DEPARTMENT OF THE INTERIOR
UNITED STATER GEOLOGICAL SURVEY

TO ACCOMPANY MAP OM-216

GEOLOGIC MAP OF THE THORNBURG OIL AND GAS FIELD AND VICINITY MOFFAT AND RIO BLANCO COUNTIES, COLORADO

By

John R. Dyni

INTRODUCTION

The mapped area includes the Thornburg and the southern part of the Iles oil and gas fields and comprises about 100 square miles in Moffat and Rio Blanco Counties in northwestern Colorado. The area is about midway between Craig and Meeker. Colorado State Highway 13 is about 3 miles north and west of the mapped area. Except for parts on the east and southeast sides, most of the area is easily accessible by gravel county roads, local ranch roads, and Jeep trails.

The Thornburg area was mapped and studied to obtain geologic data needed in administering production of leasable minerals on Federal Public Lands.

Most of the Thornburg area was mapped during part of the summer of 1959 by the author, G. H. Horn, R. L. Rioux, and Harry McAndrews. The author completed the field mapping during short periods in 1960 and 1961. Permission granted by the American Stratigraphic Co. to reproduce part of its sample log of the Lewin well is gratefully acknowledged. Measured sections of the Mesaverde Group of Late Cretaceous age and lists of fossils collected from the Mancos Shale of Early and Late Cretaceous age were reported by Dyni (1966). The report is available for public inspection at U.S. Geological Survey offices in Washington, D. C., Denver, Colo., and Salt Lake City, Utah. Locations of the measured sections and fossil collections reported by Dyni are shown on the geologic map.

The area was mapped on aerial photographs, scale 1:20,000, taken in 1950 for the U.S. Soil Conservation Service. Altitudes of formation contacts at many places and altitudes of wells drilled for oil and gas were determined by plane table triangulation and by a surveying altimeter. Geologic data were transferred from the aerial photographs by photogrammetric methods to a base map compiled from township plats.

Earlier geological work covering parts of the mapped area was published by White (1878), Gale (1907, 1910), Hancock (1925), and Sears (1924). Information on the Paleozoic and Mesozoic rocks relevant to this investigation was published by Thomas, McCann, and Raman (1945), Hallgarth (1959), and Konishi (1959a, 1959b).

The mapped area is at the southeastern end of Axial Basin, an elongate topographic basin that trends northwest for 25 miles or more. Resistant sandstones in the Mesaverde Group form high escarpments on the northeast and southwest flanks and the Mancos Shale forms the lower slopes and the floor of this part of Axial Basin. Average relief between the basin floor and the escarpments is 1,000 to 1,500 feet. The maximum altitude is about 9,600 feet on Wilson Mesa in secs. 29 and 32, T. 3 N., R. 90 W.; the lowest altitude is about 6,500 feet where Stinking Gulch leaves the area in sec. 26, T. 4 N., R. 92 W. The mapped area is drained by northward-flowing tributaries of the Yampa River drainage system—chiefly Milk, Morapos, and Deer Creeks.

STRATIGRAPHY

The aggregate thickness of sedimentary rocks exposed and penetrated by drilling in the area is about 13,000 feet. The exposed rocks, about 8,300 feet thick, include the Mancos Shale, the Iles Formation, and the Williams Fork Formation, all of Cretaceous age. Older rocks penetrated by the drill range in age from Pennsylvanian to Cretaceous. The rocks are shown graphically and the stratigraphic positions of fossil collections from the exposed rocks are indicated on the generalized columnar section.

Except for slight modification, the nomenclature for the buried Paleozoic rocks follows that shown by Hallgarth (1959); most formational names of Mesozoic rocks follow those used by Thomas, McCann, and Raman (1945).

Descriptions and thickness of the exposed rocks were determined chiefly from measured stratigraphic sections. The subdivision and description of the subsurface rocks are adapted in part from Hallgarth's description of drill cuttings from the Continental Oil Co. well 1 Lewin in the NE¼ SE¼ sec. 17, T. 3 N., R. 91 W., in the Thornburg field, in part from the American Stratigraphic Co. sample log no. 329 of the same well, and from an examination of electric logs of many wells in the mapped area. The Continental Oil Co. well 1 Lewin, near the crest of the Thornburg dome, started in the lower part of the Mancos Shale and penetrated all rocks to the lower part of the Pennsylvanian System.

