, the Entrada sandstone consists of two lithologic facies—a fine-grained, red, silty sandstone and a fine- to medium-grained, light-gray "clean" sandstone. On Whiterocks River and in Steinaker Draw, the red and gray facies are interbedded, but east of Steinaker Draw the formation is almost exclusively massive, fine- to medium-grained light-gray sandstone. Usually, the red, silty sandstone is more thinly bedded and resembles the typical Entrada of the San Rafael Swell (which is believed to have been water laid). The massive light-gray sandstone, on the other hand, is well sorted in two general sizes and has a faint trace of "tangential" crossbedding (characteristics which are generally ascribed to eolian deposition). However, the faintness of the cross-bedding on weathered surfaces suggests that some other agency, probably water, reworked the sand and destroyed some of the "tangential" bedding.

It is known that the Entrada sandstone grades westward into the Preuss sandstone, which is thought to be a great deltaic deposit which was shed from a land mass in eastern Nevada and western Utah (Neely, 1937, p. 752). The red facies of the Entrada probably was derived from this source. The average and maximum grain size of the light-gray, massive facies is so much greater than that found in the Preuss sandstone that another source, probably to the east or southeast, is indicated. Erosion of sandstone or quartzite of Mesozoic, Paleozoic, or even Proterozoic age in western Colorado probably contributed debris to the massive, light-colored facies of the Entrada. An eastern or southeastern source for this part of the Entrada closely agrees with the reasoning of Dane (1935, p. 102) that a northern source is indicated for the Entrada in the Salt Valley anticlinal area.

CURTIS FORMATION

Name.—The Curtis formation is named for Curtis Point in the northeastern part of the San Rafael Swell (Gilluly and Reeside, 1928, p. 78). It has been traced from the type section to a short distance east of the Green River, where it grades into lithology which is typical of the Summerville formation (Baker, Dane, and Reeside, 1936, p. 8, 25). As in the case of other formations in the region south of the Uinta Basin, the Curtis formation cannot be traced laterally into the Uinta River-Brush Creek area and its identification depends upon its stratigraphic position, lithology, and included fossils. Prior to 1936 the Curtis was wrongly identified as the "Twin Creek" formation in the eastern Uinta Mountains.

Lithology and thickness.—In this area, the Curtis formation is divisible into two members. The lower member consists of glauconitic sandstone of medium to coarse grain size; the upper member is soft, greenish-gray shale with thin intercalations of fine-grained, calcareous sandstone and sandy limestone, and hard, oölitic, sandy limestone at the top. The lower member is thin bedded and some beds are highly crossbedded. Concentrations of glauconite are so high that the sandstone is greenish gray. Glauconite also imparts a greenish-gray color to the upper shale member. The intercalated calcareous sandstone and sandy limestone occur as thin beds which weather into rough tan slabs. The calcareous oölites in the limestone beds have well-rounded nuclei of zircon, tourmaline, and apatite; these highly resistant minerals could not have been well rounded in a single sedimentary cycle.

The Curtis formation thickens from 150 feet on Whiterocks River and 144 feet at Steinaker Draw to 270 feet at Split Mountain and

263 feet between Brush Creek and Little Brush Creek. Although the shale and upper sandy limestone member thickens slightly from west to east, the principal variation in thickness is in the development of the lower glauconitic sandstone member which is 1.5 feet thick on Steinaker Draw, 37 feet thick on Whiterocks River, 91 feet thick between Brush Creek and Little Brush Creek, and 110 feet thick at Split Mountain.

The following sections, measured by planetable and alidade, are representative:

Section of the Curtis formation on the west side of Whiterocks River NW¼ sec. 19, T. 2 N., R. 1 E.

[Measured by D. M. Kinney, J. F. Rominger, P. Verastegui M., and R. S. Brown]

	Feet
Morrison formation:	
Shale and siltstone, light-gray to reddish variegated.	
Curtis formation:	
Upper member:	
Limestone, oölitic, argillaceous, gray, crossbedded, fossiliferous, glauconitic, with interbedded shale, dark-gray	79
Shale, dark gray-green	26
Limestone, gray, conglomeratic(?), fossiliferous	1
Shale, dark-gray	7
Lower member:	
Sandstone, light greenish-gray, fine- to medium-grained, crossbedded, glauconitic	37
	150
Entrada sandstone:	
Sandstone, moderate reddish-brown, fine-grained.	

Section of the Curtis formation on the west side of Steinaker Draw SW¼ sec. 26, T. 3 S., R. 21 E., Salt Lake Base and Meridian

[Measured by D. M. Kinney, J. F. Rominger, P. Verastegui M., and R. S. Brown]

	Feet
Morrison formation:	
Sandstone, light-gray, fine-grained and shale, light-gray, interbedded.	
Curtis formation:	
Upper member:	
Limestone, gray to greenish-gray, oölitic, slabby, glauconitic; shale, light-gray; and sandstone, light-gray, fine-grained, interbedded. Basil 2 feet of oölitic limestone forms ledge at the top of the ridge	40
Shale, dark-gray, fissile, with streaks of fossiliferous, oölitic limestone	49
Sandstone, light-gray, fine-grained, slightly calcareous, thin-bedded	30
Sandstone, light-gray, crossbedded, with pink and gray grains	17
Shale, gray, fissile	8
Lower member:	
Sandstone, light-gray, conglomeratic, fossiliferous (*Ostrea*), with pebbles of quartz and shale	1.5
	145.5
Entrada sandstone:	
Sandstone, red, fine-grained.	

Section of the Curtis formation south of road between Brush Creek and Little Brush Creek, SW¼ sec. 2, T. 3 S., R. 22 E.

[Measured by D. M. Kinney and J. F. Rominger]

	Feet
Morrison formation:	
Sandstone, fine- to medium-grained, white, friable, with semi-rounded grains and fragments of fossil wood.	
Curtis formation:	
Upper member:	
Limestone, oölitic, tan, thin-bedded, with partings of shale, dark greenish-gray	17
Shale, dark greenish-gray, fissile, with 3 beds 0.5 to 0.7 foot thick of sandstone, oölitic, tan, fine-grained, crossbedded	67
Sandstone, glauconitic, tan, fine-grained, poorly crossbedded, fossiliferous. Bed thins to 1 foot of limestone, tan, oölitic, glauconitic in 600 feet west	7
Shale, dark-gray, fissile	38
Limestone, tan, very fossiliferous (*Belemnites densus*)	1
Shale, dark gray-green, fissile	42
Lower member:	
Sandstone, gray, glauconitic, fine- to medium-grained; forms bench	50
Sandstone, gray, glauconitic, fine- to medium-grained, poorly sorted, calcareous, with pebbles to ½ inch in diameter, streaks of reddish shale, and partings of shale, dark greenish-gray. Pebbles of green and red chert, and red and green shale are common	41
	263
Entrada sandstone:	
Sandstone, white, fine-grained, crossbedded.	

Distribution and topographic expression.—The Curtis formation is present on Whiterocks River, in the faulted area between Mosby Mountain and Little Mountain, on the north side of Little Mountain, in Coal Mine Draw, and eastward from Ashley Creek to Diamond Mountain. It is also present on the flanks of Split Mountain anticline and Section Ridge anticline, east of Jensen.

The Curtis generally forms a strike ridge with the upper, resistant, sandy, oölitic limestone beds forming a dip slope. The soft, greenish-gray shale and thin interbedded limestone of the upper member crop out on the slopes beneath the ridge-forming beds. At places, the lower thin-bedded, well-cemented, glauconitic sandstone member forms a ledge which protects the underlying massive sandstone of the Entrada sandstone.

Fossils and age.—No extensive paleontologic collections were made from the Curtis formation in the mapped area. However, collections made by J. B. Reeside (1925, p. 43–44) from the "Twin Creek formation of Schultz" in Island Park on the north side of Split Mountain and a few miles east of the mapped area, and from the same unit near the Carnegie Museum Dinosaur Quarry on the south flank of Split

Mountain within the Dinosaur National Monument, are clearly from the Curtis formation. The two collections as identified by Mr. Reeside include:

Collection from lower 50 feet of the upper member of the Curtis formation (above the basal glauconitic sandstone) in Island Park 1 mile west of the Ruple Ranch

Cidaris? sp.
bryozoan
Parallelodon? n. sp.
Pinna sp.
Eumicrotis curta (Hall)
Ostrea strigilecula White
Cardinia? n. sp.
Trigonia quadrangularis Hall and Whitfield
Camptonectes platessiformis White
Modiola pertenuis Meek and Hayden
Pleuromya newtoni Whitfield
Astarte packardi White
Tancredia? inornata Meek and Hayden
Dosinia jurassica Whitfield
Quenstedticeras? hoveyi Reeside
Cardioceras cf. *C. cordiforme* (Meek and Hayden)
Cardioceras sp.
Belemnites densus Meek and Hayden

Collection from 1 foot limestone bed 27 feet above the top of the lower glauconitic sandstone member of the Curtis formation on south flank of Split Mountain anticline at Carnegie Museum Dinosaur Quarry

Eumicrotis curta (Hall)
Ostrea strigilecula White
Camptonectes platessiformis White
Astarte packardi White
Tancredia? inornata Meek and Hayden
Tancredia sp.
Dosinia jurassica Whitfield?
Cardioceras russelli Reeside
Cardioceras hyatti Reeside
Cardioceras cordiforme Meek and Hayden
Cardioceras aff. *C. wyomingense* Reeside
Cardioceras sp.

These faunas are characterized by the cardioceratid ammonites which were dominant during the Argovian stage of the European time scale. The presence of a questionable *Quenstedticeras hoveyi* Reeside suggests upper Divesian in the European scale. The Argovian and Divesian stages are middle Upper Jurassic.

Stratigraphic relations and correlation.—The lower boundary of the Curtis formation is irregular and shows evidence of erosion prior to the deposition of the lower, pebbly, glauconitic sandstone member. Fragments of shale, and pebbles of greenish and reddish chert in the basal beds, suggest erosion of earlier sediments in an adjacent area. Because the underlying Entrada sandstone is massive, no measurement can be made of the amount of erosion prior to the deposition of the lower sandstone unit of the Curtis formation. However, it seems probable that at least some of the Entrada sandstone was reworked and incorporated in the Curtis because the upper boundary of the Entrada sandstone is sharply defined. The tan-weathering, oölitic, and glauconitic sandy limestone beds at the top of the Curtis formation are abruptly succeeded by light-gray sandstone that is the base of the Morrison formation. There is no clear evidence of a hiatus, however, and the difference in lithology may reflect merely the change from marine to fluvial deposition.

The beds here referred to the Curtis formation are believed to be equivalent in age to the Curtis and to at least a part of the Summerville formation of the San Rafael Swell. This correlation is substantiated, in part, by the paleontological determinations of Imlay (1945, p. 1021), who shows the Summerville to be equivalent to the zone of *Cardioceras*, and to the determinations of Reeside, who has identified numerous species of *Cardioceras* from the Curtis in the eastern Uinta Mountains. The Curtis, as represented in this area, is equivalent to the Stump sandstone of southeastern Idaho and southwestern Wyoming, and to at least a part of the "upper Sundance" of central and eastern Wyoming. It has been traced eastward in well logs and surface sections to the vicinity of Meeker, Craig, and Dotsero in northwestern Colorado (Thomas, McCann, and Raman, 1945; Baker, Dane, and Reeside, 1936, p. 28), where it is still characterized by glauconite.

Conditions of deposition.—The Curtis formation is unquestionably of marine origin because of its invertebrate fauna and abundant glauconite (Takahashi, 1939, p. 503–512). The lower, medium- to coarse-grained glauconitic sandstone member is poorly sorted, and shows evidence of current action in the crossbedding. It probably was formed in shallow water under near-shore conditions. It carries the same minor mineral constituents as the Shinarump conglomerate, Navajo sandstone, and Entrada sandstone, which are believed to have come from the east and southeast. The upper member of the Curtis was formed in deeper water and it was seldom that the currents were strong enough to bring sand grains and oölites into the area, or to develop oölites *in situ*. The upper calcareous sandstone beds of the formation have abundant calcareous oölites which suggest shallow near-shore water. Grains of the resistant minerals tourmaline, zircon, and rutile, which make up the nuclei of the oölites, must have been derived from earlier sandstone formations, because it would take more than a single cycle of erosion to reach such well-rounded shapes. The upper part of the Curtis was probably transitional to the fluvial deposits of the overlying Morrison formation.

UPPER JURASSIC SERIES

MORRISON FORMATION

Name.—The Morrison formation was named for exposures near the town of Morrison (Cross, 1894, p. 2), in the foothills of the Front Range southwest of Denver, Colo. It has been recognized over an area of 350,000 square miles (Stokes, 1944, p. 953) in the western interior where it has been applied to rocks of somewhat heterogeneous lithology but similar stratigraphic position. At present, the Morrison formation includes all continental Jurassic sediments younger than the San Rafael group in the Rocky Mountain region (Baker, Dane, and Reeside, 1936, p. 31). The name was first used in the eastern Uinta Mountains by Sears (1924, p. 279–280, 285) while working in northwestern Colorado.

Distribution.—The Morrison formation is present in the faulted area between Mosby Mountain and Little Mountain, in a fault segment in Coal Mine Draw on the east side of Little Mountain, and continuously from east of Ashley Creek to Diamond Mountain. It is also present in the area shown on plate 1, north and west of Split Mountain anticline and on the westward plunging Section Ridge anticline. The best exposures are west of the Mosby Mountain road, at the head of Steinaker Draw (fig. 10), between Brush Creek and Little Brush Creek, on the west side of Diamond Mountain, and on the Split Mountain and Section Ridge anticlines.

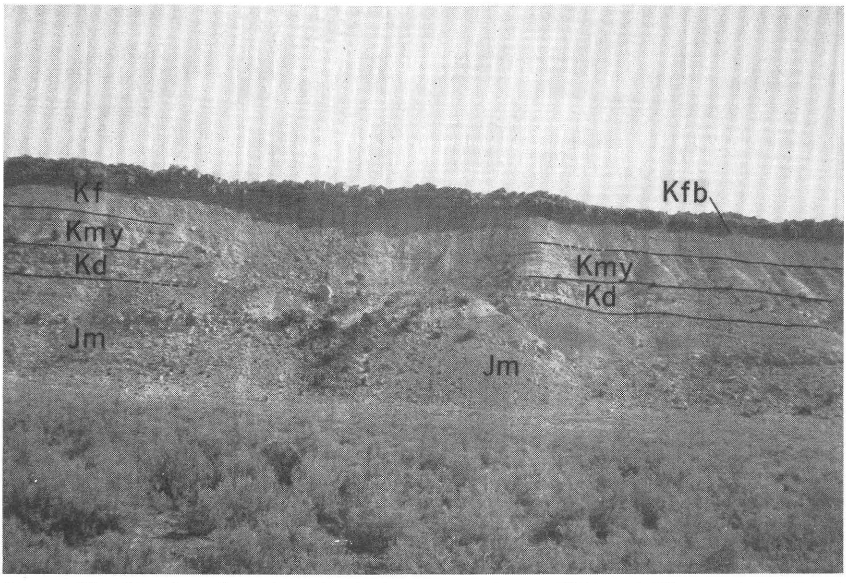

FIGURE 10.—Morrison formation (*Jm*), Dakota sandstone (*Kd*), and Mowry shale (*Kmy*) and Frontier sandstone (*Kf*) members of the Mancos shale along the east of Steinaker Draw (*Kfb*), base of massive sandstone.

Lithology and topographic expression.—In the area under study, the Morrison formation consists of light-gray, very fine-grained sandstone, variegated mudstone and shale, fine- to medium-grained sandstone, and occasional thin lenticular beds of coarse pebbly to conglomeratic sandstone. The mudstone and shale beds include calcareous, brown-weathering concretionary zones. The formation is heterogeneous, with no single unit being present in all measured sections. It ranges in thickness from 825 to 925 feet, and averages about 850 feet. In the Steinaker Draw and Little Brush Creek sections, the lower part is more sandy and the upper part includes more variegated mudstone and shale, but this division cannot be recognized in the Split Mountain and Mosby Creek sections. The sandstones in the Morrison are generally very light gray to greenish-gray, even in beds long subjected to weathering. The conglomeratic beds commonly weather to shades of dark tan, and consist of pebbles of well-rounded, dark-red and black chert in a matrix of tan quartz sand.

The Morrison formation is a soft, easily eroded formation that generally forms part of the strike valleys lying between the dip slope formed by the underlying Curtis formation and the escarpment formed by the Frontier sandstone member of the Mancos shale. Throughout most of the area, only the upper 200 to 300 feet of the Morrison are well exposed on the slope beneath the resistant Frontier sandstone member, and only under exceptional conditions is the entire formation visible.

The following sections indicate the lithology and the variability of the formation in the eastern Uinta Mountains:

Section of the Morrison formation on the west side of the Mosby Mountain road, sec. 18, T. 3 S., R. 19 E.

[Measured by P. Verastegui M., R. S. Brown, and D. M. Kinney]

Dakota sandstone:	
Sandstone, light-gray, buff-weathering, medium- to coarse-grained, in part conglomeratic, crossbedded, massive, with pebbles of black chert common.	
Morrison formation:	*Feet*
Shale and mudstone, red and gray, variegated	601
Sandstone, conglomeratic, light-brown, cross-laminated, with subangular to rounded pebbles as large as ½ inch in diameter	5
Sandstone, light-gray, fine- to medium-grained crossbedded	16
Shale and mudstone, light-gray to red variegated	270
	892
Curtis formation:	
Limestone, oölitic, argillaceous, gray, tan-weathering crossbedded, fossiliferous, glauconitic, interbedded with dark-gray shale.	

Section of the Morrison formation in Steinaker Draw, SW¼ sec. 26, T. 3 S., R. 21 E. Detailed lithology of lower part of Morrison formation from SW¼ sec. 7, T. 3 S., R. 22 E.

[Measured by D. M. Kinney, J. F. Rominger, R. S. Brown, and P. Verastegui M.]

	Feet
Dakota sandstone:	
Shale, gray, interbedded with light-gray sandstone.	
Morrison formation:	
Mudstone, light-gray, plastic	61
Shale, variegated in pastel shades	39
Sandstone, light-gray, fine-grained, with slightly calcareous concretions	10
Shale, light-gray, with calcareous concretions	67
Sandstone, light-gray to white, lenticular, medium-grained, friable	10
Shale, variegated	15
Sandstone, gray to light-gray	1
Mudstone, variegated	30
Sandstone, light-gray, conglomeratic, lenticular	12
Mudstone, light-gray, sandy	15
Sandstone, light-gray, very fine grained	63
Sandstone, brown, calcareous	1
Mudstone, variegated	65
Sandstone, gray, fine-grained	86
Mudstone and shale, gray	45
Sandstone, fine-grained, red	44
Sandstone, pebbly, crossbedded	3
Sandstone, red, fine-grained	74
Sandstone, pebbly	2
Shale, gray	7
Mudstone, gray, with thin beds of light-gray limestone	181
	831
Curtis formation:	
Limestone, gray to greenish-gray, oölitic, slabby, glauconitic, interbedded with dark-gray shale and light-gray, fine-grained sandstone.	

Section of the Morrison formation between Brush Creek and Little Brush Creek, SE¼ sec. 2, T. 3 S., R. 22 E., Salt Lake Base and Meridian

[Measured by D. M. Kinney and J. F. Rominger]

	Feet
Dakota sandstone:	
Sandstone, light-gray, coarse-grained, with angular grains and fragments of fossil wood.	
Morrison formation:	
Sandstone, white to gray, fine-grained, with angular grains	138
Sandstone, white, fine- to medium-grained, calcareous with angular grains	1
Sandstone, white to gray, fine-grained with angular grains	23
Sandstone, white, fine-grained, with angular grains	2
Sandstone, red and gray, fine-grained, soft, and red and purple shale, with brown calcareous concretions	156
Sandstone, white, fine- to medium-grained, calcareous	3
Sandstone, red and gray, fine-grained, and red and purple shale with brown calcareous concretions as large as 2 feet in diameter	74
Shale, gray, plastic, with brown calcite concretions in basal 10 feet	73

Section of the Morrison formation between Brush Creek and Little Brush Creek SE¼ sec. 2, T. 3 S., R. 22 E., Salt Lake Base and Meridian—Continued

	Feet
Morrison formation—Continued	
Sandstone, white, fine-grained, with angular grains	3
Claystone, gray, plastic, with gypsum and thin beds of brown calcite	66
Shale, light-red, with red calcareous concretions	12
Sandstone, white, fine- to medium-grained	39
Sandstone, brown, coarse-grained, crossbedded, with pebbles of black and red chert as large as ½ inch in diameter	1
Shale, grey plastic, weathers with a hard crust, gypsiferous(?)	20
Shale, red and greenish-gray, with calcareous concretions in zone 5 feet from top	32
Sandstone, white, fine-grained, massive, friable	26
Sandstone, pebbly, coarse-grained, calcareous, with semi-rounded to angular grains	2
Sandstone, white, fine-grained, massive, friable	8
Sandstone, tan, coarse-grained, with pebbles of black, yellow and red chert	1
Sandstone, white, fine- to medium-grained, massive, friable	37
Sandstone, tan, coarse-grained, with pebbles of red and black chert. Bed swells to 10 feet in a distance of 100 feet to the west	2
Sandstone, greenish-gray, fine- to medium-grained	38
Sandstone, white, fine- to medium-grained, with few beds of white, coarse-grained sandstone, with rounded grains	87
Shale, red	5
Sandstone, white, fine- to medium-grained, friable, with semi-rounded grains, and fragments of fossil wood	77
	926
Curtis formation:	
Limestone, oölitic, tan, thin-bedded, with partings of dark greenish-gray shale.	

Fossils and age.—A very complete and well-preserved dinosaurian vertebrate fauna has been recovered in a sandstone and conglomerate lens in the upper part of the Morrison formation on the south flank of Split Mountain within the Dinosaur National Monument. The conglomerate lens that carries the dinosaurian remains also includes a thick-shelled, fresh-water bivalve which was identified by Dr. John B. Reeside, Jr., as *Unio* aff. *U. felchi* White, and fragments of fossil wood. Elsewhere in the area, only small fragments of bone and pieces of fossil wood have been recognized.

The age of the Morrison formation has been the source of much speculation and considerable difference of opinion, because no comparable fauna is represented in the European section of the Jurassic. However, an evaluation of all the vertebrate evidence (Simpson, 1926, p. 215) points to a late Jurassic age, probably Kimmeridgian or Portlandian. Stokes (1944, p. 988) has emphasized the possibility that at least some of the rocks included in the upper part of the Morrison formation in the Colorado Plateau region may be Early Cretaceous in age. In the absence of definite faunal evidence, however, it seems best to consider all of the Morrison formation in the eastern Uinta Mountains to be of Late Jurassic age.

Stratigraphic relations and correlation.—The basal boundary of the Morrison formation is sharp. No erosion of the underlying Curtis formation is evident before the deposition of the basal sediments of the Morrison, although the possibility exists that poorly consolidated and easily eroded Curtis strata may have been stripped to the resistant oölitic limestone bed everywhere over the area before the deposition of the first continental sediments. Inasmuch as the upper beds of the Curtis probably were deposited in very shallow marine waters, it is believed that the Morrison formation is conformable upon the Curtis formation with fluvial deposition resting on the last sediments deposited in the retreating Sundance sea.

The Morrison formation is believed to be overlain unconformably by the Dakota sandstone, although the precise contact generally is covered by blocks of massive Dakota sandstone slumped far below their normal stratigraphic position. The unconformity may represent most of Early Cretaceous time in the places where the overlying Dakota is a single sandstone bed, but where the Dakota is tripartite, the shale and lower sandstone may be Early Cretaceous in age and the unconformity may be of lesser importance.

The dinosaurian fauna within the Dinosaur National Monument indicates a fairly close correlation of the Morrison formation in the eastern Uinta Mountains with the type Morrison along the Front Range of the Rocky Mountains, with the Morrison formation at Como Bluff, Wyo., and in the San Rafael Swell region (Stokes, 1944, p. 965). The Morrison formation has been recognized (Baker, 1947) in the Wasatch Mountains, and its equivalents are recognized in the upper part of the Beckwith formation of southwestern Wyoming, and in the Ephraim conglomerate and perhaps other formations of the thick Gannett group of southeastern Idaho. East and south of the Uinta Mountains, the Morrison formation has been recognized by its characteristic heterogeneous and variegated lithology and by its stratigraphic position.

Conditions of deposition.—The Morrison formation has long been considered to be of fluvial origin and to have been deposited on an ancient flood plain. The conglomerate lenses represent old river-channel deposits, and the finer grained sandstones and mudstones represent the sediments deposited by the aggrading streams in areas of lower current velocity or in temporary lakes. The measured sections show no consistent increase in thickness or in coarseness of sands, nor in percentage of coarse- to fine-grained sediments, which would suggest a source area. Stokes (1944, p. 975) has suggested that the Morrison formation was deposited on a plain that sloped gently toward the northeast, and the change to a sandstone facies in Arizona, reported by Baker, Dane, and Reeside (1936, fig. 14, p. 51), suggest that such an interpretation is logical. The inability to see the conglomerate lenses in the Morrison in north-south section, because of the east-west strike in the eastern Uinta Mountains and the high dips, makes the interpretation of the cross-laminations in conglomerate lenses very difficult. However, in the Dinosaur Monument area the streams must have been flowing eastward, because Gilmore (1932, p. 3) has shown that parts of some of the dinosaur skeletons were shifted in that direction before burial. It is possible, of course, that the stream was meandering, and that its general course was to the northeast or southeast.

CRETACEOUS SYSTEM

LOWER(?) AND UPPER CRETACEOUS SERIES

DAKOTA SANDSTONE

Definition.—Over the northern Great Plains and westward into the Rocky Mountain region, the Cretaceous system commonly begins with a nonmarine basal sandstone. It was named the "Dakota sandstone" (Meek and Hayden, 1862, p. 419–420) in northeastern Nebraska, where fossil plants in the upper sandstone beds indicate early Late Cretaceous age. In the type locality, lower beds of sandstone are probably of Early Cretaceous age (Reeside, J. B., Jr., personal communication, January 1948). In the Colorado Plateau region, the initial Cretaceous sandstone is referred to the Dakota sandstone, although it cannot be traced laterally from the type area and its age is generally unknown. It may be Late Cretaceous, or both Late and Early Cretaceous.

Lithology and thickness.—In the area under study, the Dakota sandstone may consist of a single light-gray to tan, medium- to coarse-grained sandstone, a sandstone underlain by brownish-gray shale and interbedded thin sandstone, or a sandstone underlain by brown to greenish-gray shale and a thin, fine-grained, light-gray, basal sandstone. The main sandstone, characteristically, is crossbedded, friable, and noncalcareous. It is composed of angular sand grains and well-rounded chert pebbles. The pebbles consist of dark-gray to black, and reddish-brown chert, and are more abundant near the base of the unit. The brownish-gray shale is interbedded with yellow, platy sandstone or greenish sandstone. It contains thin lignitic layers near Steinaker Draw. The lower sandstone is light gray to tan, very fine grained and platy. Where the lower sandstone is not present and the brownish-gray shale rests on the Morrison formation, the color change from light gray to dark brownish-gray marks the boundary.

The Dakota sandstone ranges in thickness from 50 feet to 135 feet in the measured sections, and probably reaches a thickness of 200 feet at certain localities in the mapped area. There seems to be no systematic change in thickness and lithology across the area. Individual beds pinch and swell along the strike and may lens out entirely in a few hundred feet. The variation in thickness and lithologic character is well displayed along the north- and west-facing escarpment that is topped by the Frontier sandstone member of the Mancos shale, which forms the south and east sides of Steinaker Draw.

The variation in thickness and lithology of the Dakota sandstone is given in the following representative sections:

Section of the Dakota sandstone southwest of Mosby Creek SW¼ sec. 13, T. 3 S., R. 18 W. (unsurveyed)

[Measured by P. Verastegui M., R. S. Brown, and D. M. Kinney]

	Feet
Mowry shale member of the Mancos shale:	
Shale, dark-gray, weathering silver-gray, fissile.	
Dakota sandstone:	
Sandstone, tan, medium-grained, crossbedded	61
Sandstone, light-gray, weathering tan to buff, medium- to coarse-grained, partly conglomeratic, crossbedded, massive with pebbles of black chert	34
	95
Morrison formation:	
Shale, red variegated with gray.	

Section of the Dakota sandstone in Steinaker Draw east of Utah State Highway 44, SE¼ sec. 25, T. 3 S., R. 21 E.

[Measured by D. M. Kinney, J. F. Rominger, R. S. Brown, and P. Verastegui M.]

