Uppermost Cretaceous and Tertiary Stratigraphy of Fossil Basin, Southwestern Wyoming

By STEVEN S. ORIEL *and* JOSHUA I. TRACEY, JR.

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New subdivisions of the 7,000-foot-thick continental Evanston, Wasatch, Green River, and Fowkes Formations facilitate understanding of sediment genesis and Wyoming thrust-belt tectonic events

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UPPERMOST CRETACEOUS AND TERTIARY STRATIGRAPHY OF FOSSIL BASIN, SOUTHWESTERN WYOMING

By Steven S. Oriel and Joshua I. Tracey, Jr.

ABSTRACT

More than 7,000 feet of uppermost Cretaceous and Tertiary continental strata in the northern Fossil basin, along the southern part of the western Wyoming thrust belt, is here subdivided into newly defined formal and informal rock-stratigraphic units. Recognition of these units makes possible the dating of some thrust-fault movement, of the development of the Fossil structural basin, and of some later block faulting, as well as reinterpretations of the origins of the strata.

The Evanston Formation, which is more than 2,000 feet thick and more extensive in the Fossil basin than formerly recognized, consists of an unnamed lower member, the Hams Fork Conglomerate Member, and the main body. The lower member consists of as much as 500 feet of gray to dark-gray mudstone, siltstone, claystone, and carbonaceous fine-grained, but partly gritty and conglomeratic, sandstone and is of latest Cretaceous, probably Lance, age. The Hams Fork Conglomerate Member, previously mapped erroneously as the Almy Formation along the east side of the Fossil basin, consists mainly of 450–1,000 feet of latest Cretaceous (Lance) boulder conglomerate and interstratified partly conglomeratic brown and gray sandstone and gray partly carbonaceous mudstone; sources of the well-rounded boulders and pebbles were the nearby upper Paleozoic and Mesozoic formations and lower Paleozoic units of the Paris thrust sheet in Idaho. The main body of the Evanston, 400 to more than 1,400 feet thick, consists mainly of Paleocene but also latest Cretaceous light to dark-gray carbonaceous sandy to clayey partly quartzitic siltstone, gray, tan, yellow, and brown sandstone and conglomerate, carbonaceous to lignitic claystone, ironstone, lignite, and, locally, thin beds of coal.

The Wasatch Formation is subdivided into seven mapped units:

1. The basal conglomerate member, from a few feet to several hundred feet thick, consists mainly of buff sandstone pebbles and cobbles in a matrix of sand, all derived principally from the Nugget Sandstone but including a few clasts from other units.
2. The lower unnamed member, as much as 300 feet thick, consists of interbedded light- to dark-gray, brown, pink, and red sandy mudstone, black carbonaceous silty claystone, gray, partly gritty and conglomeratic sandstone, and brown to light-gray finely crystalline and pisolitic limestone.
3. The main body, directly beneath the Green River Formation, ranges in thickness from 1,500 to 2,000 feet, where fully represented, and consists of banded variegated—mainly red, purple, yellow, and gray—mudstone with interbedded claystone, siltstone, sandstone, and marlstone and lenses of well-rounded and well-sorted conglomerate. Mudstone is dominant near the center of the basin and grades laterally into more abundant sandstone and conglomerate toward the basin margins.
4. The sandstone tongue is 40–50 feet thick in the southern part of the mapped area, where it divides the lower member of the Green River Formation into two units, and it pinches out northward. It consists of well-sorted medium- to coarse-grained brown crossbedded sandstone and green and gray mudstone.
5. The mudstone tongue, as much as 50 feet thick, lies between the two members of the Green River Formation and consists of dark- to brick-red mudstone which grades basinward into pink and gray-green claystone.
6. The Bullpen Member, which overlies the Green River Formation and is 400 feet thick, consists of red, salmon, green, and gray mudstone, fine- to coarse-grained partly conglomeratic sandstone, and thin but extensive beds of brown to white limestone similar to that in the Green River Formation.
7. The Tunp Member is a 200- to 500-thick peripheral diamictite facies of the Wasatch Formation. It consists of dark-red conglomeratic mudstone and rubble breccia with a great range in grain size; blocks from older nearby formations commonly as large as 20 feet in diameter lie in a matrix of very poorly sorted red mudstone.

Although the basal and upper parts of the formation are undated, most of the Wasatch in the Fossil basin is of early Eocene age. Unit 1 (previous list) is unfossiliferous but is tentatively assigned to the lower Eocene. Fossils from unit 2 indicate an early Eocene, probably Gray Bull (of Granger, 1914), age. Unit 3 contains abundant fossils of both early and middle early Eocene (Gray Bull and Lysite) ages. Units 4 and 5 are probably of early Eocene age. Unit 6, the Bullpen Member, may be late early (Lost Cabin) or middle (Bridger) Eocene age. Unit 7, the Tunp Member, intertongues with units 2 through 6, as well as with members of the Green River Formation.

In the Fossil basin, the Green River Formation is divided into the Fossil Butte Member and the overlying Angelo Member. Near the center of the basin, the Fossil Butte Member (200–270 feet thick) is dominantly laminated organic-rich buff to brown marlstone, limestone, siltstone, and mudstone and includes oil shale and volcanic ash; the prolific fossil fish beds at Fossil Butte are in this member. The Angelo Member, as much as 200 feet thick, is mainly white- to blue-white-weathering limestone, marlstone, and mudstone and includes siliceous limestone, chert, sandstone, volcanic ash, and low-grade oil shale. It contains less organic matter than the lower member. The laminated strata of both members grade laterally (shoreward) through ostracodal and gastropodal to algal limestone. Although the formation is commonly assigned a late early

Eocene (Lost Cabin) age in the Fossil basin, the topmost strata may be younger or older.

The Fowkes Formation, though previously assigned erroneously to the Wasatch Group, overlies both the Wasatch and the Green River Formations. The formation is divided into three new members: the Sillem, the Bulldog Hollow, and the Gooseberry. The Sillem Member, from 100 to 400 feet thick, consists of a basal conglomerate unit with pebbles of dark-gray chert and quartzite and interbedded sandstone and mudstone and an upper unit of mainly pale-pink, gray, and green-gray partly tuffaceous mudstone, siltstone, and claystone. The Bulldog Hollow Member, from 200 to 2,000 feet thick, consists of pale- to dark-green, blue-green, and white tuffaceous and ashy mudstone and green to buff and brown very tuffaceous sandstone with abundant biotite and magnetite. The Gooseberry Member, more than 200 feet thick though incompletely represented, consists of puddingstone, poorly packed rounded pebbles and cobbles of Paleozoic limestone, chert, and quartzite and sparse basalt, rhyolite, and andesite in a matrix of calcareous rhyolitic ash and ash-bearing very fine grained to subaphanitic limestone. The Fowkes Formation is middle to late Eocene in age, although the Gooseberry Member, assigned to the Fowkes provisionally, may be as young as Pliocene.