PENNSYLVANIAN SYSTEM

Belden Formation

Drilling in the Lewin well reached to within about 100 feet of the base of the Belden Formation of Pennsylvanian age (Hallgarth, 1959, col. 7). The formation consists of brown and gray limestone, some sandy and shaly limestone with lesser amounts of interbedded gray to black shale, and some gray to red arkosic sandstone. Several beds of limestone are cherty and a few others are oolitic. Several dolomite beds are near the top of the formation. The total thickness of the formation penetrated is about 1,230 feet. The total thickness of the formation is 1,500 feet in the Iles field where it was penetrated by the Stanolind Oil and Gas Co. well 1 Madison in sec. 22, T. 4 N., R. 92 W., less than a mile north of the mapped area.

Paradox Formation

The Paradox Formation of Pennsylvanian age conformably overlies the Belden Formation. It is 815 feet thick in the Lewin well. The Paradox consists of thick beds of gypsum interstratified with gray to brown gypsiferous limestone, red shaly sandstone, and red and black shale. The upper and lower contacts of the formation are gradational with the overlying and underlying formations and were

arbitrarily selected to include most of the gypsum beds. Outside the mapped area, the unit thins to the northwest and thickens greatly to the south.

PENNSYLVANIAN AND PERMIAN SYSTEMS

Maroon Formation

The Maroon Formation of Pennsylvanian and Permian age conformably overlies the Paradox Formation. The Maroon Formation, 1,020 feet thick in the Lewin well, consists of red, gray, and brown shale and sandstone, in part arkosic, and some interbedded dark-gray shaly and and sandy limestone and a few thin beds of gypsum. The formation thins northwestward and is absent near Juniper Mountain, 25 miles northwest of the Thornburg oil and gas field; it thickens greatly southward.

Weber Sandstone

Except for the uppermost 50 feet, the Pennsylvanian and Permian Weber Sandstone consists chiefly of brown to brownish-gray very fine- to fine-grained quartzitic sandstone. The uppermost 50 feet of the Weber consists of brown fine- to coarse-grained quartzitic sandstone. The top of this 50-foot unit is readily identifiable in electric logs. Hallgarth (1959) did not include this unit in the Weber Sandstone; he placed it in the lowermost part of a sequence designated "rocks of Permian and Permian(?) age, undifferentiated." The total thickness of the Weber Sandstone, as defined herein, is 275 feet in the Lewin well; however, its average thickness in wells in the Thornburg area is about 315 feet.

The thickness of the formation exceeds 1,000 feet near the east end of the Uinta Mountains in northwestern Colorado (Bissell and Childs, 1958, pl. 1). In the subsurface in the Rangely oil field, 60 miles west of Thornburg, however, and farther east toward Thornburg most of the formation changes to, and interfingers with, red beds of the Maroon Formation (Hallgarth, 1959, col. 12).

Bissell and Childs (1958) obtained a fauna identified as Permian in age from the upper part of the thick Weber Sandstone at Split Mountain, Morris Ranch, and Yampa Plateau, all near the eastern end of the Uinta Mountains about 75 miles northwest of the Thornburg area. Bissell and Childs (1958, pl. 1) indicate that it is the upper part of the formation that persists southeastward toward the Thornburg area.

Although the Weber Sandstone is tightly cemented and seems to have little porosity, the sandstone yields gas and has yielded oil and water in wells in the Thornburg field. Accumulation and production of oil and gas is probably related to fractures in the sandstone caused by tectonic deformation. The formation is the main oil reservoir in the Rangely field, and it has yielded oil and gas in the Elk Springs field 40 miles northwest of Thornburg, oil in the Maudlin Gulch field 20 miles northwest of Thornburg, and a minor amount of oil in the Buck Creek field 18 miles northeast of Thornburg.

PERMIAN AND TRIASSIC SYSTEMS

Moenkopi Formation and older rocks

A sequence of strata, mostly red beds, about 600 feet thick, overlies the Weber Sandstone. Most of the 600-foot sequence is of Triassic age, although its basal part probably includes rocks of Permian age. Because the boundary between the two parts of the sequence cannot be readily distinguished in the subsurface, the entire 600-foot sequence is designated herein as Moenkopi Formation and older rocks. In the Lewin well the lowermost 170 feet of the sequence consists of red shale, calcareous shaly sandstone and sandy shale, and a minor amount of anhydrite. Hallgarth (1959) included this part and the uppermost 50 feet of the Weber Sandstone described previously in his "rocks of Permian and Permian(?) age, undifferentiated." He indicated that this sequence is equivalent to the South Canyon Creek Member of the Maroon Formation, which contains a Permian fauna in exposures on the southwest flank of the the White River uplift, 30 miles southwest of the Thornburg area (Bass and Northrop, 1950).