	Feet
Mowry shale member of the Mancos shale:	
Shale, dark-gray.	
Dakota sandstone:	
Sandstone, light-tan, medium- to coarse-grained, with angular grains	33
Shale, gray and interbedded light-gray, thin-bedded, fine- to medium-grained sandstone	102
	135
Morrison formation:	
Claystone, light-gray, plastic when wet.	

Section of the Dakota sandstone on west side of Little Brush Creek SW¼ sec. 1, T. 3 S., R. 22 W.

[Measured by D. M. Kinney and J. F. Rominger]

	Feet
Mowry shale member of the Mancos shale:	
Shale, dark-gray, weathering light-gray, platy, with fish scales and a few thin beds of tan, fine- to medium-grained calcareous sandstone.	
Dakota sandstone:	
Sandstone, light-gray, coarse-grained, with angular grains, and fragments of fossil wood	50
Morrison formation:	
Sandstone, white to gray, fine-grained, with angular grains.	

Distribution and topographic expression.—The Dakota sandstone is present from south of Mosby Mountain eastward to Little Mountain, in Coal Mine Draw, east of Little Mountain, and continuously from Ashley Creek and Steinaker Draw (fig. 10) eastward to Diamond Mountain. It is also present on the flanks of Split Mountain anticline and on Section Ridge anticline.

Throughout the Colorado Plateau region, the Dakota sandstone commonly forms hogbacks and prominent outcrops. In the eastern Uinta Mountains, however, it is not well cemented, and only the more massive, coarse-grained sandstone is well exposed. The upper sandstone generally makes the better outcrop.

Fossils and age.—No fossils have been found in the Dakota sandstone in the area studied, but a collection of marine fossils found west of Delta, Colo., 130 miles southeast of this area, contains an *Acanthoceras* fauna of Cenomanian or early Late Cretaceous age (Reeside, 1927, p. 453–454). Characteristic leaves of the Dakota were collected by Richardson (1909, p. 14) near Elgin and Woodside, Utah, approximately 110 miles to the southeast of Vernal. In the eastern Uinta Mountains, the Dakota sandstone is believed to be nonmarine. The basal sandstone and overlying brownish shale may be of Early Cretaceous age, but the upper sandstone appears to be the initial sedimentation of the Upper Cretaceous series in the area.

Stratigraphic relations and correlations.—The Dakota sandstone is believed to rest disconformably upon the Morrison formation. The absence of the lower sandstone and brownish-gray shale at some localities suggests erosion prior to the deposition of the upper sandstone. The upper boundary of the Dakota is sharp, with no transitional beds into the Mowry shale member of the Mancos shale.

The Dakota sandstone probably correlates with the rocks grouped under the same name in northwestern Colorado (Thomas, McCann, and Raman, 1945) and in the Book Cliffs area (Baker, 1946, p. 90–91; Dane, 1935, p. 113–117; McKnight, 1940, p. 109–113; Erdmann, 1934, p. 27–28; Fisher, 1936, p. 10–11) south of the Uinta Basin. Equivalents of it are probably present in the upper part of the Beckwith formation (Reeside, 1925, p. 38) on the north flank of the Uinta Mountains. The Dakota is believed to be of continental (probably fluvial) origin because of the lenticularity of the beds, the crossbedding, and the associated carbonaceous matter.

UPPER CRETACEOUS SERIES

MANCOS SHALE

Name and definition.—The Mancos shale was named by Cross (1899, p. 4) for exposures in the Mancos Valley, in southwestern Colorado. The term was first used (Fenneman and Gale, 1906, p. 22) in the Yampa coalfield, northwestern Colorado, for the dark, marine shale of Late Cretaceous age that lithologically resembles the type Mancos shale and occupies the same stratigraphic position above the Dakota sandstone and beneath the sandstones of the Mesaverde formation. It was later used by Gale (1910, p. 61) for beds of similar lithology in northeastern Utah. The dark marine shale had previously been called the Sulphur Creek group by Powell (1876, p. 50), but that term has been shown to be unacceptable as a stratigraphic name (Veatch, 1907, p. 70) in southwestern Wyoming. Gale (1910, p. 61) recognized a threefold division of the Mancos shale in the Ashley Creek-Brush Creek area, a lower, dark-gray, fissile shale (which characteristically weathers very light-gray), a sandy shale and fine- to medium-grained sandstone, and an upper clay shale almost 5,000 feet thick.

The Upper Cretaceous rocks, equivalent in age to the Mancos shale, are much thicker in southwestern Wyoming where Knight (1902, p. 721–722) named the sandy shale and sandstone unit the "Frontier formation" and the upper shale the "Hilliard formation," and Veatch (1902, p. 64) named the lower shale the "Aspen formation." Schultz (1920, p. 71–75) used this terminology in the Rock Springs uplift in south-central Wyoming and shows in cross section (Schultz, 1920, p. 37) the Aspen shale, the Frontier sandstone, and the Hilliard shale in the Uinta Mountain uplift to the south of Rock Springs. Subsequently, Reeside (1925, p. 44) used the terminology of southwestern Wyoming for the Upper Cretaceous rocks along the Green River and south of Split Mountain.

In this report, Mancos shale is retained for the entire thickness of the strata that was named by Gale (1910) in his report on the coalfields of northwestern Colorado and northeastern Utah. On the suggestion of W. W. Rubey, the term "Mowry" is used in preference to "Aspen" for the lower, dark-gray, fissile shale member of the Mancos, because the lithology and thickness of the unit in the Mosby Creek-Brush Creek area more closely resembles the type Mowry shale of the Bighorn Mountains than the thick, highly clastic Aspen shale of southwestern Wyoming. For the sandy shale and the fine- to medium-grained sandstone that overlies the Mowry member, the name "Frontier" is retained as a member of the Mancos shale, although it is recognized that the unit may not be strictly equivalent to the typical Frontier formation of southwestern Wyoming. The thick, upper, gray shale unit is termed the "upper member of the Mancos shale" in preference to continuing the use of Hilliard shale in the eastern Uinta Mountains.

MOWRY SHALE MEMBER

Name and definition.—The Mowry shale, named for exposures on the east side of the Bighorn Mountains (Darton, 1904, p. 399–400), is recognized over central and eastern Wyoming, western South Dakota, and Montana. It is commonly a light-gray weathering, siliceous shale with abundant fish scales and interbedded thin sand stones. Gale (1910, p. 61) recognized the probable equivalence of the light-gray weathering, siliceous shale unit in northeastern Utah to the Mowry, but he did not subdivide the thick Mancos shale into members.

Lithology and thickness.—The Mowry shale member of the Mancos shale is a dark-gray, hard, and fissile shale (fig. 11), weathering into hard silvery gray flakes. These chips are so resistant that the formation can be traced on soil-covered slopes by pieces of shale in the weathered mantle. The Mowry is characterized by abundant scales of teleost fish; these scales are commonly used for identification purposes in the field. In exposures along Steinaker Draw, the lower part of the Mowry is less platy and resembles the strata known in Wyoming as the Thermopolis shale.

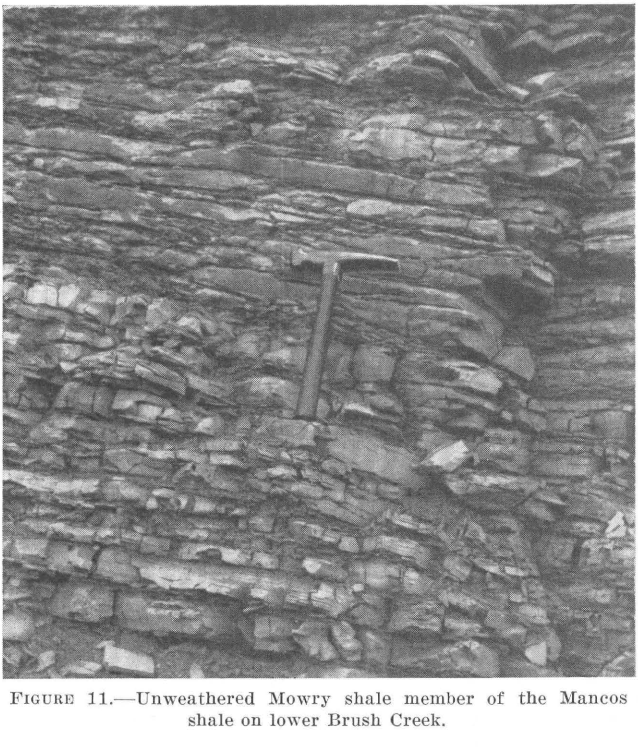

FIGURE 11.—Unweathered Mowry shale member of the Mancos shale on lower Brush Creek.

The Mowry shale thins from 123 feet in the Deep Creek area to 31 and 32 feet, respectively, on Little Brush Creek and in the section that was measured south of U. S. Highway 40. This thinning is not uniform in an easterly direction, because Thomas, McCann, and Raman (1945) report 95 feet of Mowry shale on the south flank of Split Mountain, midway between the thinner sections.

Detailed lithology and thickness of representative sections of the Mowry shale member are as follows:

Section of the Mowry shale member of the Mancos shale northwest of the coal mines, SW¼ sec. 13, T. 3 S., R. 18 E. (unsectionized)

[Measured by D. M. Kinney, J. F. Rominger, P. Verastegui M., and R. S. Brown]

	Feet
Mancos shale:	
Frontier sandstone member:	
Shale, light-gray, sandy, drab-weathering.	
Mowry shale member:	
Shale, dark-gray, silver-gray weathering, fissile, with fish scales common	123
Dakota sandstone:	
Sandstone, tan, medium-grained, crossbedded.	

Section of the Mowry shale member of the Mancos shale in Steinaker Draw, SE¼ sec. 26, T. 3 S., R. 21 E.

[Measured by D. M. Kinney, J. F. Rominger, R. S. Brown, and P. Verastegui M.]

	Feet
Mancos shale:	
Frontier sandstone member:	
Shale, light-gray, sandy, tan-weathering.	
Mowry shale member:	
Shale, dark-gray, silver-gray weathering, siliceous, fissile, with abundant fish scales	58
Shale, dark-gray	32
	90
Dakota sandstone:	
Sandstone, light-tan, medium- to coarse-grained, with angular grains.	

Section of Mowry shale member of the Mancos shale on west side of Little Brush Creek, SE¼ sec. 1, T. 3 S., R. 22 E.

[Measured by F. T. McCann and N. D. Raman]

	Feet
Mancos shale:	
Frontier sandstone member:	
Shale, gray, sandy, tan-weathering.	
Mowry shale member:	
Shale, dark-gray, silver-gray weathering, fissile, siliceous, with fish scales common	31
Dakota sandstone:	
Sandstone, light-gray, coarse-grained, with angular grains and fragments of fossil wood.	

Section of the Mowry shale member of the Mancos shale in Orchard Draw, Dinosaur National Monument, SW¼ sec. 27, T. 4 S., R. 23 E.

[Measured by F. T. McCann and N. D. Ramon]

	Feet
Mancos shale:	
Frontier sandstone member:	
Shale, dark-gray to black, blocky, fissile, interbedded with numerous thin (½ inch to 6 inch) sandstones.	
Mowry shale member:	
Shale, black, siliceous, resistant, usually fissile, light-gray weathing; forms ridge	59
Shale, dark-gray to dark-brown, clayey; forms slight valley	36
	95

Section of the Mowry shale member of the Mancos shale in Orchard Draw, Dinosaur National Monument, SW¼ sec. 27, T. 4 S., R. 23 E.—Continued

Dakota sandstone:

Sandstone, gray, friable, noncalcareous, massive, with minor black fissile shale at top of bed. Usually fine- to medium-grained but may be coarse-grained and conglomeratic. Minor black and gray chert. Limonite concentrated largely along bedding, cross-laminations, and joints. Intricate network of fine quartzitic veins, which stand out on weathered surface as tiny ridges.

Section of the Mowry shale member of the Mancos shale south of U. S. Highway 40 and north of Spring Creek, NW¼ sec. 7, T. 6 S., R. 24 W.

[Measured by D. M. Kinney and J. F. Rominger]

Mancos shale:

Frontier sandstone member:

Shale, gray, clayey, with thin interbeds of tan, fine-grained calcareous sandstone. Sandstone prominent in upper 10 feet.

	Feet
Mowry shale member:	
Shale, dark-gray, weathering light-gray, platy, with a few thin (0.1 to 0.3 inch) beds of tan, fine- to medium-grained, calcareous sandstone with fish scales	32

Dakota sandstone:

Sandstone, tan, medium- to coarse-grained, with well-rounded quartz grains and a few grains of gray chert.

Distribution.—The Mowry shale member is present in the coal-mine area of Deep Creek and eastward to Little Mountain, and it appears again in Coal Mine Draw on the east side of Little Mountain. It is present continuously from Ashley Creek eastward to Diamond Mountain, and is exposed on the north and west flanks of Split Mountain anticline and on Section Ridge anticline. The Mowry shale member forms low rounded hills in some places, and at other points it appears only as a thin, light-gray line on the escarpment held up by the Frontier sandstone member of the Mancos shale.

Fossils, age, and stratigraphic relations.—The most common fossils reported from the Mowry shale member of the Mancos shale are teleost fish scales and fragments of fish bone. Reeside (1930, p. 35–41) reports marine invertebrates from Vermilion Creek, Colo., just east of the present area. The fish remains have little stratigraphic significance, but are useful as a lithologic character for correlation. The invertebrates indicate a lower Upper Cretaceous horizon. Reeside (1944, map 3) considers the Mowry to be equivalent to a part of the Graneros shale of the type Upper Cretaceous section east of the Rocky Mountains.

The lower boundary of the Mowry shale member of the Mancos shale marks an abrupt change from the underlying Dakota sandstone and suggests a disconformity. The variation in thickness of the Mowry, and especially the absence of the nonsiliceous, dark-gray shale at the base of the member in some sections, suggest a hiatus at the base of the siliceous shale. The upper boundary of the Mowry appears as a sharp line in the well-exposed sections in Steinaker Draw. It is more noticeable in weathered outcrop because the overlying shale of the Frontier sandstone member is sandy and weathers tan. The Mowry is believed to be conformable with the overlying Frontier.

Correlation.—In the area between Mosby Creek and the eastern boundary of the mapped area, the Mowry shale member of the Mancos shale is believed to correlate, in part, with the type section of the Aspen shale of southwestern Wyoming (Rubey, 1929, p. 153), on the basis of lithologic similarity and stratigraphic position. The member thins from the Duchesne River area (Huddle and McCann, 1947) eastward along the south flank of the Uinta Mountains, and it is thicker in the vicinity of Manila, Utah (Reeside, 1925, p. 38), on the north flank of the Uintas that it is in the Mosby Creek-Brush Creek area. The Mowry has been reported in northern Colorado 150 miles to the east and has been identified from well cuttings (Thomas, McCann, and Raman, 1945) more than 50 miles to the southeast on Douglas Creek in Rio Blanco County, northwestern Colorado. Equivalents of the Graneros shale that are not lithologically similar to the Mowry are present in the lower part of the Mancos shale south of the Book Cliffs in central Utah (Reeside, 1944, map 3).

Conditions of deposition.—The fact that the Mowry is of marine origin is substantiated by fossilized remains of marine forms of both the common fish and invertebrates. Rubey (1929, p. 153–170) has shown that the Mowry shale in the Black Hills was formed by extremely slow sedimentation and that the bulk of the material was originally volcanic ash. The isopachous map by Reeside (1944, map 3) shows the center of deposition of the Mowry and Aspen equivalents to be in southwestern Wyoming, thus indicating that the source of the ash (the principal constituent of the unit) is to the west of that area. The presence of thin bands of glassy, quartzitic sandstone in the Mowry shale member of the Mancos in the Mosby Creek-Brush Creek area suggests that some clastic material was transported far eastward, or that it was derived locally. The absence of the typical lithology of the Mowry south of the Book Cliffs and the thinness of the member on the south flank of the Uinta Mountains suggest that the area is near the depositional boundary of the siliceous shale that is regarded as characteristic of the Mowry.

FRONTIER SANDSTONE MEMBER

Definition.—For many years, the sandstone, shale, and coal-bearing unit in the eastern Uinta Mountains, which occupies the stratigraphic position of the Frontier formation in southwestern Wyoming, has been known by the name "Frontier sandstone," although it is much thinner and may not be continuous with the strata at the type locality. In this report, it is considered as a member of the Mancos shale.

Lithology and thickness.—The Frontier sandstone member of the Mancos shale (fig. 10) consists of two units, an upper massive sandstone and a lower sandy siltstone which, at places, includes thin beds of fine-grained sandstone. The upper unit, which is topographically prominent and forms ridges and long dip slopes, is composed of massive to thick-bedded, in part crossbedded, medium-grained, gray to tan sandstone with angular sand grains, thin beds of tan-weathering, sandy shale and bituminous coal or lignitic shale beds. Near the base, the sandstone is well cemented with lime and, at places, carries molds of *Ostrea* and other marine fossils. The lower unit is comprised of dark-gray, sandy siltstone, which weathers to shades of tan.

The upper part of the Frontier sandstone member appears to thin eastward and southeastward from 160 feet at Steinaker Draw to 33 feet south of U. S. Highway 40; however, the underlying shale thickens over the same area. In the Deep Creek area, near the coal mines, the sandstone unit is only 94 feet thick, as compared to a thickness of 177 feet for the underlying shale, thus indicating that the increase in thickness of the upper unit is not uniform toward the west. Within the area mapped, the Frontier thins from a thickness of 273 feet near the coal mines west of Little Mountain to 209 feet on Little Brush Creek.

The detailed lithology of the Frontier sandstone member of the Mancos shale at well-exposed places across the area is as follows:

Section of the Frontier sandstone member of the Mancos shale, northwest of the coal mine area and southwest of Mosby Creek, SW¼ sec. 13, T. 3 S., 18 E.

[Measured by D. M. Kinney, J. F. Rominger, P. Verastegui M., and R. S. Brown]

Mancos shale:	
Upper shale member:	
Shale, clay, dark-gray, slightly sandy.	
Frontier sandstone member:	*Feet*
Sandstone, tan, fine- to medium-grained, calcareous, thick-bedded to massive, with fossils near base	94
Shale, gray, tannish-gray weathering, sandy	177
	271
Mowry shale member:	
Shale, dark-gray, fissile, siliceous.	

Section of the Frontier sandstone member of the Mancos shale in Steinaker Draw, north of Vernal, Utah, SE¼ sec. 26, T. 3 S., R. 21 E.

[Measured by D. M. Kinney, J. F. Rominger, P. Verastegui M., and R. S. Brown]

Mancos shale:

Upper shale member:

Shale, clay, dark-gray, slightly sandy.

Section of the Frontier sandstone member of the Mancos shale in Steinaker Draw, north of Vernal, Utah, SE¼, sec. 26, T. 3 S., R. 21 E.—Continued

Mancos shale—Continued	
Frontier sandstone member:	*Feet*
Sandstone, fine- to medium-grained, calcareous, tan or buff-weathering	6
Coal, shaly, with streaks of black, carbonaceous shale	7
Shale, dark-gray, carbonaceous	8
Sandstone, fine- to medium-grained, calcareous, light-gray, tan-weathering	92
Shale, gray, sandy, tan-weathering	51
	164
Mowry shale member:	
Shale, siliceous, dark-gray, light-gray weathering.	

Section of the Frontier sandstone member of the Mancos shale, ½ mile west of Little Brush Creek, N.W.¼ sec. 11, T. 3 S., R. 22 E

[Measured by D. M. Kinney and J. F. Rominger]

Mancos shale:	
Upper shale member:	
Shale, clay, dark-gray.	
Frontier sandstone member:	*Feet*
Sandstone, light-gray to buff, fine- to medium-grained, calcareous,	
Sandstone, light-gray to buff, fine- to medium-grained, calcareous, thick-bedded, fossiliferous at base with brown calcareous concretions as large as 5 feet in diameter at top	134
Shale, gray, tan-weathering, sandy	75
	209
Mowry shale member:	
Shale, siliceous, dark-gray, weathering light-gray.	

Section of the Frontier sandstone member of the Mancos shale in Orchard Draw, Dinosaur National Monument, SW¼ sec. 27, T. 4 S., R. 23 E., 1 mile west of Monument Headquarters

[Measured by F. T. McCann and N. D. Raman]

Mancos shale:	
Upper shale member:	
Shale, clay, slightly sandy, dark-gray, weathering silver-gray.	*Feet*
Frontier sandstone member:	
Sandstone, very fine- to fine-grained, gray to buff, slightly calcareous, yellowish-brown, gray or brown-weathering, with glassy quartz grains and some carbonaceous material	6
Shale, dark-gray to black, blocky and fissile, noncalcareous, sandy near top and bottom, brownish-gray weathering	44
Sandstone, very fine-grained, gray to buff, gray to brown-weathering, massive, slightly calcareous, with grains of subangular, glassy to slightly frosted quartz and considerable limonite near base	20
Shale, dark-gray to black, blocky, fissile, noncalcareous, buff-weathering, interbedded with numerous thin (½ to 6 inches thick) beds of sandstone, very fine-grained, gray to light-buff, noncalcareous	100
Shale, dark-gray, similar to above but without sandstone beds	14

Section of the Frontier sandstone member of the Mancos shale in Orchard Draw, Dinosaur National Monument, SW¼ sec. 27, T. 4 S., R. 23 E., 1 mile west of Monument Headquarters—Continued

	Feet
Mancos shale—Continued	
Frontier sandstone member—Continued	
Shale, black, similar to above, but weathering brownish-black and with some fish scales in lower portion	40
	224
Mowry shale member:	
Shale, dark-gray, silver-gray weathering.	

Section of the Frontier sandstone member of the Mancos shale, south of U. S. Highway 40 and north of Spring Creek, NW¼ sec. 7, T. 6 S., R. 24 E.

[Measured by D. M. Kinney and J. F. Rominger]

	Feet
Mancos shale:	
Upper shale member:	
Shale, dark-gray, light-gray weathering.	
Frontier sandstone member:	
Sandstone, tan, fine- to medium-grained, calcareous	32
Shale, gray, tan-weathering, fine- to- medium-grained, sandy	10
Shale, clay, dark-gray fissile	44
Sandstone, tan, fine-grained, platy at top	5
Shale, clay, dark-gray, fissile, with 1 foot bed of fine-grained, calcareous sandstone prominent in top 10 feet	98
	235
Mowry shale member:	
Shale, dark-gray, silver-gray weathering, platy to fissile, with fish scales and a few thin (0.1 to 0.3 foot) beds of medium-gray, fine-grained sandstone.	

Distribution.—The Frontier sandstone member of the Mancos shale has the same distribution as the Mowry member. It is present in the coal-mine area southwest of Mosby Creek eastward to Little Mountain, in Coal Mine Draw on the east side of Little Mountain, and in the ridge that extends from east of Ashley Creek along the east side of Steinaker Draw, across the valley of Brush Creek to Diamond Mountain. It also forms a hogback ridge on the north and west sides of Split Mountain, with the upper massive sandstone unit forming a dip slope on the west side of Split Mountain. The Frontier is present on the south side of Split Mountain within the Dinosaur National Monument. It is also present on the flanks of Section Ridge anticline east of Jensen.

Fossils, age, and stratigraphic relations.—A sparse fauna of *Ostrea* and other pelecypods is found near the base of the sandstone that forms the upper part of the Frontier member. Well-preserved fossil molds were noted in the measured section near the coal mines in T. 3 S., R. 19 E., and east of Utah State Highway 44 in Steinaker Draw. No collections were made in the present area, but Walton (1941, p. 104, pl. 1) has shown that in the Duchesne River area on the south flank of the Uinta Mountains, 50 miles to the west, a part of the much thicker Frontier formation contains a typical fauna of Greenhorn age. He also found the shale underlying the sandstone to be of pre-Greenhorn age, and he believed that the Greenhorn fauna ranged upward into the basal part of the upper shale member of the Mancos shale. Reeside (1930, p. 35–41) reports, from the Frontier member on Vermilion Creek, Colo., a fauna that indicates an equivalence to the upper part of the Carlile shale east of the Front Range; this zone is widespread in the Mancos shale. Reeside's isopachous map (1944, map 4) of the Cretaceous deposits in the western United States shows 200 to 300 feet of Greenhorn equivalent in the northeastern part of Utah, and about the same thickness of upper Carlile equivalent.

The lower boundary of the Frontier sandstone member is drawn at the abrupt color change from silver-gray shale of the Mowry shale member to tan drab-weathering sandy siltstone. The upper boundary of the Frontier member is drawn above the highest sandstone. It appears to be conformable throughout the area.

Correlation.—The Frontier sandstone member of the Mancos shale is equivalent to the Frontier formation as defined (Schultz, 1920, p. 73–74) on the north flank of the Uinta Mountains. Walton (1944, p. 103) has shown that it thins progressively eastward on the south flank of the Uinta Mountains and that it can be definitely correlated with the Frontier sandstone of the Red Creek and Duchesne River sections of the western Uinta Mountains. Thin-bedded sandstones and interbedded sandy shales at the horizon of the Frontier member can be traced (Thomas, McCann, and Raman, 1945) into northwestern Colorado. Walton (1944, p. 104) has suggested that the Frontier on the south flank of the Uintas correlates with the Ferron sandstone in the lower part of the Mancos shale south of the Uinta Basin. However, Clark (1928, p. 14) reports a Carlile fauna from the Ferron at Farnum Dome and Walton (1944, p. 104) has shown the Frontier of the Uinta Mountains to be Greenhorn in age, so it would appear that the Ferron sandstone member of the Mancos shale is slightly younger than the Frontier member. Bartram (1937, p. 907) has suggested that the Ferron and the Frontier could have been deposited on different deltas at slightly different times.

Conditions of deposition.—It has been suggested (Bartram, 1937, p. 902–903) that the Frontier formation of southwestern Wyoming is an old delta which was formed by streams (flowing from mountains rising in eastern Nevada and western Utah) that deposited their loads of sand and silt in a great inland Cretaceous sea. When deposition exceeded subsidence of the area, the delta was built above sea level, and the resultant fresh-water, swampy conditions resulted in lush vegetation. After burial, this vegetation formed thick coal beds. As the subaerial portion of the delta grew, the coarser particles were spread farther east. The Frontier sandstone member of the Mancos shale on the south flanks of the eastern Uinta Mountains probably represents attenuated deltaic sediments derived from the west. The lower sandy siltstone unit was deposited under marine conditions, and the lower, fossiliferous part of the Frontier is of marine origin. Only the medium- to coarse-grained, crossbedded sandstone, and the associated coal beds in the upper part of the member, are of fresh-water origin. Deposition of the member was terminated by the renewal of subsidence and the submergence of the area during the deposition of the upper shale member of the Mancos.

UPPER SHALE MEMBER

Definition.—The Mowry shale and Frontier sandstone members of the Mancos shale constitute only 5 percent of the total thickness of the formation and the remaining strata are included in the upper shale member, which resembles, in lithology, the typical Mancos shale of southwestern Colorado and the Yampa coalfield of northwestern Colorado. It rests on the Frontier sandstone member and is overlain by the sandstones of the Mesaverde formation.

Lithology and thickness.—The upper shale member of the Mancos shale consists of medium to dark gray, massive siltstone or clay shale with thin, lenticular beds of tan to brown, sandy limestone or calcareous sandstone. Along Spring Creek and northwest of Jensen, the lower 1,000 to 1,500 feet weather to light silver gray and the upper part weathers to a slightly darker gray. The brown-weathering, calcareous sandstone or sandy limestone beds are rare in the basal three-quarters of the member but, as the upper boundary of the Mancos shale is approached, thin, fine-grained, calcareous sandstone beds become more common. The siltstone or clay shale is so massive that particular reliance must be placed on the sandy limestone beds in the lower part of the member for knowledge of the attitude of the strata when calculating the thickness of the measured section.

In the area mapped, the thick upper shale member is completely exposed only in the Spring Creek drainage, south of U. S. Highway 40. At this place, 4,910 feet of gray siltstone have been measured, but an abrupt change in dip near the middle of the member suggests strike-slip faulting and the possibility that some section is missing or duplicated. The measured thickness is believed to be approximately correct, however, because a thickness of 5,000 and 5,200 feet of shale is present at the Rangely oilfield and at Vermilion Creek (Thomas, McCann, and Raman, 1945) respectively, in northwestern Colorado. Huddle and McCann (1947) report only 1,800 to 2,600 feet of the upper shale member in the Duchesne River area, because at this point the upper part of the Mancos is replaced by coarse-grained sandstones of the Mesaverde formation. Because of the fact that the upper shale member thins toward the west, it is probable that less than 4,900 feet of the upper member is present in the area overlapped by Tertiary sediments west of Little Mountain.