Both stratigraphic and geometric relations establish that the Fossil basin region had moderate relief during deposition of the described strata; many modern topographic features are exhumed from an Eocene landscape. Compositions of some conglomerates, however, record reversals of relative elevations of some features. Major movements along the thrust faults from the Absaroka fault westward had ended by latest Cretaceous time. Sinking of the Fossil basin, begun in latest Cretaceous time, continued well into the Eocene.

INTRODUCTION

PURPOSE

This report presents new data on the stratigraphy of the more than 7,000 feet of uppermost Cretaceous and lower Tertiary rocks in the northern part of Fossil basin in southwestern Wyoming. The data affect earlier interpretations of both stratigraphic sequence and geologic history. The report revises rock nomenclature for the region and discusses briefly the bearing of the new data on such general questions as origin and tectonic implications.

The rock sequence in the Fossil basin in some respects is similar to, but in other respects differs from, that along the western margin of the Green River Basin. An important objective is to determine precise relations between these sequences.

Information presented here was gathered during five summers since 1955 in the course of mapping Tertiary rocks of the Sage and Kemmerer 15-minute quadrangles (Rubey, Tracey, and Oriel, 1968; Rubey, Oriel, and Tracey, 1968) and part of the Cokeville 30-minute quadrangle, in cooperation with William W. Rubey, who studied the older rocks. These quadrangles lie in southwestern Wyoming (fig. 1) and include the south end of the thrust belt and the northern part of the Fossil structural basin.

EARLIER WORK

Publications on the geology of westernmost Wyoming are based largely on the surface mapping of Veatch (1907) and Schultz (1914). In one field season, during the summer of 1905, Veatch and his associates, including Schultz, prepared both topographic and geologic maps for some 1,800 square miles, including Kemmerer, Sage, Evanston, and a strip south of Evanston. In the course of this work, Veatch recognized and defined virtually all the stratigraphic units now in use from the Nugget Sandstone up to and including subdivisions of the Wasatch. He also recognized and delineated, with remarkable accuracy, the major structural elements of this complexly faulted region.

During the following field season, in 1906, Schultz and his associates continued this work, mapping a strip northward along the eastern edge of the thrust belt from Kemmerer to the southern flank of the Gros Ventre Range. Some 2,200 square miles was mapped topographically and geologically in an area that includes complex structural and facies relations.

The general stratigraphic relations of the Green River and Wasatch Formations were studied extensively by Sears and Bradley (1924), and detailed studies of the Green River Formation were published by Bradley (1926, 1929 a, b, 1930, 1931, 1948, 1959, 1963, 1964, 1966).

Recently published descriptions of lower Tertiary rock relations in the Green River Basin that have an important bearing on this work are those by Bradley (1964), Oriel (1962), and Lawrence (1963).

Data on subsurface rocks and structures and their relation to surface features have appeared in the 1950, 1955, and 1960 field conference guidebooks of the Wyoming Geological Association and in the 1959 guidebook of the Intermountain Association of Petroleum Geologists.

The general relations of the western Wyoming thrust belt were summarized by Rubey and Hubbert (1959) and Armstrong and Oriel (1965).

ACKNOWLEDGMENTS

Investigation of uppermost Cretaceous and Tertiary strata was undertaken at the suggestion of W. W. Rubey as a probable means of dating tectonic events in the Idaho-Wyoming thrust belt. The mapping on which this study was based, especially in areas where geometric relations are critical, was done with him. Important pieces of new information and several critical fossil localities were found by him, and many new working

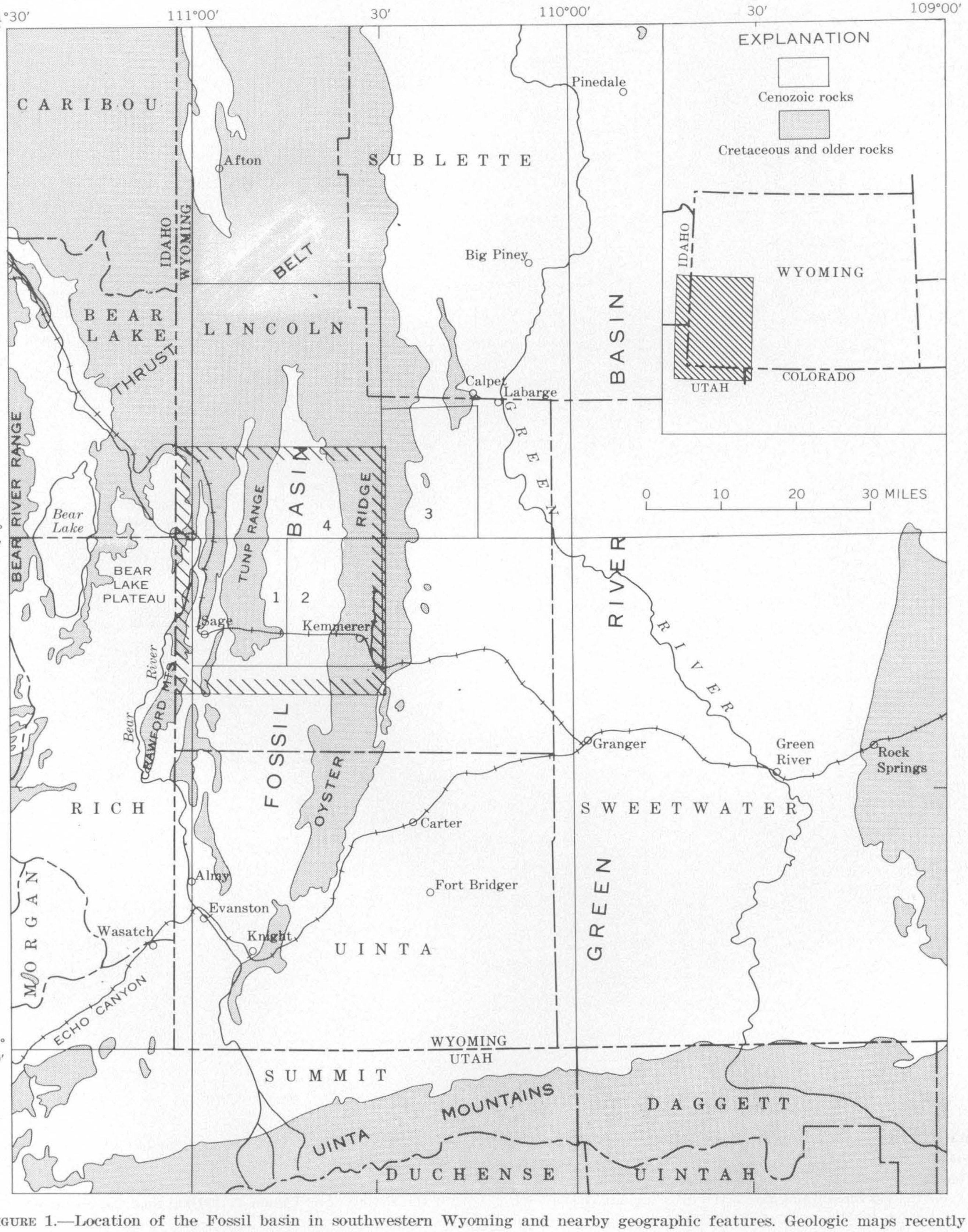

FIGURE 1.—Location of the Fossil basin in southwestern Wyoming and nearby geographic features. Geologic maps recently completed include the (1) Sage, (2) Kemmerer, and (3) Fort Hill 15-minute quadrangles and the (4) Cokeville 30-minute quadrangle. Area of figure 2 shown by hachured outline.