In the Lewin well the upper part of the 600-foot sequence consists of about 430 feet of reddish-brown, orange-red, and some gray, green, and purple siltstone and shale, in part calcareous.

TRIASSIC SYSTEM

Chinle Formation

The Chinle Formation of Late Triassic age consists chiefly of reddish-brown, orange-red, and purplish calcareous siltstone with some interbedded purplish-red and gray silty limestone (probably limestone-pebble conglomerate), and a basal conglomeratic sandstone. The Chinle unconformably overlies the Moenkopi Formation. The thickness of the formation averages about 545 feet in wells in the mapped area.

The basal unit, 75 to 160 feet thick, consists of gray, buff, and reddish fine- to coarse-grained conglomeratic sandstone containing a little purple and green shale. This conglomeratic sandstone, widespread in northwestern Colorado, has long been referred to as the Shinarump. However, a regional stratigraphic investigation by F. G. Poole and J. H. Stewart (oral communication, July 24, 1962) indicates that this unit is continuous with the Gartra Grit Member of the Stanaker Formation of Thomas and Krueger (1946) in northeastern Utah. Poole (1961) believes the Gartra is derived from a different source than the Shinarump Member of the Chinle of southeastern Utah.

The basal conglomeratic sandstone is unusually thick in the mapped area. Descriptions of cores from the Lewin well suggest that the upper part of the sandstone interfingers with, and includes beds in, the lower part of the main body of the Chinle Formation.

Commercial quantities of oil have been found in the basal sandstone unit of the Chinle Formation in the Moffat, Oak Creek, and Pinnacle fields, and commercial quantities of gas in the Pagoda field, all in northwestern Colorado, less than 60 miles from the Thornburg area. Oil-stained drill cuttings and cores of the basal sandstone have been found in wells in the Thornburg field and in the Iles field on the north boundary of the mapped area.

TRIASSIC(?) AND JURASSIC SYSTEMS

Navajo and Entrada Sandstones

The Navajo and Entrada Sandstones of Triassic(?) and Jurassic age, about 270 feet thick in wells in the mapped area, consist of gray to tan very fine- to fine-grained sand-

stone containing a few medium to very coarse rounded grains of quartz and feldspar. The sandstone is moderately to tightly cemented with clay.

The Carmel Formation, consisting of red shale, red sandy shale, and shaly sandstone, intervenes between the Navajo Sandstone and the Entrada Sandstone in the Rangely oil field and at other places in northwestern Colorado (Thomas, McCann, and Raman, 1945). The Carmel is not present in the Thornburg area, however. Accordingly, the two sandstone formations are not differentiated without the distinctive Carmel between them, and so form one thick sandstone unit.

The Navajo and Entrada Sandstones are one of the important oil- and gas-producing zones in northwestern Colorado. The zone yields gas in the Thornburg field and oil in the Iles, Moffat, Wilson Creek, and Maudlin Gulch fields, which are within 25 miles of Thornburg.

JURASSIC SYSTEM

Curtis Formation

In wells in the Thornburg area the Curtis Formation of Late Jurassic age is about 30 feet thick and consists of gray to tan very fine- to fine-grained glauconitic and calcareous sandstone, gray to green glauconitic shale, and greenish-gray glauconitic limestone. Elsewhere in northwestern Colorado marine fossils are abundant in the formation.

Morrison Formation

The Morrison Formation of Late Jurassic age ranges between 410 and 470 feet thick, and averages about 440 feet in wells. The lower part of the formation consists of gray to brown and reddish-brown very fine- to fine-grained calcareous sandstone interbedded with variegated calcareous shale. The upper part consists of gray to green sandy shale, some interbedded tan to brown limestone, and a little sandstone. The two parts were designated the "lower sandy member" and "upper shaly member" by Konishi (1959b, pl. 7) and he indicated that the two units are persistent in both the subsurface and on the outcrop in Moffat and Rio Blanco Counties, Colo.

Only gas shows have been reported in the lower part of the Morrison Formation in the Thornburg field; however, the formation is an important oil-producing zone in six fields within a radius of 25 miles of Thornburg.