Distribution and topographic expression.—The upper shale member of the Mancos shale is present from south of the coal mines in the Mosby Creek-Deep Creek drainage eastward to Little Mountain, beneath the broad Ashley Valley, in the badlands near the Buckskin Hills and east of Steinaker Draw, in the Island Park syncline between Diamond Mountain and Split Mountain, south of Split Mountain, around the Section Ridge nose, and southward to The Rim Rock.

The upper shale member generally is poorly exposed; a thin soil mantles unweathered siltstone a few inches beneath the surface. The gray siltstone supports practically no vegetation and this leads to the development of badland topography, except where terrace gravels along Ashley Creek, Brush Creek and Green River protect the underlying sedimentary rock from erosion. Most of the well-developed erosion surfaces on the upper member are cut deeply enough to give a clue to the late Cenoozoic history of the area.

The detailed lithology of the upper shale member of the Mancos shale, as exposed in the vicinity of Spring Creek and south of U. S. Highway 40, is given in the following section measured by plane-table and telescopic alidade.

Section of the upper shale member of the Mancos shale in the Spring Creek area, S½ sec. 7, sec. 18, and sec. 19, T. 6 S., R. 24 E.

[Measured by D. M. Kinney and J. F. Rominger]

Mesaverde formation:	
Sandstone, light-gray, tan-weathering, fine- to medium-grained, massive, crossbedded, with abundant grains of subangular black chert.	
Mancos shale:	
Upper shale member:	*Feet*
Shale, gray, tan-weathering, sandy, with two 1-foot beds of tan, thin-bedded, crossbedded sandstone	79
Sandstone, tan, fine-grained, thin-bedded	3
Shale, sandy, gray to tan	248
Shale, gray, grayish-tan weathering, sandy, with lenses (maximum 2 feet thick and 10 feet long) of tan, very fine-grained sandstone	709
Shale, gray (grayish-tan weathering, with thin beds of tan, fine-grained, calcareous, slabby sandstone	296
Shale, clay, gray, tan-weathering, sandy, with few tan concretionary beds. Top 5 feet of sandstone, tan, fine-grained, calcareous, interbedded with sandy, light-gray shale	379
Shale, clay, gray	1170
Shale, clay, gray, tan-weathering	762
Shale, clay, gray, tan-weathering, sandy, with thin partings of fine-grained sandstone in top 10 feet	506
Shale, clay, silver-gray	704
Shale, clay, dark gray	54
	4,910
Frontier sandstone member:	
Sandstone, tan, fine- to medium-grained, calcareous.	

Fossils and age.—Fossils are abundant at certain horizons in the upper shale member of the Mancos, but the preservation is usually poor because of weathering in surface exposures and because of the fragile character of the original shells. Some of the better fossil localities were noted at places of structural complexity and poor stratigraphic control. This discovery of fossils at places of structural complications is due to the greater detail with which such areas were studied. Similar searches of less complicated areas should yield more fossil localities. On the basis of regional isopachous maps of Reeside (1944, maps 6 and 7) and the work of Walton (1944, p. 105), the upper shale member of the Mancos probably contains equivalents to the upper part of the Carlile shale and the Niobrara formation of the standard section for the western interior, as well as 2,700 to 2,900 feet of the Montana group.

Stratigraphic relations and correlation.—The lower boundary of the upper shale member of the Mancos shale appears to be gradational with the underlying Frontier sandstone member, although the absence of the lower Carlile shale equivalent over the general area, as shown by Reeside (1944, map 5), suggests that a stratigraphic break may be present at approximately this point in the sedimentary record. Certainly, no physical evidence for such a break is found in the detailed section measured on Spring Creek. However, the character of the outcrops is such that, although a break may exist, it can easily be unnoticed. The gradational relationship of the upper boundary with the overlying Mesaverde formation is indicated by more abundant sandstone beds in the upper shale member as the boundary with the overlying massive sandstone is approached, and by evidence (Walton, 1944, p. 109) that the Mesaverde is of Niobrara age in the western part of the Uinta Mountains but is of post-Niobrara age near the Green River. Reeside (1930, p. 35–41) has indicated the presence of equivalents of the Niobrara formation, Telegraph Creek formation, Eagle sandstone, and some post-Eagle beds in the Mancos shale on Vermilion Creek, Colo.

The upper shale member is correlated with the Mancos shale and most of the Mesaverde formation of the Duchesne River area of the western Uinta Mountains, the Hilliard shale of the north flank of the Uinta Mountains, the middle and upper part of the type section of the Hilliard shale in southwestern Wyoming, and the upper member of the Mancos shale as mapped in adjacent areas of northwestern Colorado. Farther east in Colorado and south of the Uinta Basin (Erdmann, 1934, p. 29–31), the Mancos shale may include still younger Upper Cretaceous rocks, perhaps equivalent to the Lewis shale of the Montana group.

Conditions of deposition.—The upper member of the Mancos shale is unquestionably of marine origin throughout the Uinta River-Brush

Creek area. The rapid thickening of the Upper Cretaceous sedimentary rocks toward the west, and the change from marine shale to deltaic deposits (including coal), indicate a western source for most of the sediments. The source was probably in the rising mountains of western Utah and eastern Nevada. The isopachous maps of Reeside (1944, map 2) clearly show two centers of subsidence and deltaic deposition, one in southwestern Wyoming and the other in central Utah. The sediments deposited in the eastern Uinta Mountains probably were derived from the center of deposition in southwestern Wyoming.

MESAVERDE FORMATION

Definition.—The Mesaverde formation was named by Holmes (1877, pl. 35) for the Mesaverde in southwestern Colorado. There, it underlies dark marine Lewis shale and overlies similar marine shale of the Mancos. The Mesaverde was first identified in northwestern Colorado by Fenneman and Gale (1906, p. 22–23) in the Yampa coalfield and later, it was recognized in northeastern Utah by Gale (1910, p. 63). Gale recognized two members in the Mesaverde formation: a lower, primarily marine, member that is characterized by fine- to medium-grained sandstone and an upper, brackish to fresh-water member that includes beds of carbonaceous shale and lignitic coal seams. In the Axial and Monument Butte quadrangles in northwestern Colorado, Hancock (1925, p. 15–25) named these members the "Iles formation" and the "Williams Fork formation" for exposures at Iles Mountain and along Williams Fork near its junction with the Yampa River. Sears (1924, p. 289–290, pl. 35) extended these formations to the vicinity of Elk Springs, Colo., 40 miles to the east of the Green River, but he does not believe (personal communication, March 1949) that the Iles can be carried farther westward. Walton (1944, p. 110–111, 114–115) has divided the lower part of the Mesaverde, in the Vernal area, into the Asphalt Ridge sandstone (below), and the Rim Rock sandstone (above), and he has retained the name "Williams Fork" for the upper part of the Mesaverde formation. If present at all within the area under study, the Asphalt Ridge sandstone of Walton is only poorly developed because Walton has shown that it feathers out, west of the Green River, into the upper part of the Mancos. All of the sandstone at the base of the Mesaverde formation in the southeastern part of the mapped area probably would be included in Walton's Rim Rock sandstone.

Lithology and thickness.—The lower member of the Mesaverde formation consists of one-third light-gray, fine- to medium-grained sandstone and two-thirds medium-grained, light-gray speckled sandstone. The sandstone is thick-bedded to massive and, commonly, crossbedded. Some beds are highly contorted. Only 5 percent, or less, of the member is sandy shale. The sand grains are angular to subangular. The speckled appearance of some of the beds is given by a large number of grains of black chert. Except for the basal beds, which are cemented with lime, the sandstone is friable and disintegrates readily. The upper member of the formation consists of light-gray to brown, fine- to medium-grained sandstone, and dark-gray to light brownish-gray lignitic shale. Sandstone constitutes about 60 percent of the unit. It is thin bedded to massive, but only the massive beds are well exposed. The lignitic shale and thin-bedded, fine-grained, brown sandstone beds are soft, easily eroded, and poorly exposed, except along banks of streambeds.

The lower member is 528 feet thick, and the upper member is 631 feet thick at The Rim Rock and 2 miles east of the Green River. More of the upper member of the Mesaverde formation is exposed at this place than at any other place in the area. To the east, and to the west, the Tertiary rocks transgress farther north and rest on the lower member of the formation. Only 525 feet of Mesaverde formation is exposed at Point of Rocks on the west side of the Green River.

The detailed lithology of the Mesaverde formation in the area of maximum exposure east of the Green River is as follows:

Section of the Mesaverde formation 2 miles east of the Green River SW¼ sec. 8 and NW¼NW¼ sec. 17, T. 6 S., R. 23 E.

[Measured by D. M. Kinney and J. F. Rominger]

Tertiary:

Green River (?) formation:

Conglomerate, brown, with pebbles predominantly of well-rounded, dark chert and abundant fragments of silicified wood.

Mesaverde formation:

Upper member:	Feet
Sandstone, light-gray, speckled, massive to contorted bedding, crossbedded, with angular to sub-rounded grains	68
Shale, lignitic interbedded with light-gray, massive, highly lenticular sandstone	81
Lignite, dark-gray, with selenite crystals; grades into overlying bed	6
Sandstone, dusky yellow-orange, specked, with a few 1 to 2 foot beds of moderate-brown, fine- to medium-grained, calcareous sandstone and streaks of lignitic shale	73
Sandstone, light-gray, fine- to medium-grained, calcareous	2
Shale, lignitic, and lignite interbedded with light-gray, fine-grained, soft sandstone	134
Sandstone, light-gray, lenticular, massive to thin-bedded	30
Shale, medium dark-gray, fissile	10
Sandstone, light-gray, fine-grained	2
Lignite, dark-gray, thin-bedded, interbedded with light-gray, massive, crossbedded sandstone	22
Sandstone, moderate-brown, thin-bedded, contorted, overlying light-gray, massive, soft sandstone; weathers into concretions	48
Sandstone, light-gray, fine-grained, massive	10

Section of the Mesaverde formation 2 miles east of the Green River SW¼ sec. 8 and NW¼NW¼ sec. 17, T. 6 S., R. 23 E.—Continued

	Feet
Tertiary—Continued	
Mesaverde formation—Continued	
Sandstone, light-gray, fine- to medium-grained, speckled, massive, with a few thin beds of light brownish-gray, lignitic shale	91
Sandstone, light-gray, tan-weathering, fine- to medium-grained, thin-bedded with few thin beds of light brownish-gray lignitic shale at base	70
Lower member:	
Sandstone, moderate yellowish-brown, speckled, medium-grained, poorly crossbedded with angular to subrounded grains, and light-gray, specked, massive, crossbedded sandstone	70
Covered; sandstone, light-gray, fine- to medium-grained, soft, friable	77
Sandstone, light-gray, medium-grained, highly crossbedded	89
Covered; 1-foot beds of sandstone, light-gray, speckled, interbedded with shale	24
Sandstone, light-gray, speckled, fine- to medium-grained, massive, crossbedded, contorted bedded, with angular grains	34
Covered; sandstone, yellowish-gray, fine- to medium-grained, slabby, as float. Unit probably sandy shale	16
Sandstone, light-gray, speckled, medium-grained, massive, crossbedded	201
Sandstone, light-gray, tan-weathering, speckled, fine- to medium-grained, massive, crossbedded	18
	529
Total thickness	1,176
Mancos shale:	
Shale, sandy, gray, tan-weathering.	

Distribution and topographic expression.—The Mesaverde formation underlies Asphalt Ridge to the south and west of Vernal, crosses the Green River in the NE¼ T. 6 S., R. 22 E., and continues a little south of east to the eastern border of the mapped area. East of the Green River it underlies The Rim Rock (a low north-facing escarpment). It is overlapped by Tertiary rocks east of Little Mountain and does not crop out again to the west for almost 50 miles. The lower, massive to thick-bedded sandstone member forms the escarpment, and the upper thin-bedded lignitic shale and sandstone member, where it appears beneath the overlying Tertiary sediments, underlies an area of subdued topography to the south.

Fossils and age.—No fossils were found in the Mesaverde formation during the present field work, although carbonized plant remains are common in the lignitic shale of the upper member. Tolmachoff (1942, p. 41–45) reports an Upper Cretaceous marine fauna from a sandstone bed on Asphalt Ridge; Walton (1944, p. 111) correlates this sandstone bed with his Asphalt Ridge sandstone. The fauna includes:

Enchodus sp.
Apateodus sp.
Scapanorhynchus sp.
Placenticeras meeki J. Boehm
Turritella sp.
Gyrodes sp.
Margarita sp.
Fissurella sp.
Leptosolen conradi Meek
Anatina lineata Stanton
Cymella bella Conrad
Lucina sp.
Cardium kayi Tolmachoff
Tellina sp.
Cymbopora sp.
Yoldia evansi Meek and Hayden
Crenella burkei sp. nov.

Reeside (Walton, 1944, p. 111) reports that this fauna must be considered post-Niobrara in age. Because the Asphalt Ridge sandstone feathers out into the upper part of the Mancos formation east of Green River, this fauna dates the upper part of the Mancos and does not date the Mesaverde near the Green River. Gale (1910, p. 66) summarized the species collected from the Mesaverde of northwestern Colorado and northeastern Utah.

Stratigraphic relations and correlation.—The Mesaverde formation is conformable with the underlying Mancos shale and is unconformably overlain by the lowest exposed Tertiary rocks. The Lewis shale, which overlies the Mesaverde east of Lay in northwestern Colorado, is not exposed near the Green River.

The lower member of the Mesaverde is, in part, correlative with the type section of the Iles formation near Craig, Colo., with the Mesaverde formation of the north flank of the Uinta Mountains, and perhaps with the lower part of the Currant Creek formation of the western Uintas. According to Walton (1944, p. 114), Spieker and Reeside believe that the Rim Rock sandstone (basal Mesaverde) near Rangely, Colo., is 1,500 feet stratigraphically below the base of the Sego sandstone of the Book Cliffs, or about in the middle of the Star Point sandstone of the Wasatch Plateau section. Walton (1944, p. 116–117) also correlates the Mesaverde with the Adaville formation (described in southwestern Wyoming). The upper member of the Mesaverde is probably equivalent to the Blackhawk formation of the Wasatch Plateau and is partly equivalent, at least, to the Williams Fork formation of northwestern Colorado.

Conditions of deposition.—Most of the fossils from the lower member of the Mesaverde are of marine origin, although some beds may have been deposited in fresh or brackish water. The sandstone was deposited near the shore, and the sand probably was derived from great deltas which were forming to the west. The upper member of the Mesaverde formation is predominantly continental, as is shown by the frequent interbedded lignitic shale, lignite, and included invertebrate forms. It was formed on a low-lying coast that was subject to occasional readvances of the sea and submergence by marine waters.

TERTIARY SYSTEM

The present investigation is concerned principally with the rocks of Paleozoic and Mesozoic age on the south flank of the Uinta Mountains, which formed a portion of the northern border for the great Uinta Basin, an area of Tertiary deposition in northeastern Utah and northwestern Colorado. The lower Tertiary rocks on the southern border of the mapped area have been grouped together as Eocene and Oligocene(?) strata because it was believed that the naming and correlation of early Tertiary formations would require the mapping of areas and the study of sections far removed from the present assignment. The Bishop conglomerate (Miocene?), which rests on the older rocks over considerable areas, lies almost wholly within the boundaries of the mountains and was studied at many places.

Some geologists now believe that most of the coarse-grained sediments included in the Bishop conglomerate are equivalents of the finer grained early Tertiary sediments that occupy the central part of the Uinta Basin. The Bishop conglomerate, however, is essentially horizontal and overlies older Tertiary rocks that dip at noticeable angles into the surface trace of the Uinta Basin syncline, located a few miles south of the Uinta Mountain front.

BISHOP CONGLOMERATE

Definition.—The Bishop conglomerate was named by Powell (1876, p. 40, 44, 62, 169) for Bishop Mountain (now known as Pine Mountain) in southwestern Wyoming. On the north flank of the Uinta Mountains, it varies in thickness from a few feet to 200 or more feet and rests unconformably on Eocene to pre-Cambrian formations. The boulders in the conglomerate consist principally of red and white quartzites derived from the Uinta Mountain group. The more detailed work of Bradley (1936, p. 169) on the geomorphology of the north flank of the Uinta Mountains has established the fact that the Bishop conglomerate rests on a widespread erosion surface, which he named the Gilbert Peak surface for a large remnant of the surface that slopes westward and northward from the west base of Gilbert Peak. The Bishop conglomerate was identified by Powell on the south flank of the Uintas; all subsequent workers have continued his nomenclature. Bradley (1936, pl. 34) reports that the Gilbert Peak surface extends south of the crest of the range for a few miles.

Distribution and topographic expression.—In the area shown on the map (pl. 1) the Bishop conglomerate underlies Jefferson Park, Pole Mountain, Mosby Mountain, Lake Mountain, Dry Fork Mountain, Little Mountain, the high plateau from Ashley Creek eastward to Diamond Mountain, and Diamond Mountain. An isolated patch of conglomerate, tentatively identified as Bishop, underlies the Buckskin Hills between Steinaker Draw and Split Mountain.

The Bishop conglomerate is almost flat-lying and forms broad gently-rolling upland surfaces covered by clumps of pine and quaking aspen, grassy parks, and areas of boulders with only a slight soil cover. The upland surface is cut into a number of isolated flat-topped mountains by steep-walled canyons of perennial streams flowing southward from the crest of the range. The Bishop conglomerate is well consolidated and forms steep slopes and good exposures along the canyon walls and on the southern boundary of the mountains. The southern limit of the Bishop conglomerate forms the boundary of the main mountain mass that culminates along the crest of the Uinta Range. On Diamond Mountain, reentrants of Bishop conglomerate extend northward into the valley of Pot Creek and its tributaries.

Lithology and thickness.—The Bishop conglomerate at Jefferson Park consists almost exclusively of light-tan to red boulders in a matrix of coarse sandstone. The matrix is not prominent and in most outcrops only the rounded boulders are visible. On Pole Mountain, Mosby Mountain, and Lake Mountain, the lower bed of the Bishop is a characteristic basal conglomerate, 25 to 40 feet thick, composed of well-rounded boulders of limestone, chert, and sandstone in a matrix of medium- to coarse-grained sand. Overlying this basal conglomerate is a chalky-white tuffaceous sandstone, 25 to 100 feet thick, which, in turn is overlain by light-tan to buff conglomerate with a sand matrix. Eastward, the conglomerate beds are prominent on Dry Fork Mountain, Little Mountain, east of Ashley Creek, and for a short distance east of Brush Creek. However, in the escarpment formed by equivalent beds on Diamond Mountain, the conglomerate appears as streaks or thin beds, and medium-grained, partly tuffaceous, light-gray sandstone comprises most of the formation. The upper surface of the Bishop, from Ashley Creek eastward to Little Brush Creek, is dotted with occasional groups of large, angular, quartzite blocks; some of the blocks weigh several tons. These blocks are believed to be large erratic boulders that were carried far from their source by mudflows.

The Bishop conglomerate thins uniformly eastward from a thickness of 800 feet at Jefferson Park, on the western edge of the mapped area, to an approximate thicknes of 300 feet on Diamond Mountain.

Fossils and age.—No fossils have been found in the Bishop conglomerate within the area and it is believed that it is only in the fine-grained facies on Diamond Mountain that vertebrate fossils might be preserved. The Bishop conglomerate on the north flank of the Uintas is tentatively classified as Miocene(?) by the Geological Survey (Wilmarth, 1938, p. 194) because it is believed to be older than the Browns Park formation in which vertebrate fossils of Pliocene age have been found at Sunbeam, northwestern Colorado. The age of the underlying Gilbert Peak erosion surface is accepted to be of Oligocene or Miocene age by the Geological Survey (Wilmarth, 1938, p. 818).

Stratigraphic relations and correlation.—As mapped along the south flank of the Uinta Mountains, the Bishop conglomerate grades eastward from very coarse-grained quartzitic conglomerate to medium-grained tuffaceous sandstone with lenses and thin beds of boulders. At intermediate positions, and near the base of the formation, beds of chalky-white tuffaceous sandstone are found interbedded with conglomerate, thus suggesting an interfingering of facies. The tuffaceous sandstone superficially resembles the Browns Park formation of northwestern Colorado. The Bishop conglomerate of the south flank of the Uinta Mountains rests on an erosion surface, here identified as the Gilbert Peak surface of Bradley, which underlies the type Bishop conglomerate on the north flank of the mountains.

The correlation of exposures of poorly consolidated boulders on the crest of the Buckskin Hills is questionable because the altitude of the exposures is too low to correspond with the base of the Bishop. Although the boulder deposit may represent only the remnant of a high-level terrace deposit of Brush Creek, it is correlated with the Bishop conglomerate on the grounds of lithologic similarity.

STRUCTURE

METHODS OF REPRESENTING STRUCTURE

The geologic structure of the area shown on plate 1 gives the location and direction of throw of the faults and the attitude of the strata by dip and strike symbols and by structural contour lines drawn through points of equal altitude above sea level on the top of the Navajo sandstone. The structure is also shown, graphically and without distortion, by means of cross sections drawn to scale which show the inferred folding and faulting of beds at depth, based on surface observations and well information.

The structure contours are based on (1) altitudes of key beds obtained at many places by angles determined with the telescopic alidade from stations established by three-point intersection from control stations, and by distances measured on the photo-mosaics, (2) observed dips, and (3) stratigraphic interval above or below the top of the Navajo sandstone interpolated from the correlation chart (pl. 2). In contouring, the assumption is made that the folding has been of the concentric type in which the stratigraphic thickness of the beds remain unchanged in the folds. The vertical depth to the top of the Navajo sandstone (Jurassic?) has been computed by dividing the stratigraphic thickness by the cosine of the observed dip angle. The structure-contour lines are accurate for the purpose of recording the surface structure only along the line of outcrop of the top of the Navajo sandstone. In areas where younger rocks are exposed, the lines represent the inferred altitude of the top of the Navajo sandstone; the information is based upon deformation of the overlying younger beds and, where older rocks are exposed, of the inferred altitude of the top of the Navajo before erosion removed it. Of the three controlling factors used in the computation of the altitudes of the points controlling the location of structural contour lines, the observed dips are the source of the greatest inaccuracy.

Strike and dip of beds cannot be determined with a high degree of accuracy by means of Brunton compass and clinometer, and a measurement of strike and dip, which may be accurate for the particular locality, may not have regional significance. For these reasons, contour lines based on horizons some distance stratigraphically above or below the top of the Navajo sandstone only approximate the position of the Navajo prior to erosion. The field sheets, on which the published structural contour lines are based, were compiled at 200-foot intervals but only even-numbered thousand-foot contour lines are shown because of the limited distribution of control elevations in the area underlain by the thick Mancos shale and in the area overlain by Bishop conglomerate. The location of contours is primarily based on the method of equal spacing between points of different altitude; thus, the greater detail of the original compilation is reflected in the published map.

Surface altitudes for the profile of the different cross sections were taken from the topographic maps of the Marsh Peak and Ashley quadrangles of the U. S. Geological Survey and were supplemented by altitudes established by triangulation, three-point intersection, or angles determined with the telescopic alidade and by distances measured on the photo mosaics. The geologic cross sections were based on observed surface dips, the altitudes of formations in wells, the predicted altitudes of the top of the Navajo sandstone from the structure-contour lines, and the measured thicknesses of the formations.

GENERAL FEATURES

The Uinta Mountains are formed by a large anticlinal arch, 150 miles long and 20 to 40 miles wide, trending generally east-west. The axis of the fold is arcuate to the south, and the fold is asymmetrical with the steep flank on the north side. The structure of the broad anticlinal arch is complicated by a steeply dipping reverse fault on the north flank and by steeply dipping normal faults, arranged in echelon on the south flank.

The area studied lies on the south flank of thhe Uinta Mountain arch near the central and east-central part of the range. The principal structure of the area is a south-dipping homocline with superposed small, sharp, south-southeast plunging anticlinal noses and subsidiary and parallel anticlinal folds.

The area shown on plate 1 is divided, by Dry Fork of Ashley Creek and by a line trending S. 60° E. across Ashley Valley, into two parts that show different structural characteristics. East and northeast of this line, open folding predominates and faulting has only minor significance. South of Dry Fork and as far west as Uinta River, faulting is dominant and sharp folds are also present.

Eastward and northward from Dry Fork, the strata dip to the southeast, then to the south, and finally to the southwest at angles of 10° to 15°. The swing in strike of the bed along the homoclinal southern dip of the Uinta Mountains east of Dry Fork is a reflection of the Island Park syncline, which separates the Uinta Mountain arch from the parallel folds of the Split Mountain and Section Ridge anticlines to the south. The Split Mountain and Section Ridge anticlines are separated by the shallow Daniels Draw syncline, and they join in northwestern Colorado to form the Blue Mountain anticline. The Split Mountain and Section Ridge anticlines plunge steeply westward into Ashley Valley.

West of Dry Fork, the wide zone of faulting most prominently displayed in the valley of Deep Creek merges with the zone of echelon faulting known as the South Flank fault, which in general bounds the pre-Cambrian core of the Uinta Mountains. The faulting in Deep Creek probably extends southeastward to join with the faulting on the south flank of the Section Ridge anticline. The South Flank fault displacement becomes smaller to the northeast and it disappears east of Ashley Creek. Dips in the faulted area are moderate to steep and they vary in direction.

FOLDS

ISLAND PARK SYNCLINE

The steep-flanked and gently arched Split Mountain anticline is separated from the homoclinal dips on the south flank of the Uinta Mountain arch by the Island Park syncline, named for Island Park on the Green River to the east of the mapped area. The axis of the syncline trends east-west through the southern part of T. 3 S., R. 23 E., and the SE¼ T. 3 S., R. 22 E., but it is deflected to the southwest into the N½ T. 4 S., R. 22 E., by a saddle between the southeastern extension of the Ashley Creek anticlinal nose and the Split Mountain anticline. The syncline is asymmetrical; because dips of 20° to 25° to the south on the ridge of Cretaceous strata through the northern sections of T. 3 S., Rs. 22 and 23 E., rapidly diminish to a few degrees or a fraction of a degree for a distance of 2 miles north of the axis and then change abruptly to 50° to 70° toward the north as the axis is passed. This change in attitude is so rapid that the presence of faulting is suggested. Faulting cannot be proved, however, because of the lack of competent beds, the development of a masking soil cover, and the prevalence of slumping in the upper shale member of Mancos shale, which occupies the central part of the syncline. Faulting of the Frontier sandstone member of the Mancos shale is evident along the axis of the syncline a few miles east of the boundary of the map, and some northwest-trending faults cut the hogback of Cretaceous strata on the north flank of Split Mountain and enter the upper shale member where they no longer can be detected. The change in strike of the Mississippian and Pennsylvanian rocks in the northern part of Diamond Mountain from northeast to northwest is a reflection of the folding that formed the Island Park syncline. The westward plunging Ashley Creek anticlinal nose and Neal dome form a shallow closed basin in the Mancos shale area north of Split Mountain.

SPLIT MOUNTAIN ANTICLINE

Only the north and south flanks and the westward plunging strata of Mesozoic age of Split Mountain anticline are shown on plate 1, because much of the anticline is within the Dinosaur National Monument or east of longitude 109° 15′. The crest of the anticline is broad and gently arched, but the fold has steeply dipping northern and southern flanks. Two minor anticlinal axes are developed on the main fold: one extends from sec. 7, T. 4 S., R. 23 E., slightly south of west for 5 miles to sec. 17, T. 4 S., R. 22 E., and lies along the extreme north flank of the main anticlinal fold; the second, located along the south flank of the main arch, extends from sec. 20, T. 4 S., R. 23 E., westward for at least 8 miles to sec. 31, T. 4 S., R. 22 E. The intervening syncline is sharply folded near Brush Creek, but it becomes more gentle as it plunges westward. The upper shale member of the Mancos shale underlies most of the plunging Split Mountain anticline west of Brush Creek, and the structure-contour lines in the NW¼ T. 4 S., R. 22 E., are based, in part, on a detailed map of the area prepared in 1925 for the Humphrys Phosphate Co. by L. H. Williams and R. H. Ratliff. Weber sandstone (Pennsylvanian) forms the topographic crest of the anticline within the Monument area and the limestone unit of Mississippian age is exposed along the axis of the fold in Split Mountain Canyon. The fold dies out in the western part of T. 4 S., R. 22 E., in the area south of the Buckskin Hills and east of Ashley Creek.