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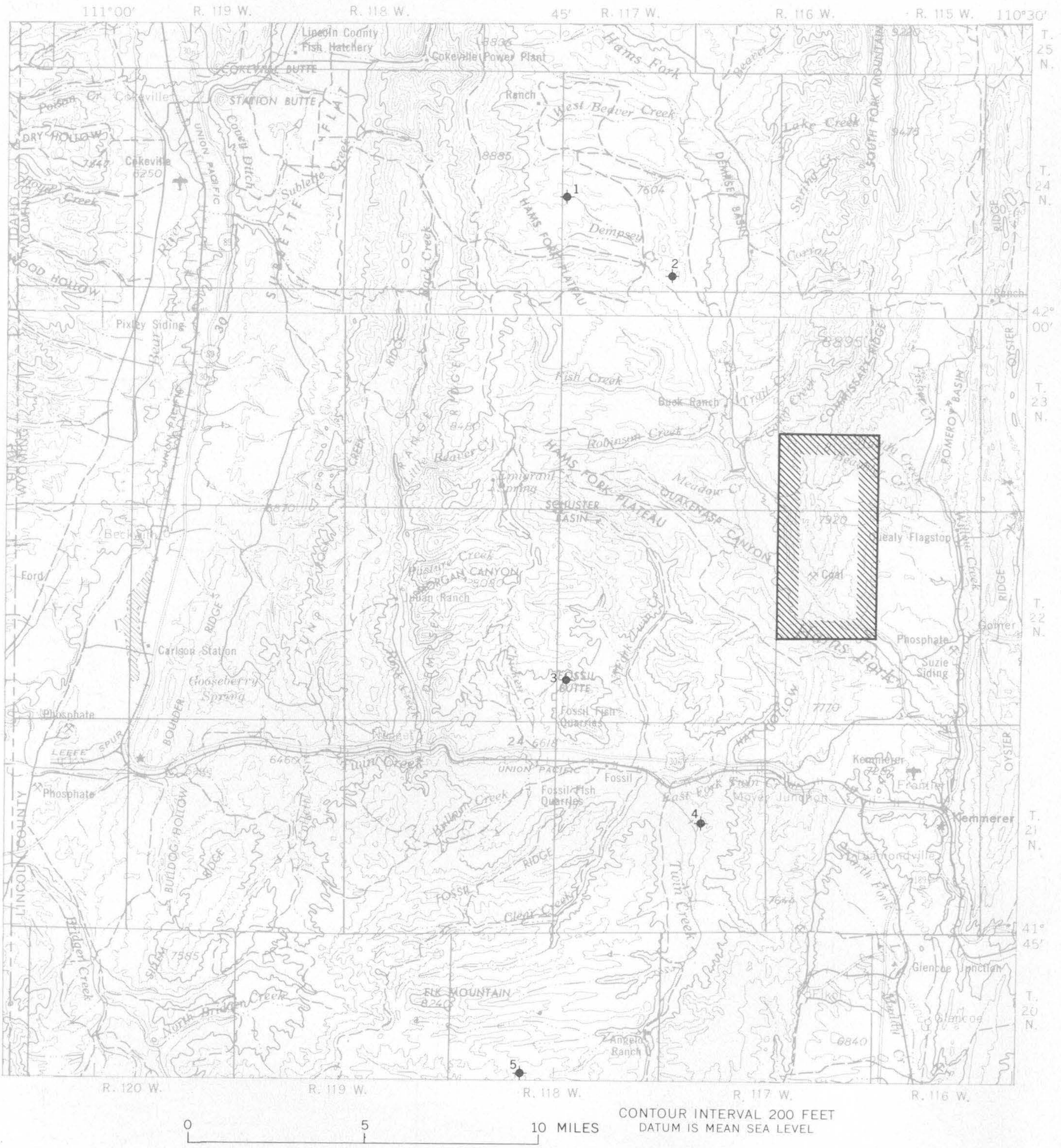


FIGURE 2.—Topographic map of the northern part of the Fossil basin showing the location of topographic and geographic features. Area of figure 8 shown by hachured outline. Dry holes drilled for oil and gas in the area include the following, mentioned in the text: (1) National Cooperative Refinery Association 1 Arthur H. Linden, (2) National Cooperative Refinery Association 1 Government-Larsen, (3) Amerada Petroleum Co. 1 Chicken Creek unit, (4) Hoxsey Oil Co. 1 Government, and (5) Roy Steele 1 Government. (From parts of the Preston and Ogden 1:250,000 topographic maps of the U.S. Geological Survey.)

ideas emerged from discussions with him. The success of the investigation, therefore, is in large measure attributable to Rubey.

Fossils collected by us were identified by C. L. Gazin and D. H. Dunkle of the U.S. National Museum and by Roland W. Brown, William A. Cobban, Estella B. Leopold, G. Edward Lewis, Raymond Peck, John B. Reeside, I. Gregory Sohn, Dwight W. Taylor, and Jack A. Wolfe of the U.S. Geological Survey. The manuscript has benefited from the constructive criticism and suggestions of M. R. Mudge and W. C. Culbertson.

GENERAL RELATIONS

The Fossil basin, as used in this report, is a small structural basin (called the "Fossil syncline" by Veatch, 1907, and by Bradley, 1959) in the southern part of the Wyoming overthrust belt. It extends from near the head of Hams Fork (T. 27 N., R. 117 W.) southward past Evanston to the north flank of the Uinta Mountains (fig. 1). The western margin of the basin is bounded on the north by the Tunp Range and on the south by unnamed en echelon ridges east of the Crawford Mountains. The eastern margin of the basin is bounded by a belt of Mesozoic rocks that underlies the prominent north-trending Oyster Ridge (fig. 2). These rocks formed a topographic barrier between the Fossil basin and Green River Basin during deposition of many of the Tertiary units. The barrier is informally referred to as the Oyster Ridge barrier in this report.

The rock units within the Fossil basin and their relations are shown in table 1.