CRETACEOUS SYSTEM

Dakota Sandstone

The Dakota Sandstone of Early Cretaceous age consists of gray to tan fine- to coarse-grained sandstone containing a little interbedded greenish-gray and black shale. Two thin units of shale in the upper and lower parts of the formation are usually distinguishable on electric logs of most wells. Locally, a conglomeratic sandstone containing pebbles of dark-gray chert is at the base of the formation.

The thickness of the Dakota Sandstone ranges from about 90 to 290 feet in wells. The electric logs of wells in the area suggest that the variation in thickness is probably due to lensing and local pinch out of the lowermost beds.

The Dakota Sandstone has yielded gas in the Thornburg field and oil or gas in the Moffat, Williams Park, Pinnacle, and Indian Run fields, all within a radius of 25 miles of Thornburg.

Mancos Shale

The Mancos Shale of Early and Late Cretaceous age includes all rocks between the Dakota Sandstone and the Iles Formation. The basal and top contacts of the Mancos Shale are conformable. Except for about the lowermost 260 feet, the entire formation is at the surface in the mapped area. Its thickness could not be determined precisely in the area because much of it is poorly exposed and no well has penetrated the entire formation. However, its thickness is estimated to be about 5,100 to 5,300 feet, for it is 5,100 feet in wells in the Moffat field 3 miles north of the mapped area and about 5,300 feet in wells in the Wilson Creek field (Kramer, 1939) 7 miles west of the mapped area.

The Mancos Shale consists chiefly of dark-gray marine shale, but several mappable units of sandstone are in the upper part of the formation. The sandstone units are described below.

Mowry Shale and Frontier Sandstone Members.—The lowermost 395 feet of the Mancos Shale is composed of the Mowry Shale and Frontier Sandstone Members. The sequence includes a lower unit of dark-gray partly siliceous shale containing several thin beds of light-gray bentonite and an upper unit, about 75 feet thick, of thin- to medium-bedded tan shaly sandstone. A few beds near the top of the upper unit are fossiliferous. The upper sandstone unit and the upper part of the lower shale unit are the oldest sedimentary rocks exposed in the mapped area (see generalized columnar section on the map). They crop out in sec. 35, T. 3 N., R. 92 W., on the northeast flank of the Yellowjacket anticline.

The contact between the Mowry Shale and the Frontier Sandstone Members is not exposed in the mapped area. Konishi (1959b, pl. 7) placed the boundary at the base of a persistent bed of bentonite that can be identified in electric logs of wells throughout this region. Thus defined, the Mowry Shale Member would be restricted to about the bottom 85 feet of the lower shale unit in the Thornburg area.

Dark-gray partly calcareous marine shale, about 2,600 feet thick, overlies the Mowry Shale and Frontier Sandstone Members and extends upward to the base of the Meeker Sandstone Member.

Four wells (now abandoned) in the Iles field, on the north boundary of the mapped area, produced oil from a fractured zone in the lowermost part of the Mancos Shale, probably the Mowry Shale Member. One of these wells, Stanolind 1-Shale in the NW¼NE¼ sec. 27, T. 4 N., R. 92 W., in the southern part of the field, is in the mapped area.

Meeker Sandstone Member.—The Meeker Sandstone Member consists of pale to medium yellowish-brown very thin- to thin-bedded very fine grained shaly calcareous sandstone. Its thickness ranges from 0 to about 160 feet. In the SW¼ sec. 23, T. 3 N., R. 92 W., the member is 160 feet thick.

From map measurements along the west flank of the Yellowjacket anticline in T. 3 N., R. 92 W., the zone between the top of the Meeker Sandstone Member and the top of the Mancos Shale is estimated to be 2,100 to 2,300 feet thick.

The Meeker Sandstone Member forms a prominent ridge near Milk Creek in the southwest part of the mapped area. Northward from Milk Creek the sandstone forms a series of low hills along the southeast side of Thornburgh Mountain to about the axis of the Collom syncline where it apparently

lenses out into shale. The unit was not recognized north of the Collom syncline along the northeast side of Thornburgh Mountain, nor was it found on the northeast side of Axial Basin.

Dark-gray marine shale, about 1,000 feet thick, overlies the Meeker Sandstone Member and extends upward to the Morapos Sandstone Member.