SECTION RIDGE ANTICLINE

The axis of the Section Ridge anticline extends westward from sec. 31, T. 5 S., R. 24 E., to the western part of T. 5 S., R. 22 E. Faulting, with downthrow on the south, is common along the steep south flank of the fold; it probably is connected with the reported thrust fault on the south side of the anticline to the east. A saddle in sec. 19, T. 5 S., R. 23 E., and sec. 24, T. 5 S., R. 22 E., and probably some faulting that is the northwestward continuation of the faults (noted above) on the south flank of the fold, separate the closed anticlinal high (the Ashley Creek oilfield) from the main part of the anticline to the east. The saddle area is covered with alluvial deposits and a heavy soil cover, thus making it impossible to obtain dip measurements in critical areas of the upper shale member of the Mancos shale. The Utah-Vernal Oil Co.'s Caldwell well 1 in the SW¼SW¼SW¼ of sec. 20, T. 5 S., R. 23 E., is structurally only 350 feet above the crest of the Ashley Creek field; the oil and gas accumulation in the field clearly indicates structural closure. Details of the Ashley Creek oilfield structure are discussed under Oil and Gas in the section on Economic Geology.

DANIELS DRAW SYNCLINE

Split Mountain anticline is separated from the Section Ridge anticline to the south by a syncline here named the "Daniels Draw syncline," for the intermittent stream that enters the Green River in sec. 32, T. 4 S., R 24 E., and generally follows the axis eastward. The syncline enters the area shown on plate 1 a short distance south of Split Mountain Gorge and west of the Green River in sec. 31, T. 4 S., R. 24 E. The axis of the Daniels Draw syncline plunges gently westward and trends slightly south of true west into the broad Ashley Valley. It is asymmetrical, with the steep north flank formed by the Split Mountain anticline and the south flank rising gently to the southeast toward the axis of the broad Section Ridge anticline. A northeast dip in the W½ sec. 6, T. 5 S., R. 23 E., suggests a saddle, or shallowing of the syncline, near the boundary between Rs. 22 and 23 E., but this dip may be a result of undetected faulting near the axis.

NEAL DOME

Neal dome, named for Charles Neal, of Vernal, who has held the leases for oil and gas in this area for many years, lies in the southwestern part of T. 3 S., R. 21 E., on the boundary between the highly faulted area west of Dry Fork and the folded area to the east. The structural high point of the fold lies in the S½ of sec. 30 at the intersection of Ashley Creek and Dry Fork of Ashley Creek. The Chinle formation, overlain by the lower massive sandstone of the Navajo, is exposed in the canyon walls, and Navajo sandstone underlies the surface in the remaining parts of the area. True dips are difficult to find in the highly crossbedded Navajo sandstone, but a calcareous-cemented, brown-weathering sandstone bed in the E½ sec. 29 and the W½ sec. 28 is believed to follow a single stratigraphic horizon and to reflect the true structure of the area.

The southwestern side of the dome is formed by a fault, downdropped on the southwest, which extends from sec. 28, T. 3 S., R. 20 E., in a southeasterly direction to sec. 6, T. 4 S., R. 21 E. A parallel fault, 1 mile to the northeast, extends southeastward as far as sec. 26, T. 3 S., R. 20 E., and may possibly extend into sec. 31, T. 3 S., R. 21 E. However, this southeasterly continuation is difficult to prove because Navajo sandstone lies on both sides of the break; nevertheless, topography and stream alinement suggest such a projection. The southeast flank of the dome is formed by the regularly dipping strata of Mesozoic age along Steinaker Draw. The northeast flank is formed by a syncline, complicated by faulting, which extends from sec. 19, T. 3 S., R. 21 E., into sec. 28, T. 3 S., R. 21 E. A thin remnant of the Carmel formation is preserved in the axis of the syncline in the N½ sec. 19, T. 3 S., R. 21 E., east of Ashley Creek. The northwest flank of the dome is formed by a shallow synclinal saddle whose axis lies near the township boundary between R. 20 E. and R. 21 E. on Dry Fork of Ashley Creek.

A structural closure of about 150 feet is indicated by surface dips and formation boundaries, but the fold does not have sufficient closure at depth to provide an oil trap.

LITTLE MOUNTAIN SYNCLINES

Two small sharp synclines, separated by a fault downthrown on the northeast, are present on the northwest side of Little Mountain. The first syncline lies high on Little Mountain in sec. 30, T. 3 S., R. 20 E., and in the W½ sec. 25, T. 3 S., R. 19 E., and the second syncline is located at a lower altitude in secs. 18 and 19, T. 3 S., R. 20 E. The first syncline involves the Morrison formation, the Dakota sandstone, and the Mancos shale. It strikes east-west and is exposed for only a mile before it is covered by the Bishop conglomerate (Miocene?). Its projection beneath the Bishop is unknown, but it may be cut off to the east by the fault that trends N. 65° W. across the S½ sec. 25, T. 3 S., R. 19 E., and intercepts the axis of the syncline to the west. The second syncline involves the same formations but it is smaller and less clearly defined.

COAL MINE SYNCLINE

The Coal Mine syncline lies in secs. 19 and 20, T. 3 S., R. 19 E., directly north of a small reverse fault and 2 miles west of the juncture of Mosby Creek and Deep Creek. The northern dips are all recorded in heavy sandstone beds in the upper part of the Frontier sandstone member of the Mancos shale. The syncline is about 2 miles long and is cut off both to the east and to the west by the reverse fault. Only a portion of the south flank of the syncline remains north of the fault.

MOSBY MOUNTAIN SYNCLINE OR FAULT

The structural conditions beneath the Bishop conglomerate on Mosby Mountain are unknown. The northeast strike on the strata in Whiterocks Canyon and the general northwest strike of the faulted Mesozoic strata in the Mosby Creek area suggest a trough or southward-plunging synclinal axis beneath Mosby Mountain. The proximity of the 12,000-foot contour (controlled by the Park City formation and Weber sandstone boundary on Lake Mountain) and the 17,000–foot contour (controlled by the limestone unit of Mississippian age and Uinta Mountain group boundary on the northeast side of Mosby Mountain) are not explained by the 20°–35° dips observed in the field. It is possible that the Weber sandstone and limestone unit of Mississipian age on the east side of Mosby Mountain are separated by a fault, downdropped on the southeast, that extends southward beneath Mosby Mountain and separates the area of steep dips in Whiterocks Canyon from the more gently dipping, but faulted, strata in the Deep Creek fault zone.

WHITEROCKS ANTICLINAL NOSE

A bowing of strata across a southward plunging nose between Whiterocks River and Farm Creek is indicated by structure contours, which trend N. 30° E. across Whiterocks River, swing to east-west between Whiterocks River and Farm Creek, and trend northwesterly in sec. 3, T. 2 N., R. 1 W. However, westward dips, measured in the lower part of the upper member of the Morgan formation in sec. 3, T. 2 N., R. 1 W., may be due to the slumping of great blocks of strata, because landslide topography is prevalent at the horizon of the black shale unit of Mississippian age on the west side of Farm Creek.

DRY FORK ANTICLINAL NOSE

The axis of the Dry Fork nose follows, for the most part, the canyon of Dry Fork of Ashley Creek. It trends about S. 30° E. and is cut by the N. 60° W. trending Deep Creek fault zone. That part of the nose extending south of Dry Fork Canyon into secs. 7 and 8, T. 3 S., R. 20 E., and secs. 1 and 12, T. 3 S., R. 19 E., is known as the Pine Ridge structure from the Tidewater Associated and Mohawk Oil Companies Government well 1–58–7 drilled in the SW¼SW¼SE¼ sec. 7, T. 3 S., R. 20 E. Weber sandstone and the Morgan formation are exposed in the walls of Dry Fork Canyon, and the Park City, Moenkopi, and Shinarump formations form the surface of the structure to the south. The surface expression of the nose in the younger rocks can best be seen in the SE¼ sec. 12, T. 3 S., R. 19 E., where the thin, resistant Shinarump conglomerate has been breached and the red Moenkopi formation is exposed beneath the ledge.

ASHLEY CREEK ANTICLINAL NOSE

The Ashley Creek anticlinal nose extends from sec. 1, T. 3 S., R. 20 E., southeastward to sec. 21, T. 3 S., R. 21 E. The fold is well defined near the mouth of Ashley Creek where dips and strikes, together with elevations on the Park City and Weber formations, have controlled the structure contours. The southeastward extension of the fold is well marked by the basal boundary of the Navajo sandstone, but its continuation to the east is poorly defined in the highly crossbedded Navajo. It is believed, however, that the Ashley Creek nose is continuous to the east with the sharp asymmetric fold that is revealed in secs. 24 and 25, T. 3 S., R. 21 E., by the trend of the ridge of Cretaceous strata. The Ashley Creek nose is bounded on the southwest by the faulted syncline which forms the northeast flank of Neal dome and on the northeast by a gentle trough which becomes more sharply defined as the synclinal axis crosses Steinaker Draw and the ridge of Cretaceous strata. Eastward, beyond the ridge, the fold dies out in the upper shale member of the Mancos shale. The fold may continue to the northwest beneath the Bishop conglomerate on Dry Fork Mountain, but data are lacking.

DAVIS SPRING ANTICLINAL NOSE

The Davis Spring anticlinal nose is situated in secs. 1 and 12, T. 2 S., R. 20 E. (unsectionized), and secs. 6 and 7, T. 2 S., R. 21 E., 1 mile east of Ashley Creek. Southwest dips in an area of northeast regional strike are well exposed in the limestone and interbedded limestone and sandstone of the Morgan formation. The axis of the fold strikes south to south-southeast and dies out beneath the unconformably overlying Bishop conglomerate. The nose does not extend northward to the dip slopes and north-facing escarpment formed by the limestone unit of Mississippian age. The segments of the South Flank fault, which die out in sec. 1, T. 2 S., R. 20 E., may be related to the anticlinal nose.

BRUSH CREEK ANTICLINAL NOSE

The Brush Creek nose lies in the E½ of T. 2 S., R. 21 E., and the SW¼ T. 2 S., R. 22 E.; it extends for a distance of 6 miles, or more, in a south-southeasterly direction. The fold is best exposed in the canyon of Brush Creek, where the strike of the strata swings abruptly from N. 25°–35° E. to N. 45°–50° W. and then, within a mile, it returns to its former trend. The fold appears to die out to the southeast where the flexure enters less competent beds of the Moenkopi formation. To the north, the flexure dies out beneath the unconformably overlying late Tertiary strata. The change in strike is so abrupt, and the southwest dips are so steep, that the fold has been mapped as a fault downthrown to the southwest (Schultz, 1919, pl. 5). Some faulting may be present in the area of steep dips but it would be difficult to detect in the massive Weber sandstone, especially as the fault, if such exists, must follow Brush Creek canyon.

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BARKER SPRING ANTICLINAL NOSE

Three miles northeast of the Brush Creek nose, the Barker Spring anticlinal nose extends from the E½ of T. 1 S., R. 21 E., south-southeast for a distance of 9 miles to the W½ of T. 2 S., R. 22 E. All rocks from the limestone unit of Mississippian age in sec. 24, T. 1 S., R. 21 E., to the Moenkopi formation in sec. 27. T. 2 S., R. 22 E., are affected by the flexure. The folding in the older, more competent rocks is more gentle, and the greatest intensity of folding is in the upper part of the Weber sandstone and the overlying Park City formation in secs. 7, 17, and 18, where the beds dip as much as 25° to the southwest. The Barker Spring anticlinal nose dies out in the Moenkopi formation towards the southeast. In many particulars, the parallel Brush Creek and Barker Spring anticlinal noses have much in common.

FAULTS

SOUTH FLANK FAULT ZONE

A series of faults, downthrown on the south and arrranged in echelon, bound the pre-Cambrian quartzite core of the Uinta Mountains from Dry Gulch eastward to Ashley Creek. The faults, although not a continuous break, have many similar characteristics which suggested their earlier identification as a single fault by Forrester (1937, p. 644), who supplied the name "South Flank" fault. The dip on the faults is nearly vertical although actual fault planes are not exposed. Some faults separate pre-Cambrian quartzite from the shale sequence at the top of the Uinta Mountain group and others separate pre-Cambrian quartzite from Mississippian or Pennsylvanian strata.

The trends on the faults range from N. 70° E. in the headwaters of Dry Gulch in T. 3 N., R. 3 W., to E. near Uinta River in T. 3 N., R. 3 W., and to N. 65°–70° W. in Whiterocks Canyon. In Whiterocks Canyon, the strike of the South Flank faults conforms closely with the strike on the wide Deep Creek fault zone (about N. 60° W.); it is possible that the two fault systems merge in the area between Whiterocks River and Dry Fork of Ashley Creek. The agreement of trends in these fault systems may be coincidental or related to a third structural feature, the suggested south- or southwest-trending fault beneath the Bishop conglomerate on Mosby Mountain. East of Whiterocks River, the strike on the fault, or faults, bounding the pre-Cambrian core of the range swings to N. 70° E., and the displacement decreases gradually and dies out a short distance east of Ashley Creek.

DEEP CREEK FAULT ZONE

The Deep Creek fault zone, named for the area between Little Mountain and Mosby Mountain in T. 3 S., R. 19 E., trends S. 60° E. from the canyon of Whiterocks River through Little Mountain into the alluvial- and terrace-covered Ashley Valley. Southeastward, the zone is believed to connect with the faults mapped on the south side of the Section Ridge anticline in T. 3 S., R. 23 E., but the lack of outcrops in Ashley Valley makes this connection uncertain. The zone represents an area of considerable structural readjustment, because 14 faults with displacements ranging from a few feet to several hundred feet occur in section C–C′ drawn perpendicular to the strike of the zone. The net vertical displacement across the zone, however, is not great because faults downthrown to the south almost balance (in total displacement) faults downthrown to the north. Horizontal movement along a fault zone is difficult to prove, but it seems probable that a horizontal movement, the southwest side shifting towards the northwest, was the principal movement along the zone and that tilted grabens and horsts were developed in adjustment to this horizontal movement.

AGE OF DEFORMATION

The earliest deformation in the area is faulting of the Uinta Mountain group on the east side of the canyon of Whiterocks River. The faulting was followed by erosion that beveled the area and left unequal thicknesses of the upper shale of the Uinta Mountain group in the different fault blocks beneath the limestone unit of Mississippian age. The N. 65°–70° W. trend of these faults, which are clearly pre-Mississippian in age, and the general trend on the Deep Creek fault zone, which affects rocks as young as the Mancos shale of Late Cretaceous age, suggest that the Deep Creek zone of faulting is the result of a rejuvenation of a very old line of weakness in the earth's crust. No sedimentary strata on the south flank of the Uinta Mountains represent the long period of time between the deposition of the Upper(?) Cambrian Lodore formation and the limestone unit of Mississippian age. If strata were deposited in the area during this period, they were removed by subaerial erosion prior to the deposition of the limestone unit. It is not known whether the faulting in Whiterocks Canyon came early, or late, in the period represented by the missing strata.

A second period of deformation, a gentle tilting of the area toward the west, took place prior to the deposition of the Shinarump conglomerate. The Moenkopi formation thins from 1,120 feet along Whiterocks River to 745 feet on the flanks of Split Mountain anticline. At least some of this thinning is due to erosion of the top of the Moenkopi which was exposed by regional tilting of the area.

The principal deformation of the strata in the area followed the deposition of the youngest Cretaceous rocks, the Mesaverde formation, and during the deposition of the earliest Tertiary rocks. Deformation did not come as a single spasm, but as a series of movements, because no pronounced angular unconformity is present at the base of the Tertiary. There is very little discrepancy in dip between the Upper Cretaceous and the lowest Tertiary sedimentary rocks; however, a pronounced angular unconformity is present at places where the Cretaceous rocks are overlain by late Tertiary rocks (the Bishop conglomerate of possible Miocene age). This observation suggests that there was continued uplift through Paleocene, Eocene, and Oligocene time into the Miocene, when uplift had almost ceased. This movement may have been caused by continued uplift of the block underlying the Uinta Mountains, by downwarping of the Uinta Basin, or by isostatic adjustment of the mountain and basin blocks as eroded sediments were transported from the mountains and deposited in the basin. The faulting and folding involved in the relative rise of the Uinta Mountain arch were not uniformly distributed but were concentrated in an elongate zone paralleling the axis of the uplift. This zone now corresponds with the area of outcrop of the strata of Mesozoic age. Dips in the area underlain by pre-Cambrian rocks in the central mass of the Uinta Mountains are gentle, and the Tertiary rocks of the Uinta Basin are almost flat lying.

GEOMORPHOLOGY

GENERAL FEATURES

The geomorphology and late Cenozoic history of the eastern Uinta Mountains have been the subject of many papers and much speculation since the exploration of the area by geologists and geographers of early Territorial Surveys. The interest in the area has centered on the anomalous position of the Green River, which crosses the axis of the Uinta Mountain uplift in a deep canyon cut in resistant rock, whereas an alternate course to the east would have avoided the uplift; on the relationship of the Browns Park formation to the Bishop conglomerate; and on the late Cenozoic history of the area, including the glaciation. With the exception of the glaciation, the investigators have given only cursory attention to the geomorphic evidence present on the south flank of the range, and they quote the observations of J. W. Powell in their discussions.

GILBERT PEAK SURFACE

The Gilbert Peak surface, upon which the Bishop conglomerate was deposited, is a surface of very low relief that usually slopes radially from the higher peaks and northward and southward from the crest of the range. The Gilbert Peak surface, now exposed, was cut on the quartzite of the Uinta Mountain group; it is due to the resistance of this formation that exposed portions of the erosion surface have been preserved. This surface is shown on plate 3 between Whiterocks River and Paradise Creek, northwest of the East Fork of Dry Fork of Ashley Creek, and on the north side of Taylor Mountain. On the younger rocks of Paleozoic and Mesozoic age, the Gilbert Peak surface is preserved only where it is protected by the overlying Bishop conglomerate; it appears as a line marking the lower boundary of the Bishop. The surface has been warped into a shallow syncline whose axis is parallel to, and approximately 3 miles south of, the South Flank fault zone. The altitude of the surface (lower boundary of the bishop) decreases gradually from Uinta River eastward to Diamond Mountain. The surface probably is continued eastward in the form of the flat-topped crest of Split Mountain and Blue Mountain.

Coarse-grained sediments derived from glacial erosion are classified as "glacial moraine" or as "glacial outwash material." These subdivisions are further divided on their relative time of formation into moraines of earliest glaciation, moraines of maximum glaciation, moraines of latest glaciation, and their respective outwash plains. The moraines were deposited directly by ice and still retain much of their original form. The glacial outwash material has been deposited by streams flowing from the glaciers. In the field, and during subsequent stereoscopic study of the contact aerial photographs, end moraines, ground moraines, and lateral moraines have been recognized, but due to the difficulty of drawing boundaries between the different types of moraines, all morainal material deposited by the same glacial advance is grouped together. Deposits of proglacial streams are classified as glacial outwash material when the source of the deposit is sufficiently close to warrant correlation, and they are termed erosion surfaces (see Vernal and Thornburg erosion surfaces above) when the gravel and boulder cover is thin and so far removed from its source that correlation with glacial deposits is problematic.

South of the Uinta Mountain front, erosion of rocks of Mesozoic and Tertiary age has formed an area of lower relief. Three gravel-veneered erosion surfaces of probable Quaternary age have been differentiated in the mapping. The older terrace, here named the "Jensen surface" (Qj), is subdivided into an upper surface (Qj_1) and a lower surface (Qj_2). Remnants of the Jensen surface flank the higher mountains or cap interstream divides. The lower surfaces, the "Vernal" (Qtv) and the "Thornburg" (Qtt) strath terraces, parallel the present stream channels. The Vernal surface, as mapped along Ashley Creek, includes two closely related strath terraces (Qtv_1) and (Qtv_2).

The basic data bearing on the late Cenozoic history of the area have been assembled from plate 1, and the photomosaics and are consolidated on plate 3 which shows the erosion surfaces and deposits of late Cenozoic age in the Uinta River-Brush Creek area. The main mass of the Uinta Mountains, as shown on plates 1 and 3, extends from

Jefferson Park on the west, eastward to Diamond Mountain and forms a high, rolling, dissected plateau that slopes southward from the crest of the range and decreases in elevation toward the east. The similarity of the summit elevations of the higher portions of this plateau are a striking feature of the geomorphology of the mountains. This high-level surface, herein named the "Lake Mountain" surface, is cut on the Bishop conglomerate which, in turn, rests on the "Gilbert Peak" surface, which was named by Bradley (1936, p. 169) from the north flank of the Uinta Mountains. The Gilbert Peak and Lake Mountain surfaces are believed to be late Tertiary in age.

LAKE MOUNTAIN SURFACE

The upper surface of Jefferson Park, Pole Mountain, Mosby Mountain, Lake Mountain, Dry Fork Mountain, Little Mountain, the area between Ashley Creek and Brush Creek, the area between Brush Creek and Little Brush Creek, and Diamond Mountain are remnants of a once extensive erosional surface cut on the Bishop conglomerate. The surface slopes southward from the crest of the Uinta Mountains at a rate of 65 to 100 feet per mile. It also slopes, or has been tilted eastward, at a rate of 30 to 35 feet per mile, or from an elevation of 10,300 feet at Jefferson Park to 7,800 feet on a few isolated flat-topped buttes on Diamond Mountain. The surface is here named the "Lake Mountain erosion surface" for the flat-topped mountain in T. 2 S., R. 19 E. The Bishop conglomerate presumably spread southward and eastward from the crest of the Uinta Mountains sometime during late Tertiary time, and the Lake Mountain surface was developed as a final stage of deposition or by later erosion. The surface apparently extended northward from Diamond Mountain into the area now occupied by the tributaries of Pot Creek. It was on this surface that the antecedents of the present Green River must have eroded headward or have been superposed from unconformable cover across the axis of the Uinta Mountain arch and Split Mountain anticline. With the inauguration of exterior drainage through the ancestral Green River to the Colorado River, erosion of the Tertiary sediments of the Uinta Basin and dissection of the Lake Mountain surface began. The Lake Mountain surface is more fully preserved west of Ashley Creek than on Diamond Mountain.

JENSEN SURFACE

The erosion of the early Tertiary sedimentary rocks in the central part of the Uinta Basin and the removal of the Bishop conglomerate from the area to the south of the present exposures required vigorous erosion and a long period of time. The erosion was not continuous, and pauses in the late erosional history of the area are recorded by two, or more, gravel-covered erosion surfaces. These surfaces are best preserved on the upper shale member of the Mancos shale between Ashley Creek and Brush Creek and are here named the "Jensen surfaces," for the community of Jensen on the Green River between the mouths of Brush Creek and Ashley Creek. The higher of the surfaces (Qj_1) is 50 to 75 feet above another surface (Qj_2), which in turn, is 250 to 300 feet above the present stream level. A veneer of caliche-coated gravel and boulders, ranging from 5 to 10 feet in thickness, caps these surfaces and contains representative rock types from the Bishop conglomerate. The pebbles and boulders on the surface are well-rounded. The surface slopes away from the higher hills at a rate of 100 to 200 feet per mile.

Those surfaces designated Qj_1 are correlated because they have similar characteristics and are adjacent to surfaces 50 or more feet lower; they may be remnants of one continuous surface. The gradient of the surfaces, the thickness of the gravel cover, and the geographical location of the Jensen surface abutting higher hills are characteristic of pediments cut under arid conditions. The lower Jensen surface (Qj_2) is well exposed on Sunshine Bench in Ts. 4 and 5 S., R. 22 E., between Ashley Creek and Brush Creek. The higher surface on Sunshine Bench is represented by a cluster of small buttes in sec. 18, T. 5 S., R. 22 E. Surfaces correlated with Qj_1 and Qj_2, along Brush Creek and north of Split Mountain, are more abundant and, except for a difference in elevation, they maintain a close relationship to each other.

The Jensen surface has also been recognized on the east and south sides of Little Mountain, the west side of Ashley Creek, east and west of Whiterocks River, and between Uinta River and Dry Gulch. These surfaces probably truncated the hogback formed by the Frontier sandstone member of the Mancos shale, from Little Mountain eastward to Diamond Mountain, at about the altitude of the present crest of the escarpment. The surfaces were formed during periods of crustal stability, uniform climate, and constant base level of the master stream in the area. Lateral planation and slope wash were the dominant agencies during formation.

YOUNGER EROSION SURFACES

One hundred and fifty to 180 feet below the Jensen surface and 100 to 125 feet above the present stream level of Ashley Creek there is a second and lower erosion surface, here named the "Vernal strath terrace" (Qtv_1), for its development along Ashley Creek, east of Vernal, Utah. A second and slightly lower terrace (Qtv_2), grouped with the Vernal surface, is present along the west side of Ashley Creek from sec. 9 to sec. 36, T. 5 S., R. 22 E., and along the Green River from sec. 24, T. 5 S., R 22 E., northeastward to Brush Creek. Terraces along the east side of the Green River and a rolling upland surface extending eastward from the river are correlated with the lower Vernal surface. The soil and debris that is mapped with the lower Vernal surface east of the Green River may be, in part, wind-transported material that was deposited during the time that the lower Vernal surface was being cut in the Ashley Valley.

The main Vernal terrace (Qtv or Qtv_1) is cut on the soft clay shale of the upper shale member of the Mancos shale; it is covered with 5 to 10 feet of boulders and coarse gravel. Most of the boulders are well-rounded, red quartzite of the Uinta Mountain group. Springs and seeps mark the base of the gravel cover on the west side of Ashley Creek. The main Vernal surface probably had its origin in the lateral planation of Ashley Creek during the interglacial stage that followed maximum glaciation in the Uinta Mountains; it tentatively is correlated with the glacial outwash from that glaciation.

Located 50 feet below the Vernal surface and 55 feet above the present low water level of Ashley Creek, there is a younger erosion surface called the "Thornburg strath terrace," which was named for Fort Thornburg (an early Army post located in the Ashley Valley north of Vernal). The Thornburg surface is also cut in soft Mancos shale and veneered with 5 to 10 feet of red quartzite boulders. It had the smallest extent of any of the erosion surfaces, and the present flood plain of Ashley Creek has largely destroyed its original development. In all probability, it dates from the closing phase of the latest glaciation in the mountains.

GLACIAL DEPOSITS

Distribution.—Atwood (1909, p. 12 and pl. 4) has shown that the the largest and longest glaciers in the Uinta Mountains had their source in the high peaks near the central part of the range and that they rapidly diminished in size and length towards the east and the west. For the most part, the size of the glaciers was directly proportional to their drainage areas. The eastward decrease in size and maximum extent of the glaciers is shown by the areal extent of the glacial deposits on the map (pl. 3).

The most extensive glacial deposits in the area are found either in the canyon of Uinta River, or adjacent to it. Massive moraines also are present in the valley of Dry Gulch to the west of Uinta River. Morainal deposits on Whiterocks River and on Dry Gulch of Ashley Creek are much less prominent than those on Uinta River. The broad flat area of glacial terrain in the headwaters of Ashley Creek probably was occupied by a nevé field. The ice formed at that place must have been thin; thus it performed less erosion and failed to move down the valley of Ashley Creek.

Lithology and dating of glacial advances. — The rock fragments making up the morainal deposits and glacial outwash plains are almost exclusively of red, tan, and white quartzite and quartzitic sandstone derived from the Uinta Mountain group. The lack of coarse-grained igneous rocks, limestone and other rocks in the central part of the range, which would yield a soil profile that would vary in depth with the time of exposure to natural weathering processes, makes it difficult to determine the relative ages of the separate ice advances in the Uinta Mountains. In the absence of soil profiles, the dating of successive ice advances is based upon: (1) relative freshness of geomorphic and topographic features (steepness of end moraines, dissection by later outwash waters, abundance of small lakes, etc.), (2) relationship of surfaces underlying different moraines, (3) relationship of lateral moraines to the end moraines of other ice advances, and (4) correlation of terrace deposits related to certain glacial moraines and outwash plains. Although the use of these criteria does not give the relative time between successive ice advances, a very satisfactory chronological succession and correlation of moraines, outwash plains, and terrace deposits is possible within the area.

Earliest glaciation.—The moraine of earliest glaciation rests on a remnant of the Jensen erosion surface in the S½ T. 2 N., R. 2 W., located 1 to 3 miles west of Uinta River. This earlier moraine has been considerably eroded by outwash waters, but it still includes shallow closed depressions, one of which has been converted and enlarged to serve as an Indian Service reservoir by building a dam on the lower side. The end moraine is 100 to 150 feet high, but it presents gently rounded contours and a fairly gentle front. Boulders and blocks of massive red quartzite are prominent constituents of the morainal material. The end moraine is cut off on a line from the NE¼ sec. 21 to the center of sec. 8, T. 2 N., R. 2 W., by the lateral moraine formed by the most recent ice advance in Uinta Canyon. Probably because the Jensen erosion surface has been largely destroyed adjacent to canyons down which the glaciers moved, this earliest moraine is not present elsewhere in the area. Glacial outwash from earlier glaciation formed an outwash plain that must have stretched southward for many miles. The surface of the outwash is only 10 to 15 feet below the level of the Jensen surface adjacent to the corresponding end moraine; however, a difference in elevation of 300 to 500 feet separates the surfaces in the NE¼ T. 1 N., R. 3 W. Although no morainal material of this earliest glaciation is located along Whiterocks River, isolated remnants of an erosion surface, 300 to 400 feet below the Jensen surface and similar to the outwash plain of the earliest glaciation west of Uinta Canyon, is present in secs. 23, 26, and 35, T. 2 N., R. 1 W. The surface is continued to the southwest by channels in sec. 34, and by outwash debris in secs. 20, 21, 27, 28, 29, 33, and 34, T. 2 N., R. 1 W., and secs. 3 and 4 of T. 1 N., R. 1 W.