TABLE 1.—*Nomenclature of uppermost Cretaceous and Tertiary stratigraphic units in the Fossil basin*

Veatch (1907)	This report
	Fowkes Formation Gooseberry Member Bulldog Hollow Member Sillem Member Upper mudstone unit Lower conglomerate unit
Bridger(?) Formation Green River Formation	Wasatch Formation: Tunp Member; Bullpen Member; Angelo Member; Mudstone tongue; Fossil Butte Member; Sandstone tongue; Main body; Lower member Green River Formation
Wasatch Group: Knight Formation Fowkes Formation Almy Formation	
	Basal conglomerate member
Evanston Formation	Evanston Formation Main body Hams Fork Conglomerate Member Lower member
Adaville Formation	Adaville Formation

Uppermost Cretaceous and lower Tertiary rocks of the Fossil basin were deposited while the structural basin was forming. The sediments consisted of muds and clays, sand, and gravel of normal fluviatile transport and of mixed and very heterogeneous material from clay size to coarse angular debris—including boulders and huge blocks—probably transported by gravitational processes. In early Eocene time, the coarse and fine material that settled around the margin of the basin formed a peripheral facies, the "Wasatch facies" of Spieker (1946, p. 138), that was predominantly fluviatile. Sediments deposited in the central part of the basin formed a lacustrine facies at the same time. The two facies constitute a genetic set or assemblage that is mapped as the Wasatch Formation and the Green River Formation. At times, the fluviatile sediments encroached upon the margins of the lakes, or conglomeratic and rubbly mudflows thickened parts of the peripheral deposits. At other times, the lake spread over lowlands that had formerly received fluviatile and other peripheral deposits.

EVANSTON FORMATION

NAME AND USAGE

Coal-bearing strata exposed north of the town of Evanston, in the vicinity of Almy (fig. 1), were first formally defined as the Evanston Formation by Veatch (1907, p. 76), though he mentioned them in an earlier report (1906, p. 332). The Evanston was described by him (1907, p. 77) as

> * * * consisting of yellow, gray, and black carbonaceous shales and irregular brown and yellow sandstone beds, but differs from the Adaville [Formation, Upper Cretaceous] in containing pronounced conglomerate beds below the upper coals * * *. The coals are much dirtier and less persistent * * *. The upper limit of the Evanston is fixed by the pronounced sandstones and conglomerates which mark the base of the Almy * * *. The Evanston is characterized by coal and by dark-colored clays and by a relatively small proportion of sandy and conglomeratic material, while the Almy is more predominantly arenaceous and conglomeratic, and in places shows a reddish tinge not seen in the Evanston.

The distribution of the formation, as mapped by Veatch (1907, pl. 3, p. 77), was limited to three small areas near Evanston.

The name Evanston was applied by Schultz (1914, pl. 1, p. 68–69) much farther north in western Wyoming to strata that were subsequently assigned to the Hoback Formation (Eardley and others, 1944; Dorr, 1952). The name Evanston has been little used by geologists in western Wyoming and adjoining areas.

Gazin (1956, p. 707) described a Paleocene mammalian fauna in the Fossil basin, from gray beds (fig. 7) 3 miles east of Fossil (fig. 2), and tentatively referred the beds to the Evanston Formation. Our studies confirm this assignment and show that the Evanston Formation is widely distributed in the basin and includes many of the rocks mapped as Almy Formation by Veatch. Not only is the formation far more extensive than hitherto realized, but recognition of the unit is critical to tectonic interpretations of the region and to the precise dating of some significant events.

The Evanston Formation may be distinguished from the overlying Wasatch Formation principally by its lack of color in contrast to the characteristic reds, oranges, and purples of the Wasatch and by the pebble composition of the conglomerate beds. Evanston conglomerates are well sorted whereas many conglomerates of the Wasatch Formation are poorly sorted, have a muddy matrix, and locally include large angular boulders composed of rock from Paleozoic and Mesozoic formations now exposed nearby as well as reworked pebbles from the Evanston Formation. Fine-grained detrital rocks of the main body of the Evanston are paler than the somewhat darker grays in comparable strata in the lower sandstone and mudstone member of the Wasatch.

The Evanston differs from the underlying Adaville Formation principally in the presence of conglomerates that contain clasts as large as boulders and in its heterogeneity. The Evanston includes thick apparently lenticular units of sandstone and conglomerate that alternate with thick poorly exposed units which consist dominantly of mudstone. The Adaville, however, is more uniform in its alternation of widespread thin beds of sandstone, mudstone, coal, and ironstone and seems to be the product of cyclic deposition, although it too includes numerous lenses.

The Evanston Formation is exposed in an extensive belt along the eastern periphery of the Fossil basin, in large bands associated with lines of disturbance along the southern and southwestern parts of the basin, and in scattered small areas within the basin, most of which are also associated with disturbed zones.

Rocks in the eastern peripheral belt have been traced southward for more than 30 miles from Commissary Ridge, where they are possibly 2,000 feet thick. Excellent exposures (fig. 5) near the middle of the south boundary of the Kemmerer quadrangle (northwestern part of sec. 31, T. 21 N., R. 116 W., and sec. 36, T. 21 N., R. 117 W.) are more than 1,200 feet thick.

Veatch (1907, p. 80) reported a maximum thickness of 1,600 feet east of the SE cor. sec. 13, T. 16 N., R. 120 W., but thicknesses probably exceed 2,000 feet in the Evanston area. Many beds that Veatch assigned to the Almy Formation are boulder conglomerates belonging to the Hams Fork Conglomerate Member of the Evanston Formation. Reconnaissance examination of rocks 6 miles northeast of Almy in Whitney Canyon and to the north indicates that at least part of the rocks assigned by Veatch (1907, pl. 3) to the Almy Formation east of the Medicine Butte fault belongs to the Evanston Formation.

In this report the Evanston Formation is divided into three units: (1) a lower dominantly mudstone member of Late Cretaceous age and (2) the Hams Fork Conglomerate Member (new name), which is chiefly of latest Cretaceous age and which grades upward and tongues laterally into (3) the dominantly silty main body of the Evanston Formation, chiefly of Paleocene age.

LOWER MEMBER

The lowest unit recognized in the Evanston Formation is exposed beneath the Hams Fork Conglomerate Member (fig. 3) in the northernmost part of the Kemmerer quadrangle on the west side of Commissary Ridge, 2½ miles east of Hams Fork. This unit, mapped as the unnamed lower member, consists mainly of gray to very dark gray mudstone,[1] siltstone, claystone, and gray carbonaceous sandstone. The sandstone is fine grained to gritty.[2] Conglomerate is present at the base of the member along Corral Creek and its tributaries, in the southern part of the Cokeville quadrangle, and includes both granules and pebbles that are composed mainly of quartzite and chert. Thin lignite and coal beds within the member have been prospected, particularly on the north side of Corral Creek.

The lower member is as much as 500 feet thick and apparently pinches out southward.

HAMS FORK CONGLOMERATE MEMBER

NAME AND TYPE

Extensive exposures of the Evanston Formation along the east side of the Fossil basin are characterized by a thick sequence of conglomeratic beds in the lower

[1] The term "mudstone" is used in this report for indurated fine-grained detrital rocks consisting of indefinite mixtures of clay and silt particles and some sand grains. It is distinguished from siltstone, which is composed predominantly of silt particles, and from claystone, which is composed predominantly of indurated clays. The term "shale" is restricted to fine-grained fissile detrital rocks.