Morapos Sandstone Member.—The Morapos Sandstone Member, another prominent ledge-forming unit, crops out about 1,000 to 1,300 feet below the top of the Mancos Shale. The sandstone is light gray and tan, very fine to fine grained, shaly, calcareous, and thin bedded. The lower part of the member grades downward into sandy shale, whereas the top of the member forms a relatively sharp contact with the overlying shale. The member ranges in thickness from 0 to about 80 feet. It is 77 feet thick in sec. 25, T. 4 N., R. 92 W., on the east side of Axial Basin near the north margin of the mapped area. From this locality the Morapos becomes increasingly shaly and thinner southeastward to beyond the Thornburg oil and gas field. About 15 feet of the Morapos is exposed in the NW¼ sec. 23, T. 3 N., R. 91 W. On the west side of the mapped area about 25 feet of Morapos was measured in sec. 3, T. 3 N., R. 92 W.

Baculites mclearni Landes (Zapp and Cobban, 1960, p. B247; USGS Mes. loc. D2340) has been collected from the Morapos Sandstone Member and from shale a few hundred feet below the member. This fossil marks one of several baculite zones of early Montana (Campanian) age (Cobban, 1962).

The Morapos Sandstone Member forms a continuous low escarpment along the northeast side of Axial Basin from Monument Butte to near Iles Mountain in the S½ T. 3 N., R. 91 W. In the western part of the mapped area the member is poorly exposed and forms a discontinuous ledge around the lower slopes of Thornburgh Mountain. The member could not be identified with certainty southward from sec. 14, T. 3 N., R. 92 W., nor near the northwest corner of the mapped area.

The following section of the Morapos Sandstone Member was measured on the east side of the county road in the SE¼ SE¼ sec. 30, T. 4 N., R. 91 W., Moffat County, Colo.:

	Feet
Mancos Shale:	
Morapos Sandstone Member:	
4. Sandstone, light-tan, fine-grained, ripple-marked, partly crossbedded; some fossil pelecypods; top of unit forms broad eastward-dipping slope	36
3. Sandstone, light-gray to light-tan, very fine- to fine-grained, calcareous, thin-bedded; contains carbonaceous streaks and fossil plant impressions	3
2. Concealed	27
1. Sandstone, light-gray, very fine- to fine-grained, calcareous; in thin beds separated by shale partings; forms weak unit	11
Thickness Morapos Sandstone Member	77
Concealed; forms slope covered with talus from sandstone beds above	18

Sandstone unit a.—Gray partly sandy marine shale, including two thin units of thin-bedded sandstone in the upper part, occupies an interval of about 750 to 1,000 feet between the Morapos Sandstone Member below and the Loyd Sandstone Member above. *Baculites asperiformis* Meek and *B. perplexus* Cobban, marking two faunal zones of early Montana age (Cobban, 1962), were collected from these rocks as indicated on the generalized columnar section.

The higher of the two sandstone units, which lies about 50 to 75 feet below the Loyd Sandstone Member, consists of brown fine-grained thin-bedded sandstone. This unit, identified herein as sandstone unit a, was mapped along the northeast side of Axial Basin from Monument Butte southeastward to sec. 14, T. 3 N., R. 91 W., where it no longer could be recognized. Sandstone unit a thins from southeast to northwest; it is about 40 feet thick in sec. 12, T. 3 N., R. 91 W., and about 20 feet thick in sec. 34, T. 4 N., R. 91 W. It was not recognized on the southwest side of Axial Basin.

Loyd Sandstone Member.—A distinctive fossiliferous marine sandstone crops out about 150 to 200 feet below the top of the Mancos Shale in the mapped area. This unit was named the Loyd Sandstone Member of the Mancos Shale by Konishi (1959a, p. 69–70) after Loyd, the field camp in the Iles oil and gas field half a mile north of the mapped area. The sandstone is greenish gray, light brown on weathered surfaces, very fine grained, and massive. It is characterized by many calcareous concretions as much as 0.5 foot or more in diameter that contain many marine fossils. Although the member is nonresistant and generally a poor ledge-former, it is easily recognized by its color and fossiliferous concretions. On Thornburgh Mountain in sec. 11, T. 3 N., R. 92 W., about 75 feet of the Loyd Sandstone Member is exposed about 170 feet below the top of the Mancos Shale. It is about 100 feet thick at the type locality 4 miles north of the mapped area (Konishi, 1959a, p. 70).

A unit of interbedded gray sandy shale and thin- to medium-bedded tan shaly sandstone about 150 to 200 feet thick is between the Loyd Sandstone Member and the base of the Iles Formation. The top of the unit is conformable and gradational with the Iles Formation.