Maximum glaciation.—The moraine of maximum glaciation in Uinta Canyon reaches an altitude of 7,000 feet on the southern border of T. 2 N. The end moraine, composed of angular pieces of quartzite, forms a ridge, 75 to 100 feet high, which swings eastward across the southern border of secs. 35 and 36 towards the Uinta River. More recent proglacial streams have removed much of this end moraine, which at one time must have joined the massive lateral moraine that is now terminated by the Uinta River in sec. 25, T. 2 N., R. 2 W., on the east side of Uinta Canyon. The lateral moraines of the maximum glaciation throughout most of the length of Uinta Canyon were altered by the latest glaciation. This later glaciation carried very little rock debris, and most of the massive lateral moraine on both the east and west sides of Uinta Canyon probably was deposited by the maximum glaciation. The ridge, which separates the channel of Pole Creek from Uinta Canyon in the E½ T. 2 N., R. 2 W., and which therefore causes the two streams to flow parallel for a distance of 4 miles, is probably underlain by lateral moraine with a core of rocks of Paleozoic, Mesozoic, and Tertiary age. The present channel of Uinta River has been incised into the end moraine blocking the canyon mouth to form a narrow notch 100 to 200 feet deep.

A small ice lobe diverged from the main glacier flowing in Uinta Canyon in sec. 3, T. 2 N., R. 2 W., and deposited an end moraine in secs. 11 and 12 in the Pole Creek drainage. The moraine still shows a few closed depressions, but the contours are gently rounded, thus indicating that considerable time for erosion has elapsed since deposition. Two glacial moraines showing a similar stage of dissection are found in Pole Creek tributaries. One moraine, located in the main channel of Pole Creek, terminates in the N½ sec. 26, T. 3 N., R. 2 W., and the other moraine, located in the southeastern continuation of Clover Creek, reaches into sec. 34, T. 3 N., R. 2 W. Clover Creek, during Pleistocene time, was a tributary of Pole Creek; recently, it has breached the lateral moraine of Uinta Canyon and has entered Uinta River in sec. 32, T. 3 N., R. 2 W.

In Dry Gulch, the moraine that is correlated with the maximum glaciation in Uinta River reaches to an approximate altitude of 8,200 feet in secs. 20 and 21, T. 2 N., R. 3 W. The morainal front is steep and well defined, and small lakes and closed depressions dot the area behind the front. The glacier that deposited this end moraine probably had its source in the headwaters of Dry Gulch and in the West Fork of Dry Gulch. Glacial outwash material from this glaciation formed a plain now preserved in secs. 20, 21, and 28, T. 2 N., R. 3 W., and in the NW. part of T. 1 N., R. 3 W.

The end moraine on Whiterocks River, correlated with the maximum glaciation in Uinta Canyon, descended to an altitude of 7,200 feet in sec. 18, T. 2 N., R. 1 E. This moraine has been greatly altered by proglacial streams, and the topographic expression has been largely destroyed. Large quartzite blocks dot the surface of the moraine. Most of the lateral moraines on canyon walls have been destroyed by the slumping of the shale in the upper member of the Uinta Mountain group.

Glacial stages in Dry Fork of Ashley Creek cannot be differentiated. By means of comparison with Uinta Canyon, most of the morainal material that clogs the canyon of Dry Fork north of Lake Mountain and east of Mosby Mountain is found to belong to the stage of maximum glacial advance. The glacier that flowed down the valley of Dry Fork stayed well within the mountain front, reaching no lower than an altitude of 8,000 feet. It was broader than the glaciers in the canyons of Uinta River and Whiterocks River, and it left a wide belt of poorly drained bogs and small lakes on the eastern side of Mosby Creek and on the divide between the North Fork of Dry Fork and Dry Fork. At places, as in the area east of Mosby Mountain, it flowed around islands of hard quartzite of the Uinta Mountain group. During its farthest advance, it extended into the drainage of the North Fork of Dry Fork and in the main channel of Dry Fork, to a point directly north of Lake Mountain. The end moraine marking this maximum advance is very massive, and the only breach that has been made by the present stream in Dry Fork is a narrow V-shaped notch. At its maximum extent, the glacial ice formed a short lobe that extended into the headwaters of the present Mosby Creek, where it deposited a rocky morainal ridge. The failure of the glacier to extend farther down the main canyon in Dry Fork is probably due to the inability of the ice advance to negotiate the sharp bend in the original stream channel.

No definite correlation is possible between the nevé field (which led to the development of the wide, poorly drained area of lakes, swamps, and forest in the headwaters of Ashley Creek) and the glacial stages recognized in Uinta Canyon. However, it is probable that the nevé field was in existence at the time of maximum glacial development in the canyons to the west.

Latest glaciation.—The most recent glacier to occupy the canyon of Uinta River failed (by more than a mile) to reach as far south as the previous ice advance. Although it was not heavily laden with glacial debris, it deposited a small end moraine and prominent lateral moraines, which extended along both the western and eastern sides of the canyon to a height of more than 800 feet above the present valley floor in T. 3 N., R. 2 W. On the west side of Uinta River, the lateral moraine is 150 to 200 feet high, and it dams the streams entering from the west to form small lakes or marshes. On the east side of the canyon, the lateral moraine is not distinct in T. 2 N. where it forms a part of the ridge dividing Pole Creek from Uinta River. Northward, in T. 3 N., the lateral moraine forms a ridge and trench that have been breached at several places by streams entering from the east. A series of ice-contact features (areas of slump and ridges parallel to the edge of the glacier ice) mark the ground moraine on the east side of Uinta River near the middle of T. 2 N., R. 2 W., and provide abundant evidence that ice occupied the canyon very recently.

End moraines in tributaries of Pole Creek correlated with the most recent glacial advance in Uinta Canyon are marked by an extremely youthful appearance, steep fronts, and a poorly drained, hummocky topography covered by dense undergrowth. The moraine in the southeastern extension of Clover Creek reached to the SE¼ sec. 28, T. 3 N., R. 2 W. It has the most youthful appearance of any moraine in the area because the melt water, which would have partly destroyed the ice-deposited rock, is diverted to the Uinta River upstream from the massive end moraine.

Two moraines in the Dry Gulch area are correlated with the most recent glacial advance. The first moraine lies in secs. 5, 8, and 17, T. 2 N., R. 3 W. It is dotted with small lakes and has a steep foot that rises above the overridden moraine of maximum glaciation. It came from the West Fork of Dry Gulch, west of the mapped area. The second moraine lies in sec. 4, T. 2 N., R. 3 W., and sec. 33, T. 3 N., R. 3 W., across the main channel of Dry Fork. The moraine has dammed the main stream to form Heller Lake in sec. 33, and the overflow from the lake is slowly cutting a deeper channel through the moraine.

The end moraine of the latest glaciation in Whiterocks Canyon reaches to an altitude of 7,300 feet and extends to the center of sec. 7, T. 2 N., R. 1 E. Most of the morainal material is on the east side of the canyon because the stream hugs the west bank and has removed all but a small quantity of glacial debris from that side. The thickest part of the moraine occurs immediately south of the narrowing of the canyon (which was caused by the resistant walls of the limestone unit of Mississippian age). Whiterocks River exposes excellent cross sections of the morainal material along its banks. The thickness of the ice-deposited material decreases abruptly in the northern part of sec. 7, and a poorly drained ground moraine occupies the canyon to the north. Definite lateral moraines related to this ice advance are not as prominent as in Uinta Canyon but the height of the ice deposits can be easily traced in the field.

The canyon of Dry Fork of Ashley Creek and the nevé field in the headwaters of Ashley Creek probably were occupied by ice during the latest glaciation period. However, the deposits of this stage cannot be differentiated from the deposits of maximum glaciation, and therefore they have been discussed in that section of this report.

Quartzite debris in the upper tributaries of Brush Creek and Little Brush Creek suggests the occurrence of ice transport but the area lacks any typical glacial depositional features. The valleys are wide and flat.

Correlation with glacial stages in adjacent areas.—It is difficult to correlate glacial advances in the Uinta River-Brush Creek area with the stages recognized by Bradley (1936, p. 194–195) on the north flank of the Uinta Mountains. The earliest glacial stage that moved outward on the Jensen surface probably corresponds to Bradley's Little Dry glacial stage, which advanced upon the Bear Mountain erosion surface. Bradley (1936, p. 196) by analogy correlates his Little Dry glacial stage with the Buffalo stage in the Wind River Range which Blackwelder (1932, p. 918) has suggested may be the equivalent of the Kansan stage of the standard section. The Little Dry glacial stage may be correlative with the stage that elsewhere in the Rocky Mountains is correlated with Atwood and Mather's (1932, p. 82–83) Cerro stage of glaciation in the San Juan Mountains. The maximum and latest glacial stages probably correspond to Bradley's Black Fork and Smith Fork stages; the latter is definitely of Wisconsin age.

CANYON DEVELOPMENT

The most rugged and picturesque scenery on the south flank of the Uinta Mountains is in the deep canyons that were cut by glacial ice and streams flowing from the higher portions of the mountains. Uinta Canyon and Whiterocks Canyon are steep-walled, flat-bottomed, or U-shaped valleys carved by glacier ice. The melt water from the glacier in Dry Fork of Ashley Creek and the melt water from the glacier in the headwater of the West Fork of Ashley Creek are responsible for cutting the steep V-shaped lower canyons of Dry Fork and Ashley Creek. Melt waters from the glacier in the headwaters of Ashley Creek also flowed southward to cut Black Canyon, and the stream to the west, known as East Fork of Dry Fork of Ashley Creek. Melt waters from the glacier in Dry Fork also cut the channel of Paradise Creek, a tributary of Whiterocks River. To a certain extent, the deep canyons of Brush Creek and Little Brush Creek, which cross the Weber sandstone, have been carved by streams swollen by the high precipitation of Pleistocene time; perhaps the melting of small glaciers or nevé fields in their headwaters aided in the development of the canyons.

ECONOMIC GEOLOGY

COAL

Introduction.—Coal beds of variable thickness occur in the upper part of the Frontier sandstone member of the Mancos shale. Coal has been recognized in the western part of T. 3 S., R. 19 E., in the Deep Creek area, eastward for a distance of 25 miles to the northwestern corner of T. 2 S., R. 23 E. and east of Little Brush Creek. It is also present south of the Island Park syncline on the westward extension of the Split Mountain anticline into T. 4 S., R. 22 E. Workable coal is not continuous, the individual beds occur as discontinuous lenses in brown shale. They are broken by faulting, concealed by unconformably overlying younger deposits, and may have been removed by erosion prior to the deposition of the overlying Frontier deposits. The coalbearing series is believed to be continuous across the area but the coal is not necessarily contemporaneous in deposition.

Coal is also reported to be present in the black shale unit of Mississippian age on Farm Creek and low-grade lignite is found in the Mesaverde formation along The Rim Rock (the extension of Asphalt Ridge east of the Green River). However, these occurrences are of minor importance.

The areas that have been mined for coal in the Frontier sandstone member of the Mancos shale are: (1) west of Deep Creek, (2) in Coal Mine Draw northwest of Vernal, (3) east and south of Steinaker Draw, and (4) along Brush Creek on the westward extension of the Split Mountain anticline. The areas of maximum development are largely controlled by the thickness of the coal, which locally thickens from an average of about 2 feet to 4 or 5 feet. Of secondary importance in regard to utilization is the distance of these local areas of thicker coal to the towns of Vernal, Fort Duchesne, and Roosevelt, Utah.

Maximum development of coal deposits in the Frontier sandstone member of the Mancos shale occurred from 1899 to 1929, when the isolated geographic position of the Uinta Basin, the lack of transportation facilities, and the high cost of freight into the basin made it necessary for the area to be almost self-sufficient. During this period, some individuals dug coal for their own use in small mines, and the larger mines in Coal Mine Draw, in Deep Creek, and along Brush Creek were developed. The decline in coal mining in the area was not prompted by a lack of coal or by poor quality of the mined product; it was caused by economic factors, including: (1) establishment of an oil refinery on the east bank of the Green River at Jensen making available a cheaper and more convenient fuel, (2) the development of the Ashley Creek gas field and the piping of the gas to the town of Vernal for heating and cooking, (3) the manufacture of hydroelectric power on Ashley Creek, (4) the improvement of roads and truck transportation and the cutting of mine props in the Uinta Mountains for the mines in Carbon County to the southwest (trucks taking props to the mine return with coal), and (5) the development in 1948–49 of the old Ashley Creek gas field as an oilfield. During the fall of 1947, only the Wardle mine (previously known as the Joe Rich mine) in SW¼SW¼ sec. 2, T. 4 S., R. 20 E., was in operation, although others might have been worked for short periods by individuals to supply their own needs. Probably not more than six mines in the entire area were operated during the period 1927–47.

Previous geologic investigations of the coal deposits.—Although coal deposits in the lower part of the Mancos shale had been noted by Hayden and Powell, the first survey devoted primarily to coal resources was by Hoyt S. Gale and party in 1907, and the report was published as U. S. Geological Survey Bulletin 415 (1910, p. 204–219). Gale's work extended westward to Coal Mine Draw on the east side of Little Mountain and 7 miles west of Vernal, Utah. The Deep Creek area of the Vernal coal district to the west of Little Mountain was studied by C. T. Lupton and partly in 1910 and was published as part of Geological Survey Bulletin 471 (1912, p. 579–594). While surveying the Deep Creek area, Lupton and his party also visited the mines on Brush Creek and north of Vernal (which had been studied by Gale) and measured many detailed coal sections in that area. In 1920, C. A. Allen, of the U. S. Bureau of Mines, sampled a coal section at the Rasmussen mine in the Deep Creek area; J. J. Bourquin and W. F. Murray, of the Conservation Division, U. S. Geological Survey, measured and sampled five detailed coal sections at active mines in the area in 1926. Since that time, other members of the Conservation Division have measured coal sections in mines operated on Government land.

To give as complete a picture as possible of coal occurring in the Frontier sandstone member of the Mancos shale in the Vernal area, selected coal sections at intervals across the area are given in plate 4. These include a few sections given in Bulletins 415 and 471, and many other coal sections measured by other geologists whose work has not been published. Where more than one section was available for a mine, a single representative section is given. All sections for which analyses have been made are included in plate 4, in order to give a complete picture of the chemical and physical composition of the coal. Earlier work is also included because exposed coal sections rapidly deteriorate, and coal sections from mines or prospects that were active 20 to 40 years ago (and measured at that time) are far superior to sections that can be measured at the present time.

Detailed stratigraphy of coal occurrences.—The detailed stratigraphy of the coal-producing beds as given on plate 4 is obtained from 52 measured sections, extending from the Warburton mine in the western part of the Deep Creek area, eastward to the mines and prospects on Brush Creek. The sections are correlated by alining the top of the coal horizon. The position of the coal in respect to the sandstone beds of the Frontier member of the Mancos shale changes progressively eastward across the area from a position lying above the sandstone along Deep Creek to 65 feet below the top of the sandstone at Coal Mine Draw east of Little Brush Creek, and then to 90 feet below the top of the sandstone at the Collier mine, as is shown in the following hand-leveled sections:

Coal Mine Draw section

[Measured by D. M. Kinney]

	Feet
Mancos shale:	
Upper shale member:	
Frontier sandstone member:	
Sandstone, tan to white, in part crossbedded, fine- to medium-grained	60.0
Gray shale, with sandstone pebbles	.25
Shale, sandy, gray, carbonaceous	.25
Sandstone, white, poorly bedded	5.5
Coal	.9
Shale, black, carbonaceous	.1
Coal	.25
Shale, gray, with conchoidal fracture	2.5
Shale, black, carbonaceaus, with streaks of coaly material	2.1
Sandstone, thick (base of measured section).	

Collier Mine section

[Measured by D. M. Kinney]

	Feet
Sandstone, light-gray, tan-weathering, massive, fine-grained	19.0
Covered, sandstone, light-gray, thin-bedded with shale partings	18.8
Sandstone, light-gray, tan-weathering, fine-grained, ledge forming	3.0
Covered; sandstone, light-gray, thin-bedded and shale	6.0
Sandstone, light-gray, fine-grained, hard, massive	3.5
Covered, probably light-gray, shale and interbedded fine-grained sandstone	27.0
Sandstone, light-gray, tan-weathering, fine-grained, hard	1.5
Sandstone, thin-bedded, light-gray, and sandy, light-gray shale	8.0
Sandstone, light-gray, thin-bedded, fine- to medium-grained	4.3
Coal, with shaly streaks	3.5
Covered; shale and thin-bedded, medium-grained, carbonaceous gray sandstone	20.0
Sandstone, light-gray, massive, medium-grained, crossbedded	8.0

The continuity of the coal beds cannot be proved because of the nature of the outcrops and because of interruptions of exposures by unconformably overlying deposits, particularly on Little Mountain, in Ashley Valley, and on Diamond Mountain. The coal sections in T. 4 S., R. 22 E., along Brush Creek, are separated from exposures to the west and north by the upper member of the Mancos shale in the Island Park syncline.

In coal section No. 33, a thin upper coal, located 8 feet above what has been interpreted as the main coal horizon, was measured. Gale (1910, p. 217) mentions, "Another small coal bed about 8 or 10 inches thick crops in the hillside above the main entry [of the Joseph Rich mine]." The measured section at the Joseph Rich mine (coal section No. 14) shows a coal bed at the same general stratigraphic position as the thin upper coal of coal section No. 33. Careful search of this horizon in the intervening area may result in identification of the upper bed elsewhere. However, it probably is not of economic importance because it would have been opened by prospects between Ashley Creek and Brush Creek.

Character of the coal.—Fresh surfaces of the coal are black and vitreous, but weathered surfaces are dull. The coal is hard and brittle, and its fracture ranges from uneven to regular. The structure of the coal is prominently bedded only on weathered surfaces.

As can be noted from the plotted sections on plate 4, the coal is interbedded with bone, dirty coal, and shale, thus making physical separation of waste difficult.

Chemical characteristics.—All coal analyses in the Vernal district (including 16 analyses from 12 mines) are given in the table below. Analyses are listed by number and mine name to correspond to the numbers of the graphic sections given on plate 4. In addition to the proximate, sulfur, air-drying loss, and calorific values, the sampler, the analyst, alternate mine names, laboratory number, ultimate analysis, and softening temperature are given where such information is available.

Analyses Nos. 5,511, 5,753, 5,754, 5,755, 5,515, 5,517, and 5,518 (bearing laboratory numbers in the 5,000 series) were made at Pittsburgh, where it was later discovered that the natural gas burners gave high results for fixed carbon. These analyses cannot be used in the classification of coal (American Society for Testing Materials, 1938, p. 6) but all acceptable analyses indicate that the coal in the Frontier sandstone member of the Mancos shale in the Vernal district should be classed as high volatile C bituminous, in accordance with the classification of the American Society for Testing Materials (1938, p. 2).

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Coal analyses from 12 mines in the Vernal district

[Coal sections numbered to correspond with plate 4. Condition of sample: 1, as received; 2, dry coal; 3, moisture and ash-free]

Coal section No.	Mine (locality)	Sample		Proximate (percent)			Ultimate (percent)						Air-drying loss (percent)	Calorific value		Softening temperature (° F.)
		Laboratory No.	Condition	Moisture	Volatile matter	Fixed carbon	Ash	Sulfur	Hydrogen	Carbon	Nitrogen	Oxygen		Calories	B. t. u.	
3	Rasmussen Bros., just off slope 300 feet from surface, cover 50 feet.	[1] 83,228	1	9.6	37.0	46.4	6.8	0.9	-------	-------	-------	-------	4.0	6,485	11,674	2,510
			2	-------	40.9	51.4	7.6	1.0	-------	-------	-------	-------	-------	7,174	12,915	-------
			3	-------	44.3	55.6	-------	1.1	-------	-------	-------	-------	-------	7,766	13,980	-------
2	F. A. Gross mine	[2] A23388	1	8.8	36.8	44.3	10.1	2.4	5.5	63.0	1.1	17.9	2.1	6,189	11,140	-------
			2	-------	40.3	48.6	11.1	2.6	4.9	69.1	1.2	11.1	-------	6,783	12,210	-------
			3	-------	45.3	54.7	-------	2.9	5.5	77.7	1.3	12.6	-------	7,628	13,730	-------
4	Reynolds mine	[3] 10,812	1	11.3	35.6	46.4	6.7	.95	-------	-------	-------	-------	4.5	6,322	11,380	2,740
			2	-------	40.1	52.3	7.6	1.07	-------	-------	-------	-------	-------	7,128	12,830	-------
			3	-------	43.3	56.6	-------	1.16	-------	-------	-------	-------	-------	7,710	13,880	-------
13	Gray mine, 46½-inch cut	[4] 5,511	1	8.5	34.3	47.1	10.1	1.6	5.3	62.8	1.0	19.2	2.9	6,250	11,250	-------
			2	-------	37.5	51.5	11.0	1.7	4.8	68.6	1.1	12.8	-------	6,828	12,290	-------
			3	-------	42.1	57.9	-------	1.9	5.4	77.1	1.2	14.4	-------	7,672	13,810	-------
13	Gray mine, 42-inch cut	[4] 5,753	1	8.6	36.4	47.7	7.3	1.3	5.6	65.6	1.1	19.1	2.6	6,600	11,880	-------
			2	-------	39.9	52.1	8.0	1.4	5.1	71.8	1.2	12.5	-------	7,222	13,000	-------
			3	-------	43.3	56.7	-------	1.5	5.5	78.0	1.3	13.7	-------	7,856	14,140	-------
14	Joseph Rich mine (now known as the Wardle mine).	[2] A23384	1	8.8	38.2	44.9	8.1	1.5	5.6	65.7	1.1	18.0	-------	6,467	11,640	-------
			2	-------	41.9	49.3	8.8	1.7	5.1	72.1	1.2	11.1	-------	7,094	12,770	-------
			3	-------	46.0	54.0	-------	1.8	5.6	79.1	1.4	12.1	-------	7,783	14,010	-------
15	Timothy mine, 2 lower benches, 17½-inch cut.	[4] 5,754	1	8.2	35.7	45.8	10.3	1.3	5.5	63.5	1.0	18.4	2.3	6,344	11,420	-------
			2	-------	38.9	49.9	11.2	1.4	5.0	69.2	1.1	12.1	-------	6,917	12,450	-------
			3	-------	43.8	56.2	-------	1.5	5.6	78.0	1.2	13.7	-------	7,790	14,020	-------
15	Timothy mine, 2 upper benches, 33½-inch cut.	[4] 5,755	1	8.6	36.7	46.7	8.0	2.1	5.8	65.7	1.0	17.4	2.5	6,539	11,770	-------
			2	-------	40.2	51.1	8.7	2.3	5.2	71.9	1.1	10.8	-------	7,156	12,880	-------
			3	-------	44.0	56.0	-------	2.5	5.7	78.7	1.2	11.9	-------	7,839	14,110	-------
16	Pack Allan Coal Co. mine (known earlier as the C. C. Rich mine).	[2] A23378	1	8.6	38.6	42.9	9.9	1.8	5.6	63.2	1.1	18.4	2.5	6,306	11,350	-------
			2	-------	42.2	47.0	10.8	2.0	5.0	69.2	1.2	11.8	-------	6,906	12,430	-------
			3	-------	47.3	52.7	-------	2.2	5.6	77.6	1.4	13.2	-------	7,739	13,930	-------
20	Gibson mine, lower 14 inches of 22-inch top bench.	[4] 5,515	1	9.4	32.8	44.9	12.9	1.9	5.1	57.8	.9	21.4	3.0	5,761	10,370	-------
			2	-------	36.2	49.6	14.2	2.1	4.5	63.8	1.0	14.4	-------	6,361	11,450	-------
			3	-------	42.2	57.8	-------	2.5	5.2	74.4	1.2	16.7	-------	7,411	13,340	-------

20	Gibson mine, middle bench, 42½-inch cut.	[4] 5, 517	1	11. 7	34. 4	44. 5	9. 4	1. 9	5. 6	59. 2	0. 9	23. 0	4. 4	5, 878	10, 580	
			2		38. 9	50. 4	10. 7	2. 2	4. 9	67. 0	1. 0	14. 2		6, 650	11, 970	
			3		43. 6	56. 4		2. 4	5. 5	75. 0	1. 2	15. 9		7, 444	13, 400	
20	Gibson mine, lower bench, 21-inch cut.	[4] 5, 518	1	10. 2	32. 7	44. 8	12. 3	. 8	5. 3	60. 0	1. 0	20. 6	3. 3	5, 939	10, 690	
			2		36. 4	50. 0	13. 6	. 9	4. 6	66. 9	1. 1	12. 9		6, 611	11, 900	
			3		42. 2	57. 8		1. 0	5. 4	77. 4	1. 2	15. 0		7, 656	13, 780	
28	Blue Bell (Massey) mine, 225 feet on main entry.	[5] 10, 712	1	9. 8	37. 2	43. 5	9. 5	1. 5					1. 8			2, 520
			2		41. 2	48. 2	10. 6	1. 7								
			3													
43	Green mine	[4] 10, 713	1	8. 8	38. 8	44. 2	8. 2	2. 4					1. 1			2, 370
			2		42. 6	48. 4	9. 0	2. 6								
			3													
45	Joseph Dudley mine	[2] A23386	1	8. 4	38. 3	43. 8	9. 5	1. 5	5. 5	64. 7	1. 1	17. 7	1. 8	6, 289	11, 320	2, 830
			2		41. 8	47. 8	10. 4	1. 6	4. 9	70. 6	1. 1	11. 4		6, 867	12, 360	
			3		46. 6	53. 4		1. 8	5. 5	78. 8	1. 3	12. 6		7, 667	13, 800	
48	Collier mine	[2] A23390	1	7. 9	39. 6	43. 8	8. 7	2. 4	5. 6	64. 8	1. 2	17. 3	1. 9	6, 417	11, 550	2, 390
			2		43. 0	47. 6	9. 4	2. 6	5. 1	70. 4	1. 3	11. 2		6, 967	12, 540	
			3		47. 5	52. 5		2. 9	5. 7	77. 7	1. 4	12. 3		7, 694	13, 850	

[1] Sampler, C. A. Allen; analyst, H. M. Cooper, U. S. Bureau of Mines.

[2] Sampler, J. J. Bourquin and W. F. Murray, U. S. Geological Survey; analyst, H. M. Cooper, U. S. Bureau of Mines.

[3] Sampler, C. T. Lupton and W. L. Mielke, U. S. Geological Survey; analyst, A. C. Fieldner, U. S. Bureau of Mines.

[4] Sampler and analyst are unknown.

[5] Sampler, C. T. Lupton, U. S. Geological Survey; analyst is unknown.

Coal in the black shale unit of Mississippian age.—Coal is reported to have been obtained from the upper part of the black shale unit of Mississippian age on Farm Creek in sec. 11, T. 2 N., R. 1 W., Uinta Special meridian. Coal prospects were located on the west side of Farm Creek, but landslides, which are prevalent in the black shale, have covered all traces of developmental work. Original claims filed on these prospects covered the SW¼ sec. 2, the E½ sec. 3, and the E½ of sec. 10, T. 2 N., R. 1 W. The SW¼ sec. 2 and the E½ sec. 3 are not underlain by the black shale, therefore it is possible that the prospects were located in ground that has been subjected to a landslide. Some lignitic material was noted in the soil underlain by the black shale unit on the trail near the crest of the divide between Farm Creek and Whiterocks River in the NW¼ sec. 12, T. 2 N., R. 1 W., and highly carbonaceous fissile shale is present at water level on Farm Creek. No record of the thickness of the coal beds in the rocks of Mississippian age is available.

Although showing higher fixed carbon, lower volatile matter and higher B. t. u. content than the coal in the Mancos shale, this coal is still high volatile C bituminous in rank. The abundance of pyrite (Fe_2S) in the black shale unit is probably responsible for the high sulfur content.

Percentage analyses of coal from two beds in the black shale unit of Mississippian age on Farm Creek, sec. 11, T. 2 N., R. 1 W., Uinta Special meridian

[Samples collected by J. C. Mulville, analyses by H. M. Cooper]

	Laboratory No.	Moisture	Volatile matter	Fixed carbon	Ash	Sulfur	Air drying loss	Calories	B. t. u.
Outcrop, upper vein [1]	83, 561	22	34. 9	50. 6	12. 3	1. 8	0. 4	7, 117	12, 810
Do.[2]			35. 7	51. 7	12. 6	1. 8		7, 278	13, 100
Outcrop, lower vein [1]	83, 562	7. 4	34. 2	48. 0	10. 4	2. 4	4. 9	6, 733	12, 120
Do.[2]			36. 9	51. 8	11. 3	2. 6		7, 272	13, 090

[1] As received.
[2] Dry coal.