[2] "Grit" and "gritty" are used here for detrital rocks that include angular quartz and chert grains of very coarse sand and granule size.

FIGURE 3.—Lower units of the Evanston Formation on the west side of Commissary Ridge. The lower member of the Evanston (Kel) unconformably overlies the Jurassic Twin Creek Limestone (Jt) and successively higher units (Jp, Preuss Redbeds, and Js, Stump Sandstone) to the north and conformably underlies the Hams Fork Conglomerate Member of the Evanston (Keh). Westward dips of resistant Hams Fork beds decrease upward in the section until they nearly parallel those in the unconformably overlying red Wasatch Formation (Tw). View is northward toward Corral and Spring Creeks from a point on the Dempsey trail in the NE¼SE¼ sec. 32, T. 24 N., R. 116 W.

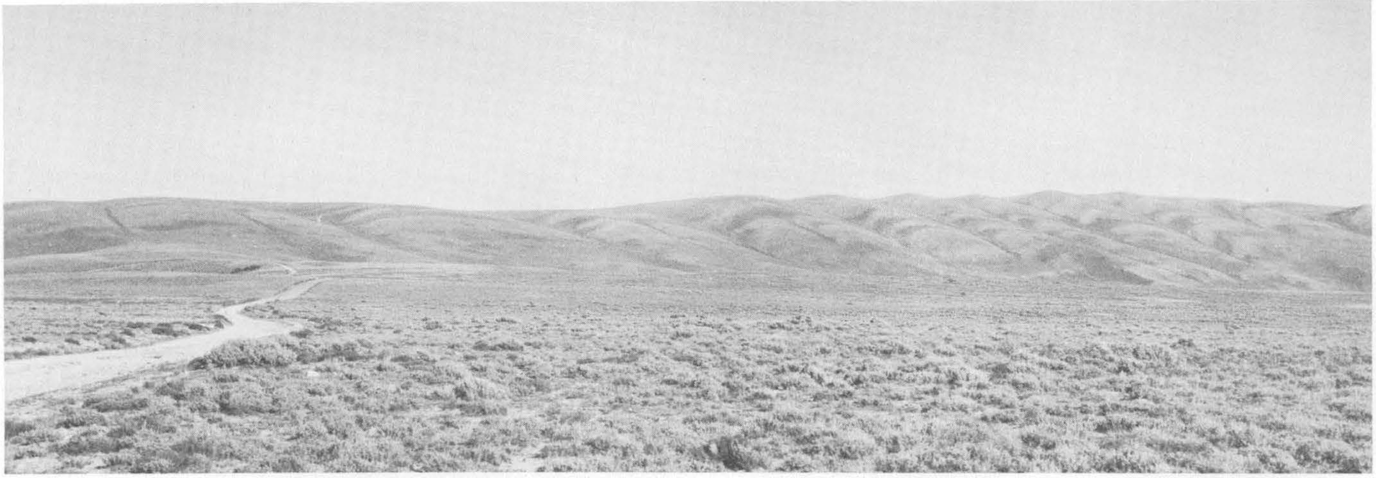
part of the formation. These beds, here named the Hams Fork Conglomerate Member of the Evanston Formation, dip rather uniformly from 20° to 35° W. in this part of the area and form the striking hogback ridges (fig. 4) north and south of Moyer, from Hams bench mark (hill 7923) 2 miles north of Hams Fork on Commissary Ridge southward to a point 2 miles north-northwest of Elkol. This belt of exposures is designated the type area. The section that was measured 1–1½ miles west of the strip mine north of Elkol, near the middle of the eastern part of sec. 36, T. 21 N., R. 117 W., is designated the type section (p. 40–42, fig. 5). Another representative section is well exposed at Morely bench mark (hill 7759), 2½ miles south of Hams Fork.

ROCKS INCLUDED

The Hams Fork Conglomerate Member consists of as many as nine beds of boulder conglomerate (fig. 3) interstratified with thick beds of coarse partly conglomeratic brown sandstone and gray mudstone; the unit forms the lowest several hundred to 1,000 feet of the Evanston Formation at most places along the east side of Fossil basin. Ridgelines of conglomerate consist of long trains of loosely packed cobbles and boulders that form a resistant lag concentrate (fig. 4*A*). In some places, a series of trains can be recognized as the outcropping of a sequence of dipping beds (fig. 4*B*); in others, the boulders spew downslope, covering the hillside and making it difficult to distinguish dipping beds. In a few places, the conglomeratic sandstone is indurated and the unit is well exposed. Individual boulder beds are exposed here and there in borrow pits or test pits, where they are thin—mainly less than 5 feet thick. In many places, the greater apparent thickness of the boulder trains probably results from concentration of the resistant boulders and winnowing of the finer grained material in a sequence of thin gravel beds.

Pebbles, cobbles, and boulders from individual beds are sparse at some places and closely packed in others. The matrix of the conglomerate ranges from coarse crossbedded sand or granule gravel to clayey fine sand or silt. The pebbles and boulders are heterogeneous in composition, size, and rounding. They generally range in diameter from 1 inch to 1 foot, although a few are as

A



B

FIGURE 4.—Ridges and flatirons formed by boulder beds in the Hams Fork Conglomerate Member of the Evanston Formation. *A*, View northward across Twin Creek from the SE¼SW¼ sec. 19, T. 21 N., R. 116 W. The Hams Fork Conglomerate Member (Keh) dips about 25° W., overlying the Adaville Formation (Kav) nearly conformably. They are overlapped on the west by the more gently dipping Wasatch (Tw) and Green River (Tgr) Formations. *B*, View southeastward from the NE. cor. sec. 30, T. 22 N., R. 116 W., of the flatirons formed by west-dipping (25°) conglomerate beds.