A zone from about the base of the Loyd Sandstone Member up into the base of the Iles Formation contains *Baculites gilberti* (Cobban, 1962), the youngest baculite of early Montana age found in the mapped area (USGS Mes. locs. D2329, D2330, D2332, D2645, and D2336).

Iles Formation

The Iles Formation, the lower formation of the Mesaverde Group, conformably overlies the Mancos Shale. It is about 1,300 to 1,400 feet thick and consists of light-gray to light-brown fine-grained sandstone in thick beds interbedded with brown to black carbonaceous shale, gray shale, and several thin beds of coal. The Trout Creek Sandstone Member is at the top of the formation. Except for the Trout Creek, the upper part of the formation is poorly exposed. A few shallow-water marine fossils were collected about 360 feet above the base of the Iles Formation (USGS Mes. loc. D2338).

The contact between the Mancos Shale and Iles Formation was drawn at the base of a thick massive sandstone ("rim rock" of Hancock, 1925, p. 12), about 150 to 200 feet above the top of the Loyd Sandstone Member of the Mancos Shale.

This sandstone is present on both sides of Axial Basin in the mapped area. It seems to be equivalent to the Tow Creek Sandstone Member of the Iles Formation, which is the basal unit of the Iles in the Williams Fork Mountains, 12 miles northeast of the mapped area (Bass, Eby, and Campbell, 1955, p. 155–156, and pl. 21).

The best exposures of the Iles Formation are in the west part of the mapped area, especially in the vicinity of Milk Creek in secs. 28 and 29, T. 3 N., R. 92 W.

Trout Creek Sandstone Member.—The Trout Creek Sandstone Member, about 50 to 100 feet thick, is the uppermost unit of the Iles Formation. It is light brown to predominantly light gray, fine grained, and massive. The unit crops out commonly as a prominent light-gray ledge. It is present on both sides of Axial Basin and on Wilson Mesa in the southeastern part of the mapped area.

Williams Fork Formation

The Williams Fork Formation of the Mesaverde Group, like the Iles Formation below it, consists of interbedded thick sandstones, carbonaceous shale, gray shale, and coal beds. The Twentymile(?) Sandstone Member forms a prominent white ledge about 800 to 900 feet above the base of the formation. The coal beds in the Williams Fork are thicker and more numerous than those in the Iles Formation. Large outcrops of the Williams Fork Formation consist of baked and distorted beds of red sandstone, fragments of hard porcelaneous shale, and clinkers due to burning of coal beds. Although much of the formation is nonmarine, a few abraded brackish-water and marine fossils were collected from the lower half of the formation (USGS Mes. locs. D2337 and D2646). *Ophiomorpha* was noted in a few sandstone beds above the Twentymile(?) Sandstone Member. The top of the Williams Fork is not exposed in the mapped area.

The maximum thickness of the Williams Fork in the mapped area, estimated to be about 2,100 feet, is exposed west of Thornburgh Mountain. About the lower 800 feet of the formation crops out northeast of Axial Basin, and the lowermost beds are exposed on Wilson Mesa in the southeastern part of the mapped area. Hancock (1925, p. 20) estimated the total thickness of the formation as 1,600 feet in parts of the Axial and Monument Butte quadrangles northeast of Axial Basin, about 10 to 15 miles north of the Thornburg area. It is known, however, that the Williams Fork Formation thickens southward. Rocks equivalent to the marine Lewis Shale which overlies the Williams Fork Formation in these quadrangles southward are nonmarine sandstone and shale of the Williams Fork. Thus, the upper part of the relatively thick Williams Fork Formation southwest of Axial Basin on the west side of the mapped area probably includes nonmarine rocks equivalent to the Lewis Shale.

Twentymile(?) Sandstone Member.—A conspicuous ledge-forming sandstone, about 40 to 80 feet thick, crops out in the western part of the mapped area about 800 to 900 feet above the base of the Williams Fork Formation. The sandstone is massive, very fine to fine grained, and crossbedded. The lower part is light tan and the upper part is light gray to white. Because of its stratigraphic position and light color, the sandstone is tentatively correlated with the Twentymile Sandstone Member of the Williams Fork Formation which is widespread in the Williams Fork Mountains and along the Yampa River north of the mapped area (Hancock, 1925, p. 18; Bass, Eby, and Campbell, 1955, p. 158, and pl. 21).