Coal production.—The following table shows the production of coal from Uintah County. The information was obtained from publications of the U. S. Geological Survey; the U. S. Bureau of Mines; the Coal Mine Inspector, State of Utah; and the Industrial Commission, State of Utah. Where the published coal production from the area has been combined with the production from other counties to conceal the output of individual mines, the production from the Uinta River-Brush Creek area has been estimated. Because some of the small producers may have been omitted from the compilations, the larger published figure has been used in each case. In addition, the total yearly production probably can be increased by 10 percent to offset the omission of the small operations. Small producers probably were operating for a few years prior to 1896, but the correction figure is probably less than 1,000 short tons.

The noticeable drop in output from 1920 to 1921 and from 1929 to 1930 can be traced to a lower farm income during times of business recession. When farm and livestock prices are high, coal is purchased for domestic heating, but when prices are low, scrub cedar on the foothills is utilized.

Coal production of Uintah County, Utah, 1896–1948

Year	Short tons	Sources of information
1896	300	Estimated from combined statistics of Utah and Uintah Counties by U. S. Geological Survey.
1897	1,000	Estimated from combined statistics of Iron, Sanpete, and Uintah Counties by U. S. Geological Survey.
1898	5,000	Utah State Coal Mine Inspectors report.
1899	6,450	Do.
1900	6,500	Do.
1901	7,750	Do.
1902	3,540	U. S. Geological Survey.
1903	10,300	Utah State Coal Mine Inspectors report.
1904	12,200	Do.
1905	12,945	Estimated from production of Summit and Uintah Counties (U. S. Geological Survey) and Summit County (Utah State Coal Mine Inspectors report).
1906	3,887	Do.
1907	4,000	Estimated.
1908	5,150	U. S. Geological Survey.
1909	4,480	Do.
1910	8,590	Do.
1911	4,700	Utah State Coal Mine Inspectors report.
1912	6,800	U. S. Geological Survey.
1913	5,595	Utah State Coal Mine Inspectors report.
1914	4,879	U. S. Geological Survey.
1915	4,341	Utah State Coal Mine Inspectors report.
1916	3,785	Do.
1917	3,500	Estimated from combined production statistics of Summit and Uintah Counties by U. S. Geological Survey.
1918	6,100	Do.
1919	9,929	U. S. Geological Survey.
1920	9,228	Do.
1921	3,814	Do.
1922	3,015	Do.
1923	3,500	Estimated from combined statistics of Grand, Iron, San Juan, and Uintah Counties by U. S. Geological Survey.
1924	4,184	U. S. Geological Survey.
1925	5,214	Do.
1926	5,510	Do.
1927	6,000	Estimated from combined statistics of Grand, Iron, Summit, and Uintah Counties by U. S. Bureau of Mines.
1928	7,484	U. S. Bureau of Mines.
1929	5,860	Do.
1930	3,544	Do.
1931	2,500	Estimated from combined statistics of Grand, Iron, Kane, Sevier, Summit, and Uintah Counties.
1932	2,581	U. S. Bureau of Mines.
1933	2,422	Do.
1934	2,500	Estimated.
1935	2,500	Do.
1936	2,500	Do.
1937	2,500	Do.
1938	2,500	Do.
1939	2,500	Do.
1940	2,500	Do.
1941	2,500	Do.
1942	2,880	U. S. Bureau of Mines.
1943	2,000	Estimated.
1944	1,140	U. S. Bureau of Mines.
1945	1,000	Estimated.
1946	599	State of Utah, Biennial report of the Industrial Commission.
1947	2,496	Do.
1948	2,950	Do.
Total	239,642	

Coal reserves.—The following rules, definitions, and basic assumptions that have been used in calculating the original coal reserves in-sure that reserve estimates from widely separated localities have comparable basic data and that these estimates can be integrated on a regional or national scope:

(1) *Rank of coal.*—Where coal of more than one rank is covered by a report, the reserve data shall be reported separately for the coal of each rank, according to specifications of the American Society for Testing Materials (D 388–38).

(2) *Overburden.*—Reserve data shall be reported according to the amount of overburden on the coal as follows: A, 0–1,000 feet; B, 1,000–2,000 feet; C, 2,000–3,000 feet.

(3) *Classes of reserves.*—On the basis of the relative reliability of data on which calculations are based, coal reserves shall be reported in three separate classes as follows:

A. Measured coal.—Measured coal is that tonnage computed from dimensions revealed in outcrops, trenches, mine workings, and drill holes. The points of observation and measurement are so closely spaced, and the thickness and extent of the coal is so well defined that computed tonnage is judged to be accurate within 20 percent or less of the true tonnage. The points of observation are approximately half a mile apart.

B. Indicated coal.—Indicated coal is that tonnage computed partly from specific measurements, and partly from projection of visible data for a reasonable distance on geologic evidence. In general, the points of observation are 1 mile apart.

C. Inferred coal.—Inferred coal is the quantitative estimate based largely on broad knowledge of the geologic character of a bed, or region, for which there are few, if any, measurements. The estimates are based on an assumed continuity.

(4) *Size of unit area.*—Coal reserves shall be calculated and reported for small geographic areas.

(5) *Reserves in individual beds.*—Within the selected geographic area, reserves shall be reported for each individual bed, and all assumptions in regard to average thickness and areal extent shall be shown.

(6) *Thickness range.*—In all reports of coal reserves, subtotals shall be prepared to show the reserves contained in beds falling within the following thickness ranges:

A. For anthracite, semianthracite, and bituminous coal: (*a*) More than 42 inches, (*b*) 28 to 42 inches, (*c*) 14 *to* 28 inches.

B. For subbituminous coal and lignite: (*a*) More than 10 feet, (*b*) 5 to 10 feet, (*c*) 2½ to 5 feet.

(7) *Original reserves.*—For each bed, or part of a bed, within a prescribed thickness range, the original reserve prior to mining shall be calculated first, and reported separately; net, or short tons of 2,000 pounds shall be used in the reports.

A. Average thickness.—The use of isopach lines is the most effective way to evaluate the thickness of a bed. Generally, however, the data are insufficient for this purpose, and average figures must be used. When this is done, the averages must be weighted according to the approximate area of bed represented by each observation. . . . Partings of more than three-eighth inch thickness shall be omitted in determining the thickness of individual beds.

B. Areal extent.—The total area of coal of all classes may be determined in several ways. When the continuity of the bed is well established by maps, the entire area of known occurrence may be taken. Persistent beds that have traced around a basin or spur may be considered to underlie the area enclosed by the outcrop. Otherwise, the length of outcrop (within the thickness limits listed above) is considered to establish the presence of coal of all classes in a semicircular area having a diameter equal to the length of the outcrop.

C. Weight of coal.—When other precise data are not available, the following values shall be assigned as the weight of coal:

Anthracite and semi anthracite, 2,000 short tons per acre-foot.
Bituminous coal, 1,800 short tons per acre-foot.

All coal in the lower part of the Mancos shale is of high volatile C bituminous rank. Although enough measured sections are available over much of the area to classify the coal as "measured," it is considered "indicated" coal because rapid changes between coal and bone along the strike make it impossible to estimate tonnages within 20 percent. Two areas are classified "inferred" coal because, in spite of the fact that the coal outcrop is covered by unconformably overlying rocks, there is geologic evidence to believe that the coal bed is continuous beneath each area.

Calculation of reserve tonnage is based on the assumption that coal in the ground weighs 1,800 short tons per acre-foot; tonnage figures are given in thousands of short tons and are rounded off to the nearest 10,000 tons. In calculating the reserves remaining in the ground, the assumption is made that losses incident to mining activities are equal to the total production to date. Mining losses have been apportioned to different townships according to the mining activity and the total production estimated to have come from each area. Seventy percent of the district's production is assigned to the Coal Mine Draw area, and 15 percent is assigned to the Steinaker Draw-Brush Creek area and to the Deep Creek area. For the sake of uniformity with other reports on coal reserves, 50 percent is assumed for estimating future recovery.

The following table gives the coal-reserve estimates for the entire Vernal coalfield, as shown on plate 4.

Reserves of coal in the Vernal district, Uintah County, Utah

[Inferred reserves marked by an asterisk (*); all others classed as indicated reserves]

Overburden (feet)	Range in thickness (inches)	Area (acres)	Thickness of coal (feet)	Estimated original reserves (thousands of tons)	Total reserves (thousands of tons)	Mined or lost in mining (thousands of tons)	Remaining reserves, January 1950 (thousands of tons)	Recoverable reserves, January 1950 (thousands of tons)
Salt Lake meridian								
T. 3 S., R. 21 E.								
0–1,000	42							
	28–42	1,001.6	3.3	5,950				
	14–28	260.8	1.8	850	6,800	10	6,790	3,395
1,000–2,000	42							
	28–42	227.2	3.3	1,350				
	14–28	233.6	3.3	1,390	2,740	0	2,740	1,370
T. 3 S., R. 22 E.								
0–1,000	42	1,080.0	4.85	9,430				
	28–42	217.6	3.3	1,290				
	14–28	100.0	1.8	320				
	42	6.4	3.6	40				
	28–42	107.2	3.5	680				
	14–28	372.8	1.9	1,280	13,040	10	13,030	6,515
1,000–2,000	42	784.0	4.85	6,840				
	28–42	1,579.2	3.3	9,380				
	14–28	219.2	1.8	710				
	14–28	73.6	1.9	250	17,180	0	17,180	8,590
2,000–3,000	42	140.8	4.85	1,230				
	28–42	1,688.0	3.3	10,020				
	14–28	1,190.4	1.8	3,870	15,120	0	15,120	7,560
T. 3 S., R. 23 E.								
0–1,000	14–28	83.2	1.9	280	280	0	280	140

T. 4 S., R. 20 E.								
0–1,000	42	499.2	3.8	3,410				
	28–42	1,289.6	2.85	6,620	10,030	270	9,760	4,880
1,000–2,000	28–42	1,609.6	2.85	8,260	8,260	0	8,260	4,130
2,000–3,000	28–42	460.8	2.85	2,360	2,360	0	2,360	1,180
T. 4 S., R. 21 E.								
0–1,000	28–42	78.4	2.85	400				
	14–28	788.8	1.8	2,550	2,950	5	2,945	1,471
1,000–2,000	28–42	12.0	2.85	60				
	14–28	1,060.8	1.8	3,440	3,500	0	3,500	1,750
2,000–3,000	14–28	1,289.6	1.8	4,180	4,180	0	4,180	2,090
0–1,000	14–28	803.2	1.8	*2,600	*2,600	0	*2,600	*1,300
1,000–2,000	14–28	1,022.4	1.8	*3,310	*3,310	0	*3,310	*1,655
2,000–3,000	14–28	1,104.0	1.8	*3,580	*3,580	0	*3,580	*1,790
T. 4 S., R. 22 E.								
0–1,000	42	17.6	4.6	150				
	28–42	120.0	2.8	600				
	14–28	3,057.6	2.2	12,200	12,950	15	12,935	6,465
	42	52.8	4.1	390				
	28–42	113.6	3.0	610	1,000	35	965	482
1,000–2,000	14–28	2,379.2	2.2	9,420	9,420	0	9,420	4,710
2,000–3,000	14–28	169.6	2.2	670	670	0	670	335
T. 3 S., R. 19 E.								
0–1,000	42	48.0	4.4	380				
	28–42	16.0	3.0	90				
	14–28	68.8	2.0	250	720	10	710	355
1,000–2,000	14–28	8.8	2.0	40	40	0	40	20
T. 3 S., R. 20 E.								
0–1,000	28–42	39.2	2.85	200	200	10	190	95

Reserves of coal in the Vernal district, Uintah County, Utah—Continued

[Inferred reserves marked by an asterisk (*); all others classed as indicated reserves]

Overburden (feet)	Range in thickness (inches)	Area (acres)	Thickness of coal (feet)	Estimated original reserves (thousands of tons)	Total reserves (thousands of tons)	Mined or lost in mining (thousands of tons)	Remaining reserves, January 1950 (thousands of tons)	Recoverable reserves, January 1950 (thousands of tons)
Uinta Special meridian								
T. 2 N., R. 1 E.								
0–1,000	42	171.2	4.4	1,360				
	28–42	88.0	3.0	480				
	14–28	150.4	2.0	540	2,380	15	2,365	1,187
1,000–2,000	42	128.0	4.4	1,010				
	28–42	116.8	3.0	630				
	14–28	235.2	2.0	850	2,490	0	2,490	1,245
2,000–3,000	14–28	14.4	2.0	50	50	0	50	25
T. 2 N., R. 2 E.								
0–1,000	42	752.0	4.4	5,960				
	28–42	57.6	3.0	310				
	14–28	54.4	2.0	200	6,470	80	6,390	3,195
1,000–2,000	42	179.2	4.4	1,420	1,420	0	1,420	710
T. 1 N., R. 1 E.								
1,000–2,000	42	12.0	4.4	100				
	28–42	54.4	3.0	290				
	14–28	12.0	2.0	40	430	0	430	215
2,000–3,000	28–42	27.2	3.0	150				
	14–28	316.8	2.0	1,120	1,270	0	1,270	635

T. 1 N., R. 2 E.

0–1,000	42	28.8	4.4	230				
	28–42	42.4	3.0	230				
	14–28	76.8	2.0	280	740	0	740	370
1,000–2,000	42	377.6	4.4	2,990				
	28–42	240.0	3.0	1,300				
	14–28	302.4	2.0	1,090	5,380	0	5,380	2,690
2,000–3,000	28–42	66.4	3.0	360				
	14–28	394.4	2.0	1,420	1,780	0	1,780	890
Total tonnage								
All beds					143,340	460	142,880	71,440
42-inch beds					34,940			
28–42-inch beds					51,620			
14–28-inch beds					47,290			
					*9,490			
Beds with 0–1,000-foot overburden				60,160				
Beds with 1,000–2,000-foot overburden				54,170				
Beds with 2,000–3,000-foot overburden				29,010				

OIL AND GAS

Surface indications.—Sandstone, impregnated with viscous or dry petroleum residue, crops out at a number of places on the north side of the Uinta Basin and at a few localities within the area shown on plate 1. The petroleum residue is found in rocks of Mesozoic and Tertiary age. The largest exposure of dry oil sand is found 1 to 2 miles south of the southern border of the map, along the north-facing escarpment of Asphalt Ridge. At that point, it impregnates both the Wasatch formation, which represents the basal Tertiary strata of the area, and sandstones of the underlying Mesaverde formation of Late Cretaceous age. The oil accumulation probably is related to the unconformity at the base of the Tertiary because saturation occurs in rocks both above and below the unconformable contact. Spieker (1931, p. 96–97) has estimated that between 1½ and 3 billion barrels of oil were present in the deposit before loss by erosion and escape of volatile constituents.

A second, but less extensive exposure of petroleum residue, is in the Navajo sandstone east and west of Whiterocks River. The impregnated sandstone is especially well exposed west of the river, where an adit has been driven 20 to 30 feet into the upper part of the steeply dipping Navajo. Heavy oil mixed with water seeps from the roof of the adit and accumulates on the floor.

Small, dry oil-impregnated sandstone localities are found in the basal Tertiary beds between Deep Creek and Whiterocks River, and a dry oil sand is exposed in the NW¼NE¼ sec. 24, T. 2 N., R. 3 W., between Uinta River and Dry Gulch.

Small particles of a shiny gilsonite-like hydrocarbon are found in a sandstone bed in the Park City formation in the NE¼NE¼ of sec. 34, T. 2 S., R. 21 E., north of Red Mountain.

Chemical composition and physical properties.—Spieker (1931, p. 94), quoting from a report by E. Theodore Erickson, of the Geological Survey, on a chemical analysis of the petroleum residue from Asphalt Ridge, states,

> The sulphur content is unusually low. Native asphalt contains from 1.7 to 10 percent of sulphur. . . . The bitumen appears to consist of residual material derived from a paraffin base petroleum.

A sample of heavy oil collected from the adit in the Navajo sandstone on Whiterocks was submitted to the Bureau of Mines Petroleum Experiment Station, Bartlesville, Okla. Harold M. Smith, petroleum chemist, reports (letter dated Sept. 15, 1949),

> . . . an unsuccessful attempt was made to analyze the oil by the Routine method. The oil is virtually a natural asphalt, and also contains some water and sediment, a distillation by normal means was almost impossible . . . The specific gravity of the sample at 60° F. was 1.011. We have also determined the sulfur

content, which surprisingly enough is only 0.41 percent. To my knowledge this is the lowest sulfur content for an asphaltic material that I have ever run across.

Additional analyses of the material for the presence of sulfur and nitrogen, by the Petroleum and Oil Shale Experiment Station of the Bureau of Mines at Laramie, Wyo., are given in the following table supplied by John S. Ball, refinery engineer. The analyses of oil and bitumen from other localities in the Uinta Basin are included for the purpose of comparison.

Sulfur and nitrogen contents of crude oils and bitumens from Uinta Basin

Oil-producing areas	Formation	Sulfur (percent)	Nitrogen (percent)
Oil, Rangley field, Colorado	Weber	0.67	0.04
Oil, Uintah Co., Utah	Green River	.31	.49
Oil, Rangely field, Colorado	Mancos	.10	.016
Oil, Rangely field, Colorado	Shinarump	.36	.018
Bitumen, Vernal deposit	Wasatch and Mesaverde	.50	1.18
Bitumen, Sunnyside deposit	Wasatch	.51	.96
Bitumen, Whiterocks	Navajo	.47	1.28

Mr. Ball states, "This material exhibited a positive spot when tested with Oliensis solvent and also with 100 percent xylene. A positive spot test is indicative of heterogeneous material."

Some physical properties of the asphaltic material from Whiterocks also were determined and are given in the following table:

Some properties of asphaltic material (sample PA–49–7) from Uintah County, Utah

Bitumen (percent)	99.8.
Bitumen soluble in carbon tetrachloride (percent)	99.9.
Ash (percent)	0.00.
Penetration:	
At 60° F., 100 gm. wt., 5 sec (decimillimeter)	84.
At 77° F., 100 gm. wt., 5 sec (decimillimeter)	240.
Softening point (° F.)	99.
Specific gravity at 77/77 F	0.986.
Spot tests:	
Oliensis:	
Initial	Positive.
After 24 hours	Do.
Heptane-xylene equivalent [1]	Do.
Sulfur (percent)	0.47.
Nitrogen (percent)	1.28.

[1] Solvent used was 100 percent xylene.

From these analyses it is concluded that: (1) the sulfur and nitrogen content of the Whiterocks bitumen is similar to other bitumen occurrences in the Uinta Basin and might have been derived from oil from Tertiary rocks (as found in the Roosevelt discovery well), and (2) the high sulfur content of the crude oil from the Weber sandstone at Ashley Creek and at Rangely, and the lower sulfur content of the bitumen at Whiterocks, makes the Weber an unlikely source of the bitumen in the Navajo sandstone at Whiterocks.

Oil and gas exploration.—Oil and gas exploration in the area by drilling is summarized in the table, "Summary of oil and gas wells in the Vernal area, Uintah County, Utah," which has been compiled from many sources. This summary is arranged according to Township and Range for ease of location, with subheadings indicating the location on known structural features. The stratigraphic data, given in the summary, are based upon examination of well cuttings and drillers' logs in wells drilled before 1940, and upon electric logs and well cuttings in wells drilled after that date. All depths are given as the number of feet below the well collar. The altitude above or below sea level at any stratigraphic point can be calculated by subtracting the depth in the well from the surface altitude of the well.

Asphalt Ridge monocline.—The first drilling for petroleum in the Vernal area was by the Uintah Development Co.; four shallow wells were drilled south of Asphalt Ridge from 1911 to 1913. These wells were drilled because of the expectation that the dry oil cropping out along the Asphalt Ridge escarpment had sealed the bed and that liquid petroleum was present down the dip. Traces of oil and small amounts of gas are reported in the drillers' logs. The Carter Oil Co. drilled a deep test well in the same area in 1947, but although the well cored oil sand, it did not achieve commercial production.

Neal dome.—Neal dome, between Steinaker Draw and Ashley Creek, and north of Vernal, was drilled in 1925 by the Maude Ellen Oil Co. in the NE¼NW¼SE¼ sec. 28, T. 3 S., R. 21 E. This well, drilled to 2,552 feet, surfaces in the Navajo sandstone and entered the Weber sandstone at a depth of 1,575 feet; water was flowing over the top of the casing in 1946. This test well was not located at the highest strutural location on the anticline and in 1947 the Vernal Oil and Gas Company drilled Hullinger well 1, located in the NW¼SW¼-SE¼ sec. 30, T. 3 S., R. 21 E. This well surfaced alluvium at the bottom of the Ashley Creek valley (which is lower than the top of the Chinle formation) and entered the Shinarump conglomerate at 97 feet, the Moenkopi formation at 150 feet, and the Weber sandstone at approximately 1,190 feet. Although structurally located about 400 feet higher than the Maude Ellen well, Hullinger well 1 also flowed fresh water from the Weber sandstone.

Ashley Creek gas field.—The Ashley Creek gas field, located in sec. 23, T. 5 S., R. 22 E., southeast of Vernal, Utah, was discovered when the Utah Oil Refining Co. completed the drilling of well 1, in the SW¼SW¼NW¼ sec. 23, on April 18, 1925. The well was located on the basis of surface dips in soft Mancos shale, which indicated a structural high point on the westward-plunging Section Ridge anticline. The wells produced from a 10-foot interval of coarse-grained sandstone in the lower one-third of the Morrison formation of Jurassic age. Of the five wells drilled on the structure between

1925 and 1934, only the discovery well and Midwest Exploration Co. well 3 were commercial producers. Utah Oil Refining Co. well 1 logged two gas sands, the first from 1,431 to 1,475 feet, and the second from 1,673 to 1,680 feet. The upper zone was rated at 15 million cubic feet of gas, and the lower zone was rated at 60 million cubic feet. Midwest Exploration Co. well 3, completed in 1928, was rated as a 29-million-cubic-foot producer and had an initial gas pressure of 580 pounds per square inch. The latter well reported production of 8 barrels of oil per day from a depth of 1,790 feet in the lower part of the Morrison formation.

Although it was discovered in 1925, with a second gas well completed in 1928, the Ashley Creek field was not produced commercially until September 1929, when a pipe line to Vernal was completed. Yearly production of the field, accumulated production, and the gas pressure at the end of the year, as compiled from the records of the Conservation Division, U. S. Geological Survey, Casper, Wyo., by Raymond M. Larsen, are shown below.

Statistics of yearly production of the Ashley Creek gas field

Year	Million cubic feet	Total (end of year)	Gas pressure (pounds per square inch)	Year	Million cubic feet	Total (end of year	Gas pressure (pounds per square inch)
1929	17,267	17,267	580	1936	51,476	344,131	200
1930	50,395	67,662		1937	49,038	393,169	200
1931	43,859	111,521		1938	43,995	437,164	180
1932	53,927	165,448		1939	47,109	484,273	195
1933	44,103	209,551	320	1940	35,639	519,912	
1934	37,441	246,992	270				
1935	45,663	292,655	230	1941 (Jan. 1 to Aug. 30)	16,424	536,336	100

A total production of 536,336 million cubic feet of gas is recorded from the sandstone of Jurassic age until the field was abandoned in 1941. During this time, the gas pressure had decreased from an initial 580 pounds per square inch to 100. It is reported in Vernal that the principal reasons for abandonment of the field were the deterioration and leaks developed in the transporting pipe and the high resale value of the reclaimed pipe. However, the drop in gas pressure indicates the depletion of the original producing sandstone.

The following analysis of the gas from the Ashley Creek field (Shaw, E. S., 1934, p. 347) shows it to be essentially methane: 0.20 percent carbon dioxide, 0.13 percent oxygen, 99.42 percent methane, 0.24 percent nitrogen, and 0.01 percent helium.

Ashley Creek oil field.—The Ashley Creek gas field, which had known structural closure, was especially promising as a potential oil-producing structure from deeper horizons following the development of Rangely oil field in Rio Blanco County, northwestern Colorado, in 1942. It was drilled in August and September of 1948, after the

Summary of wells drilled for oil and gas in the Uinta River-Brush Creek area, Uintah County, Utah

[Structure and surface formation: F, faulted nose; S, Shinarump conglomerate; A, anticline; Jn, Navaho sandstone; Qc, Quaternary alluvium on Chinle formation; M, monocline; Qm, Quaternary alluvium on Mancos shale; N, nose; T, terrace gravel on Mancos shale]

Driller	Lease and well No.	Location	Structure and Surface formation	Spud date	Completion date	Initial production (barrels per day)	Altitude (feet)	Total depth (feet)	Top of Frontier sandstone member of the Mancos shale (feet)	Top of Navajo sandstone (feet)	Top of Weber sandstone (feet)
Tidewater Associated-Mohawk.	Pine Ridge 58-7	SWSWSE sec. 7, T. 3 S., R. 20 E.	F, S	7/27/49	Abandoned 9/17/49		7,504	3,508			876
Maude Ellen Oil Co	Neal 1	NENWSE sec. 28, T. 3 S., R. 21 E.	A, Jn	7/10/25	Abandoned 11/32.		5,750	2,386			1,575
Vernal Oil and Gas Co.	Hullinger 1	SWSESE sec. 30, T. 3 S., R. 21E.	A, Qc	7/14/47	Abandoned /48.		5,780				1,190
Mayo-Utah Oil Co	Asher-Merkley 1	SWNW sec. 22, T. 4 S., R. 21E.	M, Qm	8/10/45	Abandoned 1/46.			6,773	4,210	6,103	
Equity Oil Co	Powell 1	SWNWNW sec. 34, T. 4 S., R. 22E	N, T	8/20/45	Abandoned 1/8/46.			1,763	883		
Do	Kendall 1	SWNESW sec. 33, T. 4 S., R. 22E.	N, T	7/22/49	Abandoned 9/49.		4,987	4,922	1,225	3,060	4,907
Sun Oil Co	Neal-Government 1	NESWSE sec. 26, T. 4 S., R. 22E.	T	10/21/49	12/10/49		5,274	4,302	576	2,348	4,279
California-Utah Oil Co.	Slaugh 1	C. of NESE sec. 12, T. 5 S., R. 21E.	T	9/28/49	Abandoned 11/16/49.		5,339	6,133	4,275	6,110	
Baird and Robbins	do	C. of SESW sec. 4, T. 5 S., R. 22E.	T	2/12/49	Abandoned 8/49.		5,308	5,900	2,100	4,585	5,810
H. D. Moore	Government 1	SWSENW sec. 18, T. 5 S., R. 23E.	T	6/17/49	Abandoned		4,901	4,439	923		
Utah—Vernal Oil Co	Caldwell 1	SWSWSW sec. 20, T. 5 S., R. 23 E.	N, T	5/17/49	Abandoned 6/29/49.		4,750	4,447	381	2,085	3,557
Utah Oil Refining Co	Valley Fuel Supply 1	SWSWNW sec. 23, T. 5 S., R. 22E.	A, Qm	11/20/24	4/13/25	(Gas, 15 million cubic feet)	4,910	1,685	676		
	2	NENW sec. 23	A, Qm	9/27	Abandoned 9/27.		4,892	709	708		
Midwest Exploration Co.	3	SESWNW sec. 23	A, Qm	10/11/27	2/23/28	(Gas, 29 million cubic feet)	4,904	2,720	695	2,327	
Ashley Valley Oil Co	4	NWSENE sec. 22	A, Qm	8/ 7/28	Abandoned 12/20/28		4,923	2,165	890		
Uintah Gas Co	5	C. of NESW sec. 23	A, Qm	10/23/34	Abandoned 12/4/34		4,836	1,730	785		