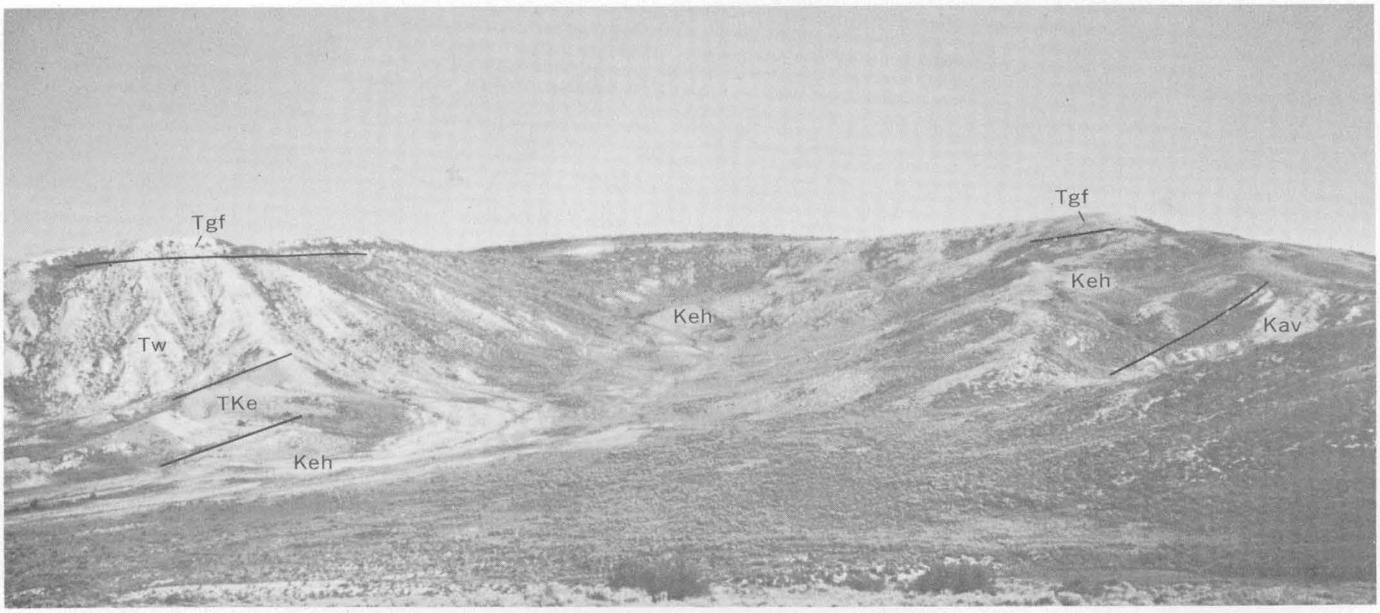


FIGURE 5.—Type section of the Hams Fork Conglomerate Member of the Evanston Formation (Keh) viewed northward from the SE¼SW¼ sec. 19, T. 21 N., R. 116 W. Boulder conglomerate beds are here almost conformable with the underlying Cretaceous Adaville Formation (Kav). The red main body of the Wasatch Formation (Tw) overlaps gray and yellow beds in both the main body (TKe) and the Hams Fork Conglomerate Member of the Evanston; all three units are overlapped by the white-weathering Fossil Butte Member of the Green River Formation (Tgf).

much as 2 feet; in most places they are dominantly very well rounded and subspherical (fig. 6).

Light- to dark-gray quartzite, gray and brown quartzitic sandstone, and pink to red conglomeratic quartzite are the most common lithologies among the pebbles (fig. 6). Gray, brown, and black cherts are common. Gray, blue, or black limestone, although absent from some beds, is sparse in some and is a major component in others.

Much of the quartzite and limestone is derived from Mesozoic and upper Paleozoic formations that are exposed not far away (less than 1 mile to the east), but the degree of rounding and sphericity suggest greater transport (fig. 6); some is derived from formations that are now exposed at a considerable distance (40 miles) to the west. The red and pink conglomeratic quartzite, for example, resembles most closely the Cambrian and Precambrian Brigham Quartzite, and the gray quartzitic arkose resembles the Worm Creek Quartzite Member of the Cambrian St. Charles Limestone, now exposed no closer than the Bear River Range in southeastern Idaho. Some of the chert and limestone probably was derived from lower and middle Paleozoic formations exposed in the Bear River Range above the Paris thrust fault (Oriel and Armstrong, 1966, p. 2618).

DISTRIBUTION AND THICKNESS

The Hams Fork Conglomerate Member has been recognized throughout the belt mapped as Almy by Veatch (1907, pl. 3) along the east side of the Fossil basin. The belt extends northward into the Cokeville quadrangle where it is overlapped by the Wasatch Formation. Another exposed belt of the member mapped as Almy by Veatch (1907, pl. 3) extends southwestward from Evanston.

The member is 455 feet thick where measured in the NE¼ sec. 36, T. 21 N., R. 117 W. (fig. 5). The National Cooperative Refinery Association 1 Arthur H. Linden oil test in sec. 19, T. 24 N., R. 117 W., is reported to have penetrated 1,382 feet of Evanston conglomerates, probably of the Hams Fork Member, and its 1 Government-Larsen oil test in sec. 33, T. 24 N., R. 117 W., is reported to have drilled through 1,310 feet of the unit. The thicknesses of the member in these boreholes, however, may be somewhat less because the attitude of bedding may be steeper than assumed. The member is about 1,000 feet thick where examined at other localities.

MAIN BODY

The main body of the Evanston Formation in the Fossil basin consists of light- to dark-gray carbonaceous

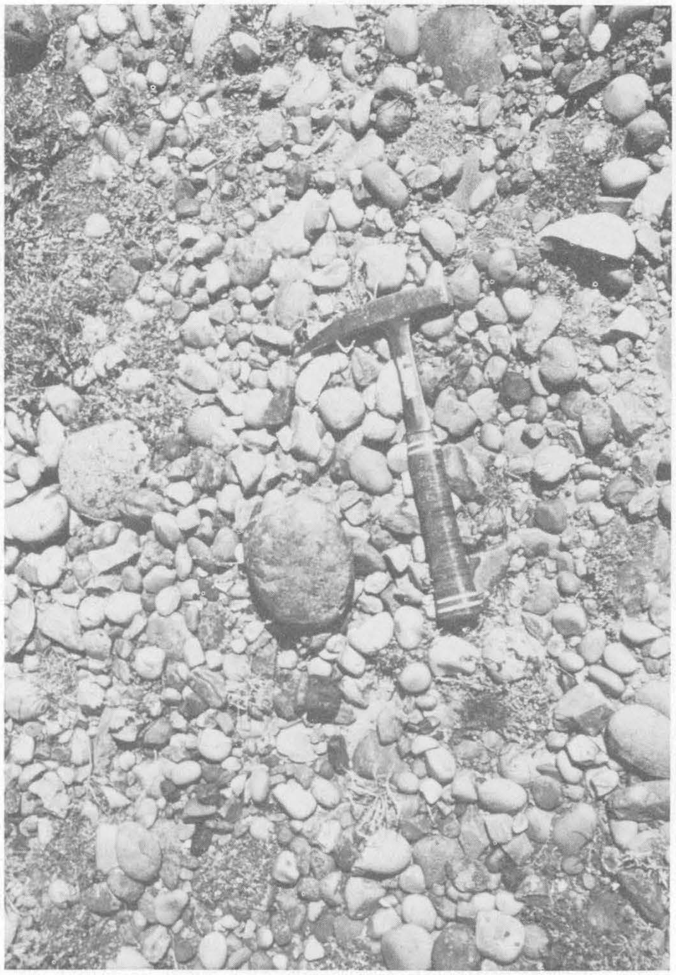


FIGURE 6.—Well-rounded and subspherical mainly quartzite pebbles and cobbles in the Hams Fork Conglomerate Member of the Evanston Formation on the south end of Commissary Ridge in the NE¼NW¼ sec. 5, T. 22 N., R. 116 W. The larger clasts close to and above the pick are of purple conglomeratic quartzite derived from the Cambrian and Precambrian Brigham Quartzite.

sandy to clayey siltstone (fig. 7) interbedded with gray, tan, yellow, and brown sandstone and conglomerate and carbonaceous to lignitic claystone. Ironstone and lignite beds are common and coal beds are sparse except locally.