TERTIARY(?) AND QUATERNARY DEPOSITS

Unconsolidated surficial deposits.—Poorly exposed undifferentiated surficial deposits consisting of angular boulders of basalt and subangular to well-rounded pebbles and cobbles of chiefly granite, basalt, and quartzite form a thin veneer in parts of T. 3 N., Rs. 91 and 92 W. A small hill in secs. 31 and 32, T. 4 N., R. 91 W., is capped by the same material (mapped as basalt by Hancock, 1925, pl. 19). Slide debris is also included in the deposits mapped in the south half of T. 3 N., R. 91 W. These deposits were not mapped in detail, but were delineated on the basis of reconnaissance mapping.

Residual basalt boulders.—Large angular boulders and blocks of vesicular basalt cover the top of Wilson Mesa in T. 3 N., R. 90 W. They are probably weathered debris of a Tertiary basalt flow that extended from the Flat Tops south of the mapped area northward into the mapped area.

QUATERNARY DEPOSITS

Landslide deposit.—A landslide deposit of Quaternary age consisting of unconsolidated material derived chiefly from the Dakota Sandstone occupies parts of secs. 33, 34, and 35, T. 3 N., R. 92 W. The material ranges in size from sand to large angular boulders and blocks. The surface of the deposit is quite hummocky and a few small natural ponds are in some of the depressions. This deposit is part of a larger landslide deposit that covers several square miles south of the mapped area in T. 2 N., R. 92 W. Here, the Dakota Sandstone and the upper part of the Morrison Formation in which the landslide occurred are exposed in the main landslide scarp in the east half of the township.

Alluvium.—Stream alluvium and some alluvial fans of Recent age were mapped along Milk Creek and Wood Gulch. The alluvium consists of silt, sand, and gravel. Alluvium is also along the streams in Axial Basin, but it was not mapped.

Unmapped terrace deposits of probable Quaternary age occur above stream level in the valley of Milk Creek. Terrace gravel as much as 20 feet thick is in the NE ¼ sec. 34, T. 3 N., R. 92 W. Here, the gravel consists of pebbles and cobbles of quartzitic sandstone, gray shale, and tan fine-grained sandstone derived probably from underlying bedrock.

STRUCTURE

The mapped area is in a region of folded Cretaceous rocks on the north side of the White River uplift. The principal structural features of the area and their relation to the general structure of the surrounding region are shown on the inset small-scale map.

Structure contours at 250- and 500-foot intervals were drawn on the top of the Dakota Sandstone to show the structure of the mapped area. Where surface data are adequate, the surface positions of fold axes are shown on the map in black; elsewhere the approximate positions of fold axes are shown in red on the structure contour horizon.

The Axial Basin anticline, the principal structural element of the mapped area, is a large asymmetrical fold that trends northwestward across the central part of the mapped area and beyond for as much as 40 miles (Sears, 1924, pl. 35).

The southeastern end of the anticline apparently terminates a short distance southeast of the Thornburg oil and gas field, as indicated by the structure contours on the map. Rocks on the steeper southwest limb of the fold dip from about 35° to as much as 65°; the northeast limb is much flatter with dips ranging about 5° to 15°.

The Thornburg dome near the southeastern end of the Axial Basin anticline is about 3 miles long and 1.5 miles wide. Dips around the flanks of the dome range from a few degrees to 28°, with the steeper dips on the west side. Structural closure on the Dakota Sandstone is about 400 feet. Many slabs of calcite that may indicate the presence of faults were found in the Mancos Shale on the Thornburg dome.

The southernmost part of the Iles dome extends into the mapped area in T. 4 N., R. 92 W. Structural closure on the dome (on the Dakota Sandstone) is about 400 to 500 feet (Nelson, 1955).

The Yellowjacket anticline, a northward-trending asymmetrical fold, extends into the mapped area in T. 3 N., R. 92 W., and terminates near the Collom syncline. Dips on the west limb range from about 30° to as much as 60°. On the east limb dips range from 10° to 20°.

An anticlinal nose is present on the east side of the mapped area in sec. 17, T. 3 N., R. 90 W. This fold may be continuous with Seely dome which is east of the mapped area.

The west end of the Hart syncline is near the north edge of the map. Here, the axis of the fold trends more or less westward across Monument Butte and terminates near the Axial Basin anticline.