Equity Oil Co.	Ashley Valley Oil Co 1	N. of NWSW sec. 23	A, Qm	8/14/48	9/14/48	300	4,904	4,152	690	2,408	4,138
	2	SWNESW sec. 23	A, Qm	2/ 3/49	3/13/49	430	4,895	4,218	625	2,340	4,065
	3	SWNWSE sec. 23	A, Qm	3/18/49	4/18/49	480	4,894	4,268	700	2,425	4,105
	4	SENWSW sec. 23	A, Qm	4/19/49	5/15/49	295 (1/8-inch choke)	4,904	4,271	605	2,339	4,076
	5	SENESE sec. 22	A, Qm	5/24/49	6/16/49	265	4,912	4,290	804	2,430	4,147
	6	SESENE sec. 22	A, Qm	6/24/49	7/16/49	432 (1/4-inch choke)	4,923	4,293	770	2,451	4,185
	7	SWSENW sec. 23	A, Qm	9/ 9/49	10/1/49	960 (1/4-inch choke)	4,897	4,230	701	2,414	4,152
	8	SWSWNE sec. 23	A, Qm	3/11/50	4/16/50	100	4,875	4,239	786	2,440	4,220
	9	C. of SWNW sec. 23	A, Qm	4/19/50	5/20/50	99	----	4,260	729	2,460	4,214
Stanolind Oil and Gas Co.	Government 1	NESWSW sec. 23	A, Qm	2/28/49	4/11/49	288 (14/64-inch choke)	4,902	4,327	610	2,375	4,088
	2	NWNWNE sec. 26	A, Qm	4/19/49	5/23/49	375	4,889	4,310	720	2,380	4,107
	3	NWNENW sec. 26	A, Qm	4/17/49	5/16/49	1008	4,912	4,287	700	2,424	4,146
	4	NESESE sec. 22	A, Qm	5/21/49	6/20/49	95	4,933	4,308	774	2,458	4,188
	5	NWNENE sec. 26	A, Qm	5/29/49	7/3/49	174 (13/64-inch choke)	4,868	4,243	720	2,408	4,093
	6	N½NWNW sec. 26	A, Qm	6/22/49	7/26/49	240	4,916	4,301	769	2,473	4,205
	7	NWNWNW sec. 25	A, Qm	8/2/49	9/8/49	792	4,856	4,216	757	2,478	4,168
	8	NENWSE sec. 22	A, Qm	8/22/49	9/18/49	257	4,946	4,306	920	2,585	4,280
	9	NENENE sec. 27	A, Qm	11/1/49	12/9/49	55 (4/64-inch choke)	4,922	4,290	918	2,630	4,268
	10	NESWSE sec. 22	A, Qm	1/24/50	2/19/50	100 (Park City production).	4,962	4,331	995	2,642	4,328
Crane and Griffith Drilling Co.	Hall 1	NWSESW sec. 23	A, Qm	10/31/48	12/11/48	502	4,890	4,122	628	2,350	4,080
	3	NWSESE sec. 23	A, Qm	3/22/49	4/26/49	600	4,858	4,208	713	2,427	4,135
	4	SESESE sec. 23	A, Qm	9/18/49	10/21/49	480	4,860	4,200	738	2,424	4,132
	Rennie 1	NESWNE sec. 26	A, Qm	1/23/49	----	720	4,878	4,255	----	----	4,202
	Government 1	NESENW sec. 26	A, Qm	5/3/49	5/29/49	101	4,926	4,307	878	2,523	4,294
	Uintah Basin 3	NWSWNW sec. 25	A, Qm	6/20/49	7/23/49	142 (wet)	4,823	4,205	810	2,475	4,193
	Hillman 1	SESWNW sec. 15	A, Qm	8/2/49	Abandoned 9/49.	----	4,995	4,378	----	----	----
Hollandsworth and Travis.	Government 1A	NWSENE sec. 26	A, Qm	3/28/49	4/21/49	864	4,881	4,235	796	2,486	4,184
R. Lacy Production Co.	Government 1B	NESWNW sec. 26	A, Qm	4/28/49	Abandoned 5/23/49. Tested (4,372–4,393)	----	4,954	4,393	1,079	2,677	4,372
	3	NWSWNW sec. 25	A, Qm	6/20/49	7/23/49	142	4,823	4,205	810	2,475	4,193
	1	NWSWSE sec. 23	A, Qm	1/23/49	3/3/49	734	4,878	4,255	812	2,510	4,227
California Company	Wyman 1	SWNESW sec. 23	A, Qm	4/25/49	6/22/49	132 (10% cut)	4,844	4,235	752	2,448	4,204
	Gentry 1	SESWNE sec. 22	A, Qm	10/9/49	11/15/49	137 (9/64-inch choke, 10% cut).	4,931	4,301	916	2,605	4,277
Robert Six—Carter Oil Co.	Nelson 1	SWSWSW sec. 24	A, Qm	8/13/49	9/49	130 (5/64-inch choke)	4,856	4,190	774	2,463	4,163
	Massey 1	SWSESW sec. 24	A, Qm	10/31/49	Abandoned 11/28/49.	----	4,776	4,255	788	2,509	4,249
Stewart—Six and others	Hullinger 1	SWNENW sec. 23	A, Qm	12/5/49	1/50	----	4,887	4,534	1,000	2,705	4,526

mineral ownership of the land had been clarified in court. The first well, Equity Oil Co.'s Ashley Valley 1, topped saturated Weber sandstone at 4,136 feet, and when completed, it flowed 260 barrels per day of 31 to 34 degree gravity oil from the interval 4,136 to 4,152 feet. Subsequent drilling of 27 wells on the structure in 1949 established a reported potential of more than 10,000 barrels per day and actual production of about 2,700 barrels per day. The producing area of the field will be approximately 800 acres. At first, the oil was hauled to Salt Lake City, but later it was trucked to Rangely, Colo., for transport via pipeline to refining facilities in Salt Lake City. By January 1, 1950, the field was approximately one-third drilled out.

An analysis by K. P. Moore, of the Geological Survey, of an oil sample from the Stanolind Oil and Gas Co.'s Government well 1, located near the crest of the Ashley Creek oilfield, showed a gravity (API) of 31.7, pour point of 45 F. and a sulfur content of 0.75 percent. The oil is brown and has an intermediate base. The approximate summary of the distillation by the Hempel method is as follows:

	Percent
Total gasoline and naphtha	23.7
Kerosene distillate	10.8
Gas oil	14.3
Nonviscous lubricating distillate	11.2
Medium-lubricating distillate	5.5
Viscous-lubricating distillate	2.6
Residuum	31.8
Distillation loss	0.1

A structure-contour map of the field, drawn on the top of the Weber sandstone, by J. S. Adair, Conservation Division, U. S. Geological Survey, and based for the most part on electric logs, is given in figure 12. Edgewater elevation on the southwest side of the field was established by the Stanolind Oil and Gas Co.'s Government well 1 and well 2, when both drilled completely through the saturated Weber sandstone. Edgewater elevations are 623 and 599 feet above sea level, respectively. Hollandsworth Drilling Co.'s well 1B, on the southwest flank, topped Weber at 4,372 feet depth (573 feet above sea level) and was abandoned. Robert Six-Carter Oil Co.'s Massey well 1 topped Weber at 527 feet above sea level on the southeast end of the field and Robert Six-Carter Oil Co.'s Hullinger well 1 topped Weber at 361 feet above sea level on the north flank of the field; both wells were abandoned.

Stanolind Oil and Gas Co.'s Government well 10 (fig. 12, No. 33), an edge well on the southwest flank of the anticline, was completed as a 60-barrel-per-day producer through a 5/64-inch choke from the Park City formation. Equity Oil Co. well 2-A, near the crest of the structure, was drilled in 1950 to test oil saturation in the Entrada sandstone. It pumped 12 barrels of oil per day from the Entrada sand-

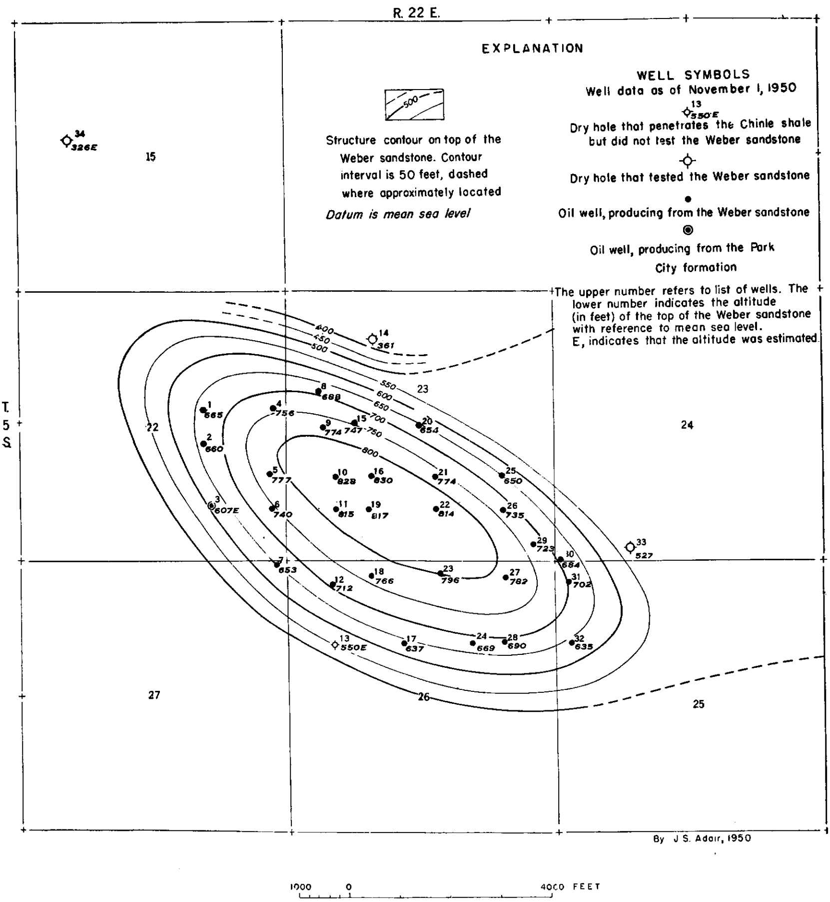

FIGURE 12.—Subsurface structure-contour map of the Ashley Creek oilfield.

stone, was plugged back to 1,872 feet in the basal part of the Morrison formation, and was completed as a 5½-million-cubic-foot gas well.

Split Mountain anticline.—The rapid development of the Rangely oilfield from 1943 to 1945 led to increased exploration for oil in adjacent Uintah County, Utah. In addition to the Vernal Oil and Gas Co.'s Hullinger well 1, on Neal dome, and the Mayo-Utah Oil Co.'s Asher-Merkley well 1, drilled to 6,150 feet in the SW¼NW¼ sec. 22, T. 4 S., R. 21 E., the Equity Oil Co. tested the westward plunging nose of the Split Mountain anticline, east of the community of Naples, with the Powell well 1 located in the SW¼NW¼NW¼ sec. 34, T. 4 S., R. 22 E. This well, drilled to 1,763 feet, topped the Morrison formation at 1,295 feet, but it did not enter the underlying Curtis formation. The well was abandoned in January 1946. The nose was further tested in 1949 by the Equity Oil Co.'s Kendall well 1, located in the SW¼NE¼SW¼ sec. 33, half a mile to the southwest of the Powell well, and by the Sun Oil Co.'s Neal-Government well 1, in the NE¼-

SW¼SE¼ sec. 26, T. 4 S., R. 22 E. Equity Oil Co.'s Kendall well 1 was drilled to 4,992 feet and entered the Weber sandstone at a depth of 4,907 feet; the Sun Oil Co.'s Neal-Government well 1 topped the Weber at 4,279 feet and was drilled to a total depth of 4,296 feet. Both wells were abandoned as dry holes.

Section Ridge anticline.—The successful completion of the Ashley Creek field as a petroleum producer resulted in the drilling of a number of wildcat wells to the north and east of the field. The Utah-Vernal Oil Co. drilled Caldwell well 1 in the SW¼SW¼SW¼ sec. 20, T. 5 S., R. 23 E., 3 miles east of the field, to a depth of 4,447 feet on the westward plunging axis of the Section Ridge anticline. This well was structurally higher than the Ashley Creek field, but the anticline had no closure at that point. H. D. Moore drilled Government well 1 in the SW¼NE¼NW¼ sec. 18, T. 5 S., R. 23 E., 2 miles northeast of the field, to a depth of 4,439 feet on the northwest flank of the Section Ridge anticline. Caldwell well 1 topped the Weber sandstone at 3,757 feet and Government well 1 topped the Park City formation at 4,569 feet (more than 500 feet structurally lower than the Ashley Creek field). Baird and Robins drilled Slough well 1, in the center of SE¼SW¼ sec. 4, T. 5 S., R. 22 E., to a depth of 5,787 feet and probably tested the Park City and Weber formations in the bottom of the hole. Slough well 1 is located almost 3 miles northwest of the Ashley Creek field, and structurally, it is 1,500 to 1,700 feet lower (on the top of the Weber standstone).

Dry Fork anticlinal nose.—In 1949, the Tidewater Associated-Mohawk Petroleum Co. Pine Ridge well 58–7 tested the highly faulted anticlinal nose, 1 mile west of Dry Fork. The well surfaced on the Shinarump conglomerate, topped the Park City formation at 730 feet depth, the Weber sandstone at 876 feet, the black shale unit of Mississippian age at 2,588 feet and the limestone unit of Mississippian age at 2,735 feet. It was abandoned at 3,508 feet total depth, after testing most of the Mississippian section.

Oil and gas possibilities.—The most obvious oil and gas structures in the rocks of Mesozoic and Paleozoic age of the Vernal area, the Ashley Creek field, the Neal dome and the Pine Ridge anticlinal nose have already been tested by wells. The better remaining possibilities are at localities where Tertiary rocks overlap on rocks of Mesozoic and Paleozoic age. At these points, the structure of older rocks is hidden, and the true attitude of the covered beds can only be inferred by geophysical exploration. One area offering such possibilities is the glacial outwash plain south of Whiterocks Canyon. The saturated sandstone in the Navajo sandstone along Whiterocks River appears to be localized on a slight anticlinal nose, which plunges southward. The Dakota sandstone, Frontier sandstone member of Mancos shale, and Mesaverde formation may have offered suitable reservoir conditions for oil accumulation under sufficient cover. The great overlap of Tertiary rocks over rocks of Mesozoic and Paleozoic age west of Whiterocks River covers an area offering both reservoir rocks and complex structural conditions, especially faulting. The area should also be closely examined for conditions favorable to oil accumulation. A considerable amount of seismic geophysical prospecting already has been done by major oil companies in the area south of Uinta Canyon, but no information is available in regard to their success in the recording of seismic reflections from beneath the glacial outwash.

METALLIC MINERAL DEPOSITS

Introduction.—The Uinta Mountains have not been intruded by igneous rock, and because rich metalliferous deposits generally are associated with intrusive rocks, the area is only slightly mineralized. A few copper, lead, and iron prospects have been developed in the lower part of the limestone unit of Mississippian age in the Carbonate district, T. 1 S., R. 21 E., and small iron deposits are scattered across the area adjacent to the South Flank fault. The high terraces along the Green River have been prospected for placer gold, and a gold dredge has worked the sands of the Green River above, and below, Split Mountain and on Horseshoe Bend on the southern boundary of the mapped area.

COPPER

Dyer mine.—The principal copper production from the Carbonate district has been from the Dyer mine, an open cut 50 to 75 feet in diameter, lying along the crest of an east-trending ridge that descends from the high peak lying between Brush Creek and Little Brush Creek. The Dyer mine is located in the NW¼ sec. 16, T. 1 S., R. 21 E., and can be reached by a truck trail that leaves the Iron Springs road at Iron Springs camp ground and winds northward 3.5 miles through scattered pine and aspen to the mine. In addition to the open cut, the area is pitted with numerous prospect holes 3 to 6 feet deep. Most of these pits were sunk in the soil cover until limestone was encountered. Other pits are located on the red sandy shale of the Uinta Mountain group, which underlies the thin Lodore formation at this locality. The open cut has been prospected by shafts sunk in the bottom of the pit and by tunnels driven southward into the north-facing limestone escarpment.

The maximum yearly production from the Carbonate district was reached between 1898 and 1901, when, for a 2-year period beginning in October 1899, a blast furnace was operated in the SE¼ sec. 7, T. 1 S., R. 21 E., to treat ore from the Dyer mine. Several unsuccessful attempts to find additional ore bodies in the vicinity of the mine have been made.

Ore.—The ore, so far as it can be observed from dumps in the vicinity of the open cut, consisted of the carbonate of copper, malachite, and a small amount of azurite. It is reported that the sulphide (chalcocite) was present only as incompletely oxidized cores of large ore masses and that these cores were filled with minute veinlets of carbonate (Butler, Laughlin, Heikes, and others, 1920, p. 604). The ore formed irregular bodies in limestone, and two such bodies, one directly beneath the other, were mined in the open pit. The upper of these bodies extended to the surface, and float was present below the outcrop. It seems probable that the primary ore body was chalcocite (formed by replacement of limestone), and that subsequently the chalcocite was partly altered to copper carbonate.

The metal content of the original ore body can best be estimated from assay reports of carload shipments. Butler (Butler, Laughlin, Heikes, and others (1920, p. 602) reports one shipment of 400 tons of copper glance (sulfides) assayed 49.47 percent of copper, 26 ounces of silver, and $6 of gold per ton. Another shipment assayed 51.5 per cent copper. The ore treated at the blast furnace is reported to have averaged 33.5 percent copper. Earlier shipments of hand-sorted ore, which were shipped by wagon to the railroad at Carter, Wyo., averaged between 49 and 51 percent of copper.

The output of the Carbonate district, as reconstructed from published sources for the period 1891 to the present time, is given in the following table.

Metals produced in the Carbonate district

[Years 1891–1917, from Butler, B. S., and others, 1920, p. 601]

	Quantity of ore (short tons)	Gold (fine ounces)	Silver (fine ounces)	Copper (pounds)	Value
1891	18	5.22	468	17,784	$2,865
1892	73	21.19	1,898	71,136	10,341
1893	93	26.99	2,418	90,896	12,261
1894	73	21.19	1,898	71,136	8,392
1895	36	10.45	936	35,568	4,630
1896	111	32.22	2,886	108,680	14,365
1897	30	8.71	780	30,900	4,356
1898	500	96.75	10,000	300,000	45,100
1899	906	175.31	18,120	558,800	110,051
1900	1,751	350.00	35,020	1,156,100	220,859
1901	270	39.18	20,250	108,000	30,996
1904	500	125.00	8,000	25,000	10,289
1915	6	-----------	27	5,724	1,016
1916	5	-----------	26	5,423	1,351
1917	5	-----------	20	4,098	1,250
1918	1	-----------	6	372	-----------
1925	1	-----------	4	743	109
1919 [1]	-----------	-----------	-----------	-----------	-----------
1931	4	-----------	5	1,276	-----------
1935	-----------	-----------	-----------	5,831	502
1936	-----------	-----------	-----------	3,804	357
1937	-----------	3	31	3,000	492
1938	-----------	-----------	-----------	1,235	179
1939	-----------	-----------	-----------	596	101
1940	8	-----------	14	1,000	123
1941	2	-----------	-----------	100	12

[1] One truckload of ore shipped. No statistics available.

LEAD

Four patented mineral claims, filed on occurrences of high-grade lead carbonate in the soil overlying the limestone unit of Mississippian age and a few showings of galena (PbS) in limestone ledges, are located a mile and a quarter south of the Dyer mine, near the center of sec. 21, T. 1 S., R. 21 E. The galena, mostly altered to the carbonate of lead (cerussite), occurs as thin lenses lying parallel to the bedding of the gently dipping limestone. The lenses appear to have been formed by replacement of certain limestone beds. The high-grade lead carbonate (found at the surface) has been concentrated from these lenses by solution of the surrounding limestone. From the limited exposures noted in the area, no structural control of the replacement bodies is evident.

The carbonate ore on the surface or in the upper few feet of the soil is cheap to mine and load for shipment, but most of the readily available ore has been removed. The replacement-type sulphide bodies are small and would be expensive to mine. In conjunction with development work on these prospects in 1947, churn drilling and geophysical prospecting of adjacent areas was carried on; the results of this prospecting are unknown.

In the summer of 1948, a road was built from a point on the Iron Springs road and 1 mile east of the bridge over Brush Creek to a small galena-lead carbonate prospect a short distance upstream from Brush Creek Cave near the quarter-section corner between secs. 20 and 32, T. 1 S., R. 21 E. This prospect, developed in fractured dark gray cherty limestone in the lower part of the limestone unit of Mississippian age, is an enlargement of a natural cave formed along a joint plane. At the time of this investigation, a small quantity of galena was stockpiled at the end of the automobile road; reserves are very limited.

Other mineral claims are located on the south side of Little Brush Creek Mountain in the S½ sec. 13 and the N½ sec. 24, T. 1 S., R. 21 E. These prospects are similar to those to the west, but some structural control for their localization is evident. They lie near the crest of the southeast plunging anticlinal nose developed in the limestone unit of Mississippian age.

IRON

Iron prospects in the Uinta River-Brush Creek area occur in the brown-weathering sandy shale of the upper part of the Uinta Mountain group, in the lower part of the limestone unit of Mississippian age, and as cement in breccias formed of the limestone unit of Mississippian age or of Uinta Mountain group shale along the South Flank fault zone. A small deposit of brown iron ore, cementing a fault breccia of sandy shale, was noted in a prospect shaft in sec. 10, T. 2 S., R. 19 E. (unsectionized). An occurrence of similar appearance, part of the Pope deposit mentioned by Butler (Butler, and others, 1920, p. 603), is present below the peak of limestone that lies to the northwest of the Dyer mine.

The Pope deposit yields high-grade red hematite in very limited quantities from pits sunk in soil covering the shale in the upper part of the Uinta Mountain group. This hematite probably comes from the underlying red sandy shale, although Butler reports that iron oxide replaces certain limestone beds in the Pope area. Gradations from high-grade ore, to partly replaced ore, to little-altered limstone is said to be present in the Pope area. Some of the ore was used as a flux for the Dyer blast furnace. It is reported to be low in both sulfur and phosphorus.

Brown oxide of iron cements a limestone breccia on the east side of Black Canyon in sec. 8, T. 2 S., R. 20 S. (unsectionized). This occurrence was described as the Woodside deposit by Butler and lies along a branch of the South Flank fault zone. An additional gosson-like, brown iron ore deposit, located along a fault zone in the limestone unit of Mississippian age in the NW¼ sec. 33, T. 3 N., R. 1 W., on the west side of Farm Creek, is being developed for its reported gold content. It can be reached by a timber road and trail, which branches from the road up Pole Mountain in the east half of sec. 4, T. 2 N., R. 1 W. A short adit trends generally west into the brecciated iron-stained limestone unit of Mississippian age a short distance above the Uinta Mountain group boundary.

GOLD

The high terraces of the Green River south of the Dinosaur National Monument are pockmarked with prospect holes sunk to test the gold content of the gravels. No development has been done for many years, and the prospects are presumed not to be of economic importance. A gold dredge has been operated on the Green River above Split Mountain, south of Split Mountain, and on the great Horseshoe Bend of the river (on the southern boundary of pl. 1). The source of the auriferous gravels is unknown, but some gold-bearing gravel may have been derived from the pre-Cambrian rocks of the Red Creek quartzite in Browns Park, northwestern Colorado and the pre-Cambrian Uinta Mountain group.

PHOSPHATE

The phosphate deposits of the Phosphoria formation underlie a large area centering in southeastern Idaho and extending into central Montana, western Wyoming, and northern Utah. Although included in the Park City formation in northeastern Utah, the phosphate-bearing beds along the flanks of the Uinta Mountains are markedly similar and continuous with the beds in the Phosphoria formation.

Lithology and occurrence.—Phosphate rock, interbedded with phosphatic mudstone and argillaceous and phosphatic limestone, occurs in the basal member of the Park City formation. The lower member of the Park City formation rests on the thick, massive to crossbedded Weber sandstone and is overlain by an upper member of interbedded light-gray, sandy and cherty dolomitic limestone, light-tan to red, fine- to coarse-grained sandstone, and light-gray shale. The lower member of the Park City, 20 to 30 feet thick, is soft, and easily eroded; it forms a gentle slope or bench above the rugged, almost vertical cliffs of the Weber. The upper member weathers into two ledges separated by soft, easily eroded beds. These ledges were mapped by L. E. Smith, of the Mineral Deposits Branch of the Geological Survey, so that phosphate reserves under different thicknesses of overburden might be calculated. The top of the lower ledge is 39 to 43 feet above the phosphatic member of the Park City formation, and the base of the upper ledge is 66 to 78 feet above the phosphatic member. The lithology, thickness of beds, and graphic portrayal of three detailed sections, together with the chemical analyses and graph of the phosphate content of the individual beds, is given on plate 5. The phosphatic member crops out on Whiterocks River, in limited areas in the complexly faulted zone between Mosby Mountain and Dry Fork Mountain, in the banks of dry creek gulches from Ashley Creek to Brush Creek, and along dip slopes and in dry gulches tributary to Brush Creek between Brush Creek and Little Brush Creek. Beds at the same stratigraphic position as the phosphatic member on the flanks of Split Mountain within the Dinosaur National Monument contain only a few very thin beds of low-grade phosphate rock. West of Ashley Creek the phosphatic member is broken, intermittent in outcrop, of lower grade, and not of economic importance. The extent of the phosphate rock beneath Diamond Mountain is unknown.

The phosphate rock in T. 2 S., Rs. 21 and 22 E., and T. 3 S., R. 21 E., dips at angles ranging from 6° to 23° to the south and southeast. The resistant ledges of the upper member have protected the underlying phosphate from erosion. This protection has resulted in broad exposures of the phosphatic member, under relatively thin cover, in an area where the phosphatic member reaches its maximum thickness and grade.

Physical appearance.—The phosphate rock is soft, pale-olive to light olive-gray, and is thin-bedded to massive. It contains abundant ovules and pellets, or angular fragments, of phosphate. The ovules range in size from very fine- to very coarse-grained. Small ovules having very poorly defined outlines, as well as some fully rounded ovules are present in parts of the phosphatic mudstone and limestone beds. The P_2O_5 content of the rock is roughly proportional to the abundance of the ovules, the more abundant the ovules, the higher the grade. The higher grade rock is granular in texture and is formed almost entirely of phosphate ovules cemented by calcite, dolomite, or silt-sized particles. The leaching of the cementing material in surface outcrop results in a soft, friable rock that readily disintegrates upon handling. At least some of the phosphate fragments are mechanically worn shell fragments that have been replaced by phosphate. Small bivalves, a few Ostracoda, and small immature gastropods (completely replaced by phosphate) are present in some beds and readily weather from the matrix.

The color of the phosphatic member, pale-olive to light olive-gray, usually reflects the color of the individual phosphate ovules and fragments. The phosphate rock approaches specific gravity 2.8. It reacts with moderate-to-strong effervescence to concentrated hydrochloric acid. Some of the released carbon dioxide is from the carbonate that cements the ovules, but at least a part of it is from the carbonate radical included in the complex collophane molecule. The phosphate rock gives a strong fetid odor when freshly broken or when dissolved in acid. The rough quantitative test for phosphate, the formation of a white coating after application of concentrated hydrochloric acid, (Gardner, 1947, p. 16–17) does not give good results because the rock rapidly absorbs the acid, partly by reaction with the carbonate present as cement and partly in pore spaces between the ovules before reaction with the phosphate is possible.

The phosphate rock in the Vernal area differs in some characteristics from rock typical of the Phosphoria and Park City formations to the west. The most noticeable difference is the lighter color of the higher grade phosphate beds in the Vernal area. In southeastern Idaho, western Wyoming, the Wasatch Mountains, and even in the Duchesne River area of the western Uinta Mountains, the unit is a black to dark-gray, highly organic shale that frequently has been prospected for coal. Organic matter is relatively rare in the Vernal area; thin streaks of carbonaceous material were noted in petographic thin sections from Brush Creek Gorge. Similar light-colored phosphate rock has been noted near the eastern boundary of the Phosphoria formation in the Wind River Mountains of west central Wyoming (King, R. H., 1947, p. 42). Thin sections of chips from six representative beds from the Brush Creek Gorge section (pl. 5), chosen on the basis of physical characteristics and chemical analysis, have been examined. They show a great variation in microscopic characters of the beds and especially in the phosphate ovules and fragments.

In contrast to many of the thin sections studied from the southeastern Idaho area and reported by Mansfield (1927, pl. 63, 65, 66), true oölites of phosphate mineral are extremely rare in the Park City formation of the Vernal area. The thin sections from beds 3 and 5 of the Brush Creek section (pl. 5) include a few large complex ovules which enclose as many as five smaller ovules or nuclei of collophane cemented by collophane. Under polarized light, these included nuclei are of two types—brown collophane cemented by clear material, and clear collophane surrounded by brown collophane. The variation in these nuclei suggests sources in previously consolidated beds, mechanical disintegration, and concentration of the large complex oölites in a single bed. Under crossed Nicols, the included nuclei show faint rims of a weakly birefringent fibrous mineral, probably francolite. All simple ovules in thin section, examined under a binocular microscope or with a hand lens, fail to show oölitic structure. Clear rodlike crystals (perhaps francolite), rounded to subangular crystals of quartz, and rhombic crystals or irregular particles of carbonate are included in the ovules. The inclusions closely resemble, in size and relative proportion, the particles in the adjacent groundmass. In a carbonate-cemented rock, the inclusions in the collophane ovules are carbonate, and, when sand grains are common, some have been included in the ovules. Small particles of collophane were noted in the groundmass of bed 20. Detrital sand grains and silt-sized particles are relatively common in most of the beds. The abundance of detrital material probably reflects proximity to a land area and the edge of the basin of deposition of the phosphate member.