Many beds of light-gray siltstone containing scattered sand grains are cemented by calcite; some are cemented by silica to form a quartzitic siltstone that spalls on weathering and forms angular chips. The quartzitic siltstone is restricted to this formation in the Fossil basin and has been recognized at many localities, including the type section.

Conglomerate beds within the main body of the Evanston are generally low in the section and in places can be traced laterally into the Hams Fork Conglomeratic Member. Light-gray beds dominate the upper part of the main body of the formation, and thin discontinuous brownish-red to brick-red layers are found locally near the top. Siltstone, sandstone, and claystone in the main body are somewhat paler than the darker grays and grayish browns of the Hams Fork Conglomerate Member.

The main body is more than 250 feet thick where measured beneath an angular unconformity at the base of the Wasatch Formation in the small badland buttes south of U.S. Highway 30N in the NE¼ sec. 15 and the NW¼ sec. 14, T. 21 N., R. 117 W. (fig. 7).

In the Hoxsey Oil Co. 1 Government test in sec. 14, T. 21 N., R. 117 W., spudded about 100 feet below the contact of the Evanston Formation with the overlying Wasatch, about 1,355 feet of the main body of the formation was penetrated before older rock was entered; the Hams Fork Conglomerate Member is absent.

Small and comparatively thin exposures of the main body of the Evanston Formation are on and around the south end of the Tunp Range, for example in secs. 3 and 4, T. 21 N., R. 118 W., along Collett Creek in the southeastern part of T. 21 N., R. 119 W., and west of Elk Mountain in the east half of T. 20 N., R. 120 W., where the rocks were assigned by Veatch (1907) to the Knight Formation.

The Evanston Formation does not underlie the Wasatch Formation everywhere that the Wasatch occurs in the Fossil basin, for the overlapping Wasatch rests directly on Paleozoic and Mesozoic rocks in many places. The Evanston is known from drill-hole information in parts of the basin, however, and thicknesses apparently are similar to those in surface exposures.

LOWER CONTACT

The Evanston Formation rests with marked angular unconformity on virtually all older formations now exposed in the Fossil basin.

Along the eastern margin of the basin, strata of the Hams Fork Conglomerate Member of the Evanston Formation now dip westward and strike roughly parallel to the Oyster Ridge barrier. From Hams Fork southward almost to Little Muddy Creek, the formation seems to rest conformably on the Adaville Formation (fig. 5). Locally, however, it truncates individual beds of the Adaville. North of Hams Fork, the Evanston rests directly first on older Cretaceous formations, the Hilliard and the Frontier, and then on formations in the thrust sheet above the Absaroka fault, from the Pennsylvanian and Permian Wells up to the Jurassic Twin Creek Limestone (fig. 3); in the Cokeville quadrangle, the

FIGURE 7.—Main body of the Evanston Formation. The badlands exposed in the NE¼ sec. 15, T. 21 N., R. 117 W., consist dominantly of light- to medium-gray and partly yellowish siltstone and claystone. Vertebrate remains of Tiffany age (Wood and others, 1941) have been found in these exposures near the base of the distant badlands left of center in the photograph. Fossil Butte forms the skyline on the right.

Evanston Formation rests on beds as high, stratigraphically, as the Lower Cretaceous Gannett Group.

Boreholes drilled through the Evanston Formation along the eastern side of the basin have entered diverse units below. In the National Cooperative Refinery Association 1 Arthur H. Linden oil test, the Evanston is underlain by the Twin Creek Limestone; in the same company's 1 Government-Larsen oil test, it is underlain by the Phosphoria Formation; in the Hoxsey Oil Co. 1 Government oil test, it is underlain by the Wells Formation.

Farther west, in the Sage quadrangle, the formation rests on rocks of Triassic and Jurassic age.

FOSSILS AND AGE

The Evanston Formation is Late Cretaceous and Paleocene in age, as previously reported (Rubey and others, 1961). Additional fossil data are presented below.

LOWER MEMBER

The lower member has yielded well-preserved Late Cretaceous leaves, pollen, and spores at several places. One collection of leaves from about 50 feet above the base of the member in the NE¼SE¼SE¼ sec. 29, T. 24 N., R. 116 W., was identified (J. A. Wolfe, written commun., Dec. 22, 1959) as the dicotyledons *Dryophyllum subfalcatum* Lesquereux, *Cinnamomum linifolium* Knowlton, and *Dombeyopsis obtusa* Lesquereux; these forms are of probable Lance or latest Cretaceous age. Samples from the same horizon and locality (USGS Paleobot. loc. D1493) contain the following pollen and spores:

Araucariacites australis Cookson
Proteacidites retusus Anderson
P. callosus Cookson

Smilacipites sp.
Pinuspollenites labdacus (Potonié) Raatz
Cicatricosisporites cf. *C. dorogensis* Potonié and Gellentich
Monoletes major Cookson
Triplanosporites sinuosus Pflug
Pollenites (*Tricolporopollenites*) *cognitus* Potonié
Tricolporopollenites kruschii (Potonié) Pflug
Taxodiaepollenites hiatus (Potonié) Thiergart
Sphagnumsporites stereoides Potonié and Venitz
Monosulcites minimus Cookson
Abiespollenites

Although the collection is surely of Late Cretaceous age, it does not contain species peculiar to Lance pollen floras and may be older than Lance (E. B. Leopold, written commun., 1960).

Two other collections from the lower member in the NE¼SE¼ sec. 29, T. 24 N., R. 116 W., at the head of Corral Creek (north of Trail Creek in fig. 2), contain *Sequoia reichenbachi* (Geinitz) Heer, *Dryophyllum subfalcatum* Lesquereux, and *Ficus* sp., all of Late Cretaceous age (R. W. Brown, written commun., 1954). A collection from Camp Creek, in the NW¼NE¼ sec. 17, T. 24 N., R. 116 W., includes *Protophyllocladus subintegrifolius* (Lesquereux) Berry, *Ficus planicostata* Lesquereux, and *Cinnamomum affine* Lesquereux (R. W. Brown, written commun., 1958). Two other collections from the north side of Spring Creek, in south-central sec. 8, T. 24 N., R. 116 W., include *Dryophyllum subfalcatum* Lesquereux, *Ficus* sp., *Myrica torreyi* Lesquereux, and a poorly preserved calyx resembling the calyx of *Paleoaster inquirenda* Knowlton, all of Late Cretaceous age (R. W. Brown, written commun., 1954).