The Monument Butte fault, the largest fault in the mapped area, nearly parallels the axis of the Hart syncline. The fault passes through Monument Butte where the Morapos Sandstone Member of the Mancos Shale on the south side of the fault is nearly in contact with the basal part of the Iles Formation on the downthrown north side. The maximum vertical displacement on the fault is slightly more than 1,000 feet.

Two folds, the Elkhorn and Collom synclines, intersect near the west boundary of the map where they form a local relatively deep structural basin. This downwarped area is occupied by a thick sequence of rocks of the Williams Fork Formation.

The axis of a northwest-trending syncline, here called the Wilson Mesa syncline, crosses Wilson Mesa and terminates near the east boundary of T. 3 N., R. 91 W., in the southeastern part of the mapped area. Dips range from 5° to 25° around the fold.

OIL AND GAS

The Thornburg oil and gas field was discovered in March 1925 by the completion of the Continental Oil Co. well 1 Wymore in the SW¼NW¼ sec. 16, T. 3 N., R. 91 W. The well's initial yield was reported to be 20,000,000 cubic feet of gas per day from the Dakota Sandstone. Commercial gas in the Navajo and Entrada Sandstones was discovered in the Continental Oil Co. well 1 Henderson in the SW¼SW¼ sec. 16, T. 3 N., R. 91 W., when the well, originally drilled in 1926 and 1927, was deepened in 1936.

In March 1951 gas was discovered in the Weber Sandstone and the uppermost part of the Maroon Formation with the completion of the Continental Oil Co. well 1 Lewin in the NE¼SE¼ sec. 17, T. 3 N., R. 91 W. Development drilling during 1955 to 1957 led to the discovery of oil in the Weber Sandstone; however, the oil pool was small and the wells rapidly went to water. No oil has been produced from the Weber since January 1960. Three dry holes, drilled in 1961 along the flanks of Thornburg dome, tested the lower part of the Mancos Shale.

Gas has been produced in the field since 1936 and oil was produced for a few years in the 1950's. At present four wells in the Thornburg field produce gas intermittently from the Navajo and Entrada Sandstones and from the Weber Sandstone. Most of the gas is piped to Craig for local domestic use.

Total accumulative oil and gas production from the Thornburg field is as follows:

Producing zone	Total accumulative production (through December 31, 1962) Oil (bbls)	Gas (MMCF)	Water (bbls)
Dakota Sandstone	--	3,771	--
Navajo and Entrada Sandstones	--	3,305	--
Weber Sandstone	785,505	3,084	5,068,662

From the time drilling commenced until January 1, 1964, about 63 wells have been drilled in the area; data on these wells are summarized in the table included with the map. About one-third of the wells were drilled to shallow depths in the Mancos Shale. Twenty wells were drilled to the Weber Sandstone or below; most of these were in the Thornburg field.

The area between the Iles and Thornburg domes may be worthy of additional exploration. Only one deep test to the Weber Sandstone, the Texas Pacific Coal and Oil Co. well 1 in the SE¼SW¼ sec. 35, T. 4 N., R. 92 W., has been drilled in this area. A significant show of oil in the lower part of the Mancos Shale was reported in the Woodward well 1 in sec. 33, T. 4 N., R. 92 W., which was drilled recently along the steep west flank of Axial Basin anticline.

COAL

Coal is present in the Iles and Williams Fork Formations in the mapped area. The thickness of most beds of coal in the Iles Formation ranges from 1 to 3 feet which is too thin to be of current economic importance. However, a coal bed about 4.5 feet thick was found in the upper part of the Iles Formation near Wilson Mesa in the SE¼ sec. 24, T. 3 N., R. 91 W. Hancock (1925, pl. 15) also reported a coal bed 4.5 feet thick in the upper part of the formation in sec. 4, T. 3 N., R. 92 W.

The Williams Fork Formation contains minable beds of coal. On the south flank of the Hart syncline in T. 4 N., R. 91 W., Hancock (1925, pl. 14) reported the presence of coal beds as much as 15 feet thick. Coal is relatively abundant in the formation in the west part of the mapped area where beds as thick as 12 feet or more are present (Hancock, 1925,pl. 15).

The abandoned Wilson mine on the south side of Milk Creek in the SE¼ sec. 29, T. 3 N., R. 92 W., was opened more than 50 years ago on a coal bed about 11 feet thick near the base of the Williams Fork Formation (Gale, 1910, p. 169–170). The mine was worked in recent years, but no records are available. A few old coal prospects are present elsewhere in the mapped area.

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