Bedding in the phosphate unit usually depends upon the quantity of argillaceous material in the individual bed. The higher grade phosphate is massive to thick bedded, and the argillaceous phosphate beds are thinner bedded. The bedding in thin section was observed only in bed 10, where phosphate ovules, calcite particles in the groundmass, and the organic material, are concentrated in parallel bands that give the rock a schistose appearance. The same thin section shows a flattening of ovules in contact; in other sections, the ovules maintain their spheroidal shape when in contact.

Terminology.—The amount of phosphate in a rock is usually reported in percentage of phosphorus pentoxide (P_2O_5) or tricalcium phosphate $Ca_3(PO_4)_2$. The latter is called "bone phosphate of lime" or B. P. L., and equals 2.18 times the amount of P_2O_5. The term "phosphate rock" is limited to rocks containing over 50 percent collophane (19.6 percent P_2O_5 or 42.7 percent B. P. L) just as "limestone" is limited to rocks containing over 50 percent calcite ($CaCo_3$). The modifying adjective, "phosphatic," is used where collophane amounts to more than 20 percent of the rock (7.85 percent P_2O_5 or 17.1 per cent B. P. L.). This usage is a modification of previous Geological Survey practice which divided phosphate-bearing rock into three groups: high-grade rock that has 70 percent or more B. P. L. (32.1 percent P_2O_5), medium-grade rock that has 50 to 70 percent B. P. L. (22.9 to 32.1 percent P_2O_5), and low-grade rock that has 30 to 50 percent B. P. L. (13.7 to 22.9 percent P_2O_5); the adjectival modifier "phosphatic" was reserved for rocks containing less than 30 percent B. P. L. and was prefixed to other lithologic types, such as phosphatic mudstone or phosphatic limestone.

Composition.—Splits of samples from the three detailed sections were submitted to the Bureau of Mines' Northwest Electrodevelopment Laboratory, at Albany, Oreg., where all samples from the Brush Creek Gorge section were analyzed for P_2O_5, Al_2O_3, Fe_2O_3, V_2O_5, Acid Insoluble, and Loss on Ignition. All samples from the Rock Canyon and Little Brush Creek sections were analyzed for P_2O_5 and Acid Insoluble, and in addition, those samples containing more than 13.8 percent P_2O_5 were analyzed for Al_2O_3, Fe_2O_3, V_2O_5, and Acid Insoluble. These analyses are given in the right-hand columns of plate 5, and are correlated with the proper beds, columnar section, thickness, and graphic representation of phosphate content. Radiometric analyses of the Brush Creek Gorge section are given in the extreme right-hand column. Additional splits of the Brush Creek Gorge section (except for sample DMK–5) were analyzed by spectrograph, and these determinations are given in the following table. A detailed chemical analysis of sample DMK–5 from the Brush Creek Gorge section is also given below.

Analysis of sample DMK–5, Brush Creek Gorge section, Uintah County, Utah

[Analyst: Harry Levine]

Elements	*Percent*
P_2O_5	27.88.
CaO	39.44.
MgO	0.27.
SiO_2	15.16.
F	2.92.
Organic matter	0.40.
Cr_2O_3	0.11.
TiO_2	0.04.
V_2O_5	0.03.
MoO_3	0.003.
MnO	0.007.
Co	0.002.
Li	0.001.
W	
Ag	
Cu	0.001.
Pb	0.001.
Zn	0.0008.
BaO	([1]).
Li_2O	([1]).
SrO	([1]).
Na_2O	0.48.
K_2O	0.64.
CO_2	Present.
S	Present.

[1] Not detectable with flame photometer. Examination was made on solution without prior chemical separation and therefore does not imply absence of these elements.

Spectrographic analyses in weight percent,[1] *of samples from the Brush Creek Gorge section, Uintah County, Utah*

[Analyses by trace elements laboratory, U. S. Geol. Survey]

Samples	Si	Al	Ca	Mg	P	Fe	Na	Pb	Cr	Ba	Mn	Sr	Ni	Ti	V	Y	La	Zr	Cu	Ga	Mo	B	Zn	Yb	Be
DMK 25	a	b	b	b	b	b	c	d	d	d	d	d	d	d	d	e	e	e	e	e	e	e	e	f	f
DMK 24	a	c	b	b	c	b	c	d	d	d	d	d	d	d	d	e	e	e	e	e	e	e	------	f	------
DMK 23	a	b	b	b	b	b	c	d	d	d	d	d	d	d	d	e	e	e	e	e	e	e	------	f	f
DMK 22	a	a	b	b	b	b	c	d	d	d	d	d	d	d	d	e	e	d	e	e	e	e	------	f	f
DMK 21	a	c	b	b	b	b	c	d	d	d	d	d	d	e	d	e	e	------	e	------	e	e	e	f	------
DMK 20	b	b	a	b	b	c	c	d	d	d	d	d	d	d	d	e	e	e	e	e	e	e	------	f	------
DMK 19	b	c	a	b	a	c	c	d	d	d	d	d	d	d	d	e	e	e	e	e	e	f	------	f	------
DMK 18	a	b	b	b	b	c	c	------	d	d	d	d	d	d	d	e	e	e	e	e	e	e	------	f	------
DMK 17	b	c	b	a	b	b	c	c	d	d	d	d	d	d	d	e	e	e	e	e	e	e	------	f	------
DMK 16	a	b	b	b	b	b	c	e	d	d	d	d	d	d	d	e	e	e	e	e	e	e	------	f	f
DMK 15	b	c	a	b	a	c	c	------	d	d	d	d	d	d	d	d	e	e	e	e	e	f	------	f	f
DMK 14	a	b	b	b	b	b	c	------	d	d	d	d	d	d	d	e	e	e	e	e	e	e	e	f	f
DMK 13	b	c	a	c	b	c	c	------	d	d	e	d	e	d	d	e	d	e	e	e	------	f	------	f	------
DMK 12	a	b	b	b	b	b	c	------	c	d	d	d	d	d	d	e	e	e	e	e	------	e	------	f	f
DMK 11	a	c	b	b	b	c	c	------	d	d	d	e	d	d	d	e	e	e	e	e	------	f	------	f	------
DMK 10	a	c	b	b	b	c	c	------	d	d	d	d	d	------	d	e	e	e	e	e	e	f	------	f	f
DMK 9	a	b	b	c	b	b	c	------	c	d	d	d	d	d	d	e	e	e	e	e	------	e	------	f	f
DMK 8	b	c	a	c	b	b	c	e	d	d	e	d	d	d	d	d	d	e	e	e	e	f	------	f	------
DMK 7	b	c	a	c	b	c	c	------	d	d	e	d	d	d	d	d	d	e	e	e	------	f	------	f	------
DMK 6	a	a	b	b	b	b	c	e	c	d	e	d	d	d	d	e	e	e	e	e	------	e	------	f	f
DMK 5[2]	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------
DMK 4	b	c	b	a	c	c	c	e	d	c	c	e	d	d	d	e	e	e	e	e	------	f	------	f	------
DMK 3	a	a	b	b	b	b	c	d	c	c	e	d	e	d	d	e	e	e	e	e	------	e	------	f	f
DMK 2	b	a	b	b	b	b	c	d	c	d	e	d	e	d	d	e	e	e	e	e	e	e	------	f	f
DMK 1	a	c	b	c	b	b	c	d	d	c	d	d	d	d	d	d	d	e	e	e	e	f	------	e	------

[1] a = more than 10 percent, b = 1.0–10.0 percent, c = 0.1–1.0 percent, d = 0.01–0.1 percent, e = 0.001–0.01 percent, f = 0.0001–0.001 percent.
[2] No spectrographic analysis.

Phosphate content.—Analyses of individual beds range from 3.1 to 28.5 percent P_2O_5 in the Brush Creek Gorge section, from 4.6 to 25.5 percent P_2O_5 in the Rock Creek Canyon section, and from 4.6 to 28.2 percent P_2O_5 in the Little Brush Creek section. The total thickness, weighted average grade of the individual sections, and the weighted average thickness and grade of the three sections, is given in the following table:

Sections	Thickness (feet)	Weighted average grade P_2O_5 (percent)	Average thickness and weighted average grade
Rock Creek Canyon	16.85	16.4 (35.8 B. P. L.)	17.8 feet, averaging 20 percent P_2O_5 (43.6 B. P. L.)
Brush Creek Gorge	19.70	20.5 (44.8 B. P. L.)	
Little Brush Creek	16.90	23.0 (50.1 B. P. L.)	

All phosphate in the Vernal area is medium- to low-grade rock, and the average grade falls within the limits of "low grade" according to earlier Geological Survey practice. In the three detailed sections, 28.6 percent of the beds contain less than the minimum for low-grade rock, 31.5 percent of the beds are low grade, and 39.9 percent of the beds are medium-grade rock. No high-grade rock is present.

Iron oxide and alumina.—Acid soluble Fe_2O_3 and Al_2O_3 are undesirable in phosphate rock that is to be treated with sulfuric acid to form superphosphate. An upper limit of between 3 and 4.5 percent of Fe_2O_3 and Al_2O_3 is generally provided in foreign standards, and, although not acceptable from the standpoint of phosphate content, most of the medium-grade rock in the Vernal area ranges between these stated limits. However, if the rock is to be used as charge for an electric furnace, the iron and alumina of the rock combined with the high Acid Insolubles should form a self-fluxing charge.

Vanadium.—Content of V_2O_5 in the samples ranged from less than 0.005 percent to a maximum of 0.066 percent. Of the eight samples containing more than 0.025 percent V_2O_5, all had phosphate contents ranging between 10 and 13 percent, but the acid insoluble content ranged from 37.0 to 60.0 percent, and the combined Al_2O_3 plus Fe_2O_3 ranged between 9 and 20 percent. As has been observed in southeastern Idaho and western Wyoming (Gardner, 1947, p. 19), the vanadium is more abundant in the phosphatic mudstone and is less prevalent in the highly phosphatic beds; the most vanadiferous beds contain approximately 1 to 2 percent P_2O_5 (V. E. McKelvey, personal communication, July 1951). It has been suggested that the amount of vanadium in phosphate rock may vary with the amount of organic matter. However, in the Brush Creek area, the scarcity and the small variation of the organic content between the different beds precludes such an association. Other factors that might possibly control the abundance of V_2O_5 are the Fe_2O_3 plus Al_2O_3 content or the silt-sized particles of the mudstone. It is noteworthy that the beds containing the higher quantities of V_2O_5 are generally less than 0.5 foot thick. The vanadium content of the mudstones in the Vernal area is very low, and it is not economically comparable to beds in the Phosphoria formation of Wyoming and Idaho, where concentrations of more than 1.0 percent are recorded.

Hydrocarbons.—In southwestern Montana, phosphatic shales of Permian age yield (on distillation) 25 to 30 gallons of oil per ton. The position of the phosphatic member of the Park City formation above the petroleum producing Weber sandstone, the frequent oil staining and oil production from one well in the formation in the Ashley Creek field, and the presence of dry gilsonitic hydrocarbon in a sandstone bed of the Park City formation at Red Mountain, suggest the possibility that the unit might be a source rock for petroleum.

Sample splits from the Brush Creek Gorge section were combined into six composite samples representing groups based on general lithology and P_2O_5 content, and weighed amounts of the individual samples were analyzed at the Petroleum and Oil Shale Experiment Station of the Bureau of Mines at Laramie, Wyo. The phosphatic unit at Brush Creek carries no detectable hydrocarbons. The distillation analyses by the modified Fischer retort method are given in the following table.

Oil shale assays of Brush Creek Gorge section

[Determined by the modified Fischer retort method by Petroleum and Oil-Shale Experiment Station U. S. Bureau of Mines, Laramie, Wyo. Shale disclosed no oil and no tendency to coke]

Composite samples	Yield				Properties of spent shale (percent of original shale)		Lithology
	Percent by weight			Gallons per ton of water			
	Water	Spent shale	Gas loss		Ignition loss	Ash	
Group 1	1.9	98.1	0.0	4.6	14.2	83.9	
Group 1	1.9	98.1	.0	4.6	13.7	84.4	
Average	1.9	98.1	.0	4.6	13.9	84.2	Mudstone.
Group 2	1.3	97.8	.9	3.1	4.4	93.2	
Group 2	1.3	97.9	.8	3.1	5.1	92.8	
Average	1.3	97.9	.8	3.1	4.8	93.0	Phosphatic mudstone.
Group 3	1.4	98.6	.0	3.2	25.3	73.3	
Group 3	1.4	98.6	.0	3.2	24.8	73.8	
Average	1.4	98.6	.0	3.2	25.0	73.6	Limestone.
Group 4	1.0	98.6	.4	2.4	21.3	77.3	
Group 4	1.0	98.7	.3	2.4	21.3	77.4	
Average	1.0	98.6	.4	2.4	21.3	77.3	Phosphatic limestone.
Group 5	1.7	98.0	.3	4.0	4.9	93.1	
Group 5	1.7	97.8	.5	4.1	5.2	92.6	
Average	1.7	97.9	.4	4.0	5.0	92.9	Phosphate rock.
Group 6	.8	98.8	.4	1.8	2.0	96.8	
Group 6	.8	98.6	.6	1.8	1.9	96.7	
Average	.8	98.7	.5	1.8	1.9	96.8	Phosphatic sandstone.

Development of the phosphate deposits. — The continuity of the phosphate rock along the south flank of the Uinta Mountains was first demonstrated by A. R. Schultz, of the Geological Survey, whose findings during a reconnaissance in the summer of 1914 resulted in the removal of parts of Tps. 18–25 E., Rs. 2–4 S. as Phosphate Withdrawal No. 24, Utah No. 3, and the publication of Geological Survey Bulletin 690–C. Placer claims, now held by the Humphreys Phosphate Co. in T. 2 S., Rs. 21 and 22 E., were filed prior to Phosphate Withdrawal No. 24. The outlines of Phosphate Withdrawal No. 24, Utah No. 3, and its relationship to the patented claims, are shown in figure 13.

Development work required of the Humphreys Phosphate Co. to patent its claims has exposed the phosphate-bearing beds at a hundred or more prospects distributed over the patented area and has resulted in the cutting and chemical analyses of thousands of channel samples. The results have been made available by Mr. Harry Ratliffe, resident manager of the Humphreys Phosphate Co., Vernal, Utah, to many geologists interested in the area, but they are not available to the general public. Since publication of Geological Survey Bulletin 690, the only published studies of phosphate in the Uinta Mountains has been by Williams (1939) and Williams and Hanson (1942).

Reserve estimates.—Reserve estimates of phosphate rock in the Ashley Creek-Brush Creek area are presented in the following table. In these estimates, the thickness of overburden and of phosphatic section is based on detailed measurements of the Park City formation by Kinney and Rominger. The grade of the phosphate is dependent upon the analyses of the Bureau of Mines, and the extent of the different depths of overburden is based upon a detailed map of the Park City formation in the Ashley Creek-Brush Creek area prepared by L. E. Smith, of the Mineral Deposits Branch of the Geological Survey. It is assumed that the phosphate unit maintains uniform thickness over the area and that 11.8 cubic feet of rock weigh 1 ton, or 1 acre-foot weighs 3,700 tons.

Undoubtedly, reserves exist beneath the unconformably overlying Bishop conglomerate, but because the phosphatic member may be channeled and inaccessible, they have not been considered. Phosphate rock of a grade similar to that found along Brush Creek may extend to the east beneath Diamond Mountain, but because the eastern limits are unknown, no tonnage is alloted for that area. Faulting and lower grade rock make it impracticable to calculate the reserves and mining potentialities of phosphate rock west of the divide between Ashley Creek and Dry Fork.

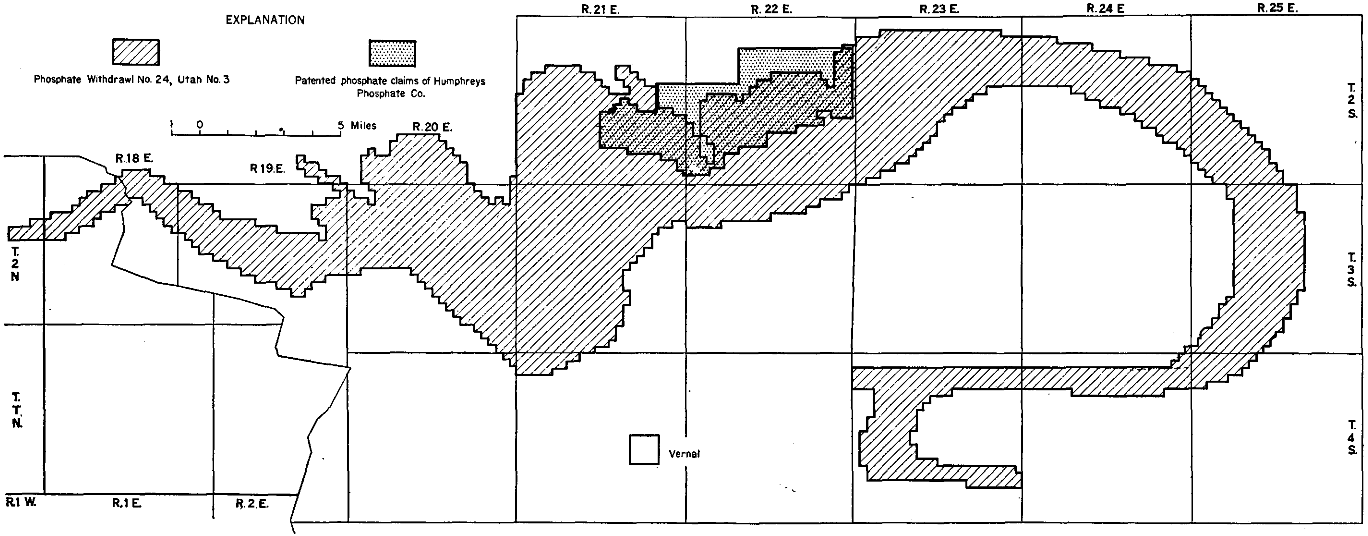

FIGURE 13.—Outline map showing Phosphate Withdrawal No. 24, Utah No. 3, and patented claims of the Humphreys Phospate Co.

Estimates of reserves of phosphate rock in the Ashley Creek-Brush Creek area

Township	Dip	Area along bed (acres)	Thickness (feet)	Reserves (millions of tons)
43 feet or less of overburden				
T. 2 S., R. 22 E	5°–25°	2,022	18.3	136.7
T. 2 S., R. 23 E	5°–10°	62	16.9	3.9
T. 2 S., R. 21 E	5°–10°	1,357	18.3	91.8
T. 3 S., R. 21 E	5°–10°	315	16.9	19.8
T. 3 S., R. 20 E	10°–20°	274	16.9	17.2
Total				269.4
43 to 78 feet of overburden				
T. 2 S., R. 22 E		3,267	18.3	220.0
T. 2 S., R. 23 E		131	16.9	8.2
T. 2 S., R. 21 E		2,080	18.3	140.7
T. 3 S., R. 21 E		346	16.9	21.7
T. 3 S., R. 20 E		270	16.9	16.9
Total				407.5
78 to 100 feet of overburden				
T. 2 S., R. 22 E		5,392	18.3	366.0
T. 2 S., R. 23 E		339	16.9	21.2
T. 2 S., R. 21 E		4,523	18.3	307.0
T. 3 S., R. 21 E		1,234	16.9	77.0
T. 3 S., R. 20 E		349	16.9	21.8
Total				793.0
More than 100 feet of overburden to top of water level in streams				
T. 3 S., R. 20 E		343	16.9	21.4
T. 3 S., R. 21 E		1,803	16.9	112.5
T. 2 S., R. 21 E		1,255	18.3	85.0
T. 2 S., R. 22 E		830	18.3	56.2
T. 2 S., R. 23 E		1,280	16.9	80.0
Total				355.1
From stream level to 1,000 feet below stream level				
T. 3 S., R. 20 E		1,220	16.9	76.3
T. 3 S., R. 21 E		2,930	16.9	183.2
T. 2 S., R. 21 E		144	18.3	9.7
T. 2 S., R. 22 E		3,930	18.3	266.0
T. 3 S., R. 22 E		580	16.9	36.2
T. 2 S., R. 23 E		1,338	16.9	83.5
Total				654.9

Summary of phosphate rock reserves in millions of tons

	Amount of overburden					
	43 feet or less	43 feet to 78 feet	78 feet to 100 feet	100 feet to top of water level in streams	Stream level to 1,000 feet below stream level	Total
T. 3 S., R. 20 E	17.2	16.9	21.8	21.4	76.3	153.6
T. 2 S., R. 21 E	91.8	140.7	307.0	85.0	9.7	634.2
T. 3 S., R. 21 E	19.8	21.7	77.0	112.5	183.2	414.2
T. 2 S., R. 22 E	136.7	220.0	366.0	56.2	266.0	1,044.9
T. 3 S., R. 22 E					36.2	36.2
T. 2 S., R. 23 E	3.9	8.2	21.2	80.0	83.5	196.8
Total	269.4	407.5	793.0	355.1	654.9	2,479.9

Utilization.—The phosphate reserves of the Ashley Creek-Brush Creek area are undeveloped for two important reasons. In the first place, no railroad enters the Uinta Basin, and a long expensive truck haul of more than 100 miles is required to reach a railhead, and in the second place, the average grade of individual beds (maximum: 28.5 percent P_2O_5) that might be recovered by selective mining is below standards required in the present process for manufacturing superphosphate by treatment of the rock with sulfuric acid. If rail transportation could be made available, a process for separating the phosphate from the gangue minerals by using flotation, or by some other method relying upon the greater specific gravity of the phosphate minerals, probably could be devised. Such a process would not only raise the grade of the phosphate, but it would also remove objectionable Fe_2O_3 and Al_2O_3 impurities.

The entire phosphatic member could be mined at a relatively low cost by stripping the overlying slabby limestone, dolomite, and shale of the upper part of the Park City formation and removing the phosphate rock by the use of power shovels; the ease of mining may prove to be an important factor in influencing the ultimate utilization of the deposit.

SAND AND GRAVEL

The increased use of concrete in the building industry and in construction of hard-surface roads has made it increasingly important to have large supplies of sand and gravel. Not only must the quantity of sand and gravel be adequate, but only limited percentages of deleterious minerals (especially chert) may be present. John M. Cattermole, of the Engineering Geology Branch of the Geological Survey, examined a number of deposits with the writer in October 1947 to assist in their evaluation and description; he also made a mechanical size analysis of finer grained constituents of the samples collected from the gravel pits.

Occurrence.—Sand and gravel occur in terrace deposits above the present levels of Green River, Ashley Creek, Brush Creek, Whiterocks River, and Uinta River. They also occur as the sedimentary cover on an old pediment (the Jensen erosion surface) 300 feet or more above the present level of the streams, and as the principal constituents of the Bishop conglomerate, which underlies the high and almost flat surface that forms the summits of Little Mountain, Dry Fork Mountain, Mosby Mountain, Pole Mountain, and Jefferson Park. The terrace deposits are the most accessible and most easily mined gravels in the area and have been the source of most of the material used in the area.

The gravel deposits of the terraces range in thickness from 6 to 15 feet and average about 8 feet; the gravel cover on the pediment is somewhat thinner, averaging about 5 feet; and the Bishop conglomerate is as much as 800 feet thick west of Uinta Canyon. The largest boulders commonly found in the terraces are 6 to 8 inches in diameter; occasionally, some pieces as large as 18 to 24 inches are present. Gravel that is more than three-fourths inch in diameter is round or subround. The coarse sand is subangular to angular, but the fraction that passes the 30-mesh screen contains many rounded to subrounded frosted grains. Most of the finer fractions (even below 200-mesh) consist of fragmental unweathered material.

Counts of pebbles ranging from 1/4 to 1 1/2 inches in diameter from deposits at different elevations above the level of the Green River show the following percentage ranges:

Rock types	(1)	(2)	(3)	(4)	Rock types	(1)	(2)	(3)	(4)
Quartzite	43	26	48	49	Quartz	7	1	4	9
Limestone	28	49	27	21	Chert	2	8	4	4
Granite	16	10	15	14	Sandstone	4	6	2	3

(1) Vernal Sand and Gravel Co., 20 feet above level of Green River SE1/4NW1/4SW1/4 sec. 21, T. 5 S., R. 23 E.
(2) Stewart Gravel Co., 40 feet above level of Green River NE1/4SW1/4 sec. 19, T. 5 S., R. 23.
(3) Utah State Highway Commission, 200 feet above level of Green River NE1/4SW1/4 sec. 22, T. 5 S., R. 23 E.
(4) Utah State Highway Commission, 300 feet above level of Green River SE1/4SW1/4 sec. 33, T. 4 S., R. 23 E.

The quartzite is brick-red, mottled red and white, or tan, and is undoubtedly derived either directly from the Uinta Mountain group or from boulders of the Uinta Mountain group in the coarse-grained Bishop conglomerate. The limestone is from the Madison or Morgan formations and the different sources frequently can be determined by the characteristic red chert associated with the limestone of the Morgan formation. The granite, quartz, and occasional large euhedral crystals of pink feldspar (which have been counted as granite) are from outcrops of pegmatitic intrusives into the pre-Cambrian Red Creek quartzite, which underlies the Uinta Mountain group in Browns Park on the north side of the Uinta Mountains. The chert could be from a number of sources, the Madison, the Morgan, or the Park City formations.

The gravel may be coated with a white caliche-like material, and streaks of gravel have been slightly cemented by soluble salts. Caliche cementation is common in the gravel that veneers the pediment surface. Most of the terrace deposits are cut on the upper part of the Mancos shale, and fragments of shale are included in the gravel near the contact.

Deposits.—Sand and gravel deposits in the Vernal area are operated for only short periods; a deposit is opened to fulfill a specific demand, and the equipment is moved and the pit is abandoned when that demand is satisfied. The principal use for sand and gravel is as a base for hard-surfaced or gravel roads in areas underlain by the sticky Morrison or Mancos formations. Generally, the material is used without crushing or other processing except for the removal of the larger boulders. Gravel for the surface-chip coat on improved highways is processed according to specifications of the Utah Highway Commission engineers. Deposits used for road base provide poorly sorted material that has sufficient "fines" to bind the gravel.

Any of the terrace deposits along Ashley Creek or Green River appears to be suitable for use as road material, and because these deposits are thicker and closer to areas of demand, they will be used before the thin but cleaner gravel covering the Jensen surface is utilized. In 1947, a deposit in the NW¼NW¼NW¼ sec. 19, T. 4 S., R. 23 E. was used to surface part of the road from Vernal northward to the hogback of the Frontier sandstone member of the Mancos shale on Utah State Highway 44.

The demand for sized sand and gravel for use in concrete has been met from deposits west of Jensen and 20 to 40 feet above the Green River. The sand and gravel is clean and, after crushing and sizing, the material in excess of current demand is stockpiled for future use. Some of this concrete aggregate is trucked as far as the Rangely oilfield in northwestern Colorado.

The following deposits represent most of the sand and gravel pits that have been operated in the area shown on plate 1:

Name of owner or operator	*Location*
Vernal Sand and Gravel Co	SENWSW sec. 21, T. 5 S., R. 23 E.[1]
Stewart Gravel Co	NESW sec. 19, T. 5 S., R. 23 E.[1]
Name unknown	SWNE sec. 19, T. 5 S., R. 23 E.[1]
Utah State Highway Commission	NESW sec. 22, T. 5 S., R. 23 E.[2]
U. S. Park Service	SESW sec. 33, T. 4 S., R. 23 E.[2]
Utah State Highway Commission	NWNW SW sec. 27, T. 5 S., R. 23 E.[2]
Do	NWNW NW sec. 19, T. 4 S., R. 23 E.[2]
Do	NESE sec. 35, T. 3 S., R. 21 E.[2]
U. S. Forest Service	NWSE sec. 22, T. 2 N., R. 2 W.[2]

[1] Concrete aggregate.
[2] Highway base and surface.

Reserves.—Adequate reserves of sand and gravel for road building are located in the general area, although many of the naturally occurring deposits are not suitable for concrete aggregate. These unsuitable deposits contain too high a percentage of fine-grained sand and silt, and the included chert might cause concrete failure if used with high-alkali cement. In the event that large quantities of aggregate should be required for concrete construction, local supplies would soon be exhausted, and some other source, such as crushed quartzitic sandstone of the Uinta Mountain group, must be utilized.

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