HAMS FORK CONGLOMERATE MEMBER

The Hams Fork Conglomerate Member includes several forms of Late Cretaceous age. The Lance *Triceratops* jaw reported previously (Rubey and others, 1961) was found 218 feet above the base of the member 400 feet south-southeast of the NW. cor. sec. 31, T. 21 N., R. 116 W. Leaves from about 75 feet and 325 feet above the base of the member in the NE¼ sec. 36, T. 21 N., R. 117 W., were identified (R. W. Brown, written commun., Sept. 29, 1954) as the Late Cretaceous *Protophyllocladus subintegrifolius* (Lesquereux) Berry and *Ficus* sp. Gastropods from the upper part of the member, in the NW¼SW¼ sec. 19, T. 21 N., R. 116 W. (Mesozoic loc. 27590), include *Cleopatra*? 2 spp., cf. *Amerianna*, *Physa* sp.; the collection is more likely Cretaceous than Tertiary (D. W. Taylor, written commun., May 10, 1960).

Pollen and spores were identified in samples collected from the Hams Fork Member. Samples from 105 feet (USGS Paleobot. loc. D1391A) and 145 feet (D1391B) above the base of the member and from 94 feet below the top of the member (D1392A) in a section measured from the SE¼NE¼ to the SE¼NW¼ sec. 36, T. 21 N., R. 117 W., include the following:

Alsophilidites
Deltoidospora 4 spp.
Guthörlisporites Bharwaj
Osmundacidites
Cyathidites
Neoraistrickia Potonié
Ephedra
Schizaeoisporites pseudodorogensis Potonié
Pityosporites cf. *labdacus* Potonié
Pityosporites 3 spp.
Taxodiaepollenites hiatus (Potonié) Thiergart
Monoletes undet.
Alnus
Quercoipollenites henrici Potonié
Proteacidites retusus Anderson
Tricolpopollenites kruschi subsp. *contortus* (Pflug and Thomson)
Tricolporopollenites kruschi subsp. *pseudolaesus* Potonié
Multiporopollenites
Dinoflagellata
Erdtmanipollis
Triletes undet.
Dicots undet.
Selaginellites cf. *ariadnae* Miner
Cicatricosisporites
Trivestibulopollenites betuloides Thomson and Pflug

All three collections represented a single assemblage that loses types upward in the section; the assemblage resembles that of the Lewis and Lance Formations on the southern flank of the Green River Basin and is latest Cretaceous in age (E. B. Leopold, written commun., Mar. 23, 1959).

Three other samples (USGS Paleobot. loc. D1679, samples 1, 2, and 3) from the lower part of the Hams Fork Conglomerate Member in the NW¼NE¼ sec. 7, T. 21 N., R. 116 W., are also of Late Cretaceous age and include the following (E. B. Leopold, written commun., Mar. 19, 1965):

Aquilapollenites
Cicatricosisporites
Appendicisporites
Classopollis classoides Pflug
Proteacidites
Sterioisporites
Hymenozonotriletes reticulatus Bolchovitina
Sporopollis?
Podocarpidites biformis Zaklinskaya
Eucommiidites

MAIN BODY

The main body of the Evanston Formation is mostly of Paleocene age; but because the basal part of it intertongues with the Hams Fork Conglomerate Member, some strata of latest Cretaceous age are present.

The Paleocene age is well documented in the Kemmerer quadrangle by a varied vertebrate fauna found between 250 and 300 feet below the top of the formation; the fauna is of early late Paleocene (Tiffany) age (Gazin, 1956, p. 708).

The gray mudstone and siltstone hills (fig. 7) in which the vertebrate remains were found, in the NE¼ sec. 15, T. 21 N., R. 117 W., were also sampled for pollen (USGS Paleobot. loc. D1680–2). The sample includes the following forms:

Momipites tenuipolus Anderson
Pachysandra (large form)
Nyssoipollenites
Alnus, six-pored
Picea
Carya

The pollen confirm a middle or late Paleocene age (E. B. Leopold, written commun., Mar. 19, 1965). Another sample (USGS Paleobot. loc. D1680–1), some 30 feet lower stratigraphically and the lowest horizon exposed in a gully at the base of the hills, however, includes the following forms of Late Cretaceous age:

Cicatricosisporites
Gleichениidites senonicus Ross
Pinuspollenites
Araucariacidites
Proteacidites
Appendicisporites

Leaves from the lower part of the main body, in the SE¼NW¼ sec. 36, T. 21 N., R. 117 W., include ?*Libocedrus* sp., ?*Quercus greenlandica* Heer, and ?*Platanus raynoldsi* Newberry and are assigned a probable Paleocene age (R. W. Brown, written commun., Sept. 23, 1958). Samples collected for pollen at the same locality 1 foot (D1392–B) and about 200 feet (D1392–C) above the Hams Fork Conglomerate Member include the following:

Momipites tenuipolus Anderson (abundant)
Triporopollenites robustus Potonié
Periporopollenites
Tricolpopollenites microhenrici Potonié
Pityosporites
Tricolporopollenites cf. *kruschi* Potonié
Tricolpopollenites microreticulatum Pflug and Thomson
Alnus

The pollen collections are regarded (E. B. Leopold, written commun., Mar. 23, 1959) as middle and late Paleocene in age.

Another sample collected along Collett Creek, about 100 yards N. 45° W. from BM (bench mark) 6783, in NW¼NE¼ sec. 26, T. 21 N., R. 119 W. (USGS Paleobot. loc. D1681–A), includes the following pollen:

Carya (dominant)
Nyssoipollenites
Momipites
Kurtzipites
Ulmipollenites undulosus Wolff
Monocolpopollenites
cf. *Engelhardtia*
Salicoidites
Alnus, six-pored

A late Paleocene, possibly Tiffany, age is inferred (E. B. Leopold, written commun., 1965). Leaves from the same locality, however, include *Protophyllocladus subintegrifolius* (Lesquereux) Berry, which is assigned a Late Cretaceous age (R. W. Brown, written commun., 1958). Possibly strata of both ages are present.

Two other leaf collections from the main body are of Paleocene age. One collection from about 1 mile north-northeast of Nugget, in the SW¼SE¼ sec. 33, T. 22 N., R. 118 W., includes *Metasequoia occidentalis* (Newberry) Chaney, *Betula stevensoni* Lesquereux, and *Platanus raynoldsi* Newberry (R. W. Brown, written commun., 1958). The other, from the center of the NW¼ sec. 23, T. 21 N., R. 117 W., about 1 mile south of the vertebrate locality and about 100 feet below the top of the Evanston Formation, includes *Fagus* or *Zelkova* sp., *Carya antiquora* Newberry, *Rhamnus* or *Ficus* sp., *Laurophyllum* sp., and *Carpites* sp. (R. W. Brown, written commun., 1955).

The Cretaceous and Paleocene ages of the Evanston Formation in the northern part of the Fossil basin, therefore, are well supported by paleontologic data and agree with the age assignment in the type locality to the south (Rubey and others, 1961). Although the Evanston bridges both the Cretaceous and Paleocene, it is curious that no fossils of early and early middle Paleocene age have been found. The absence of such fossils may reflect (a) incomplete sampling, (b) a possible hiatus within the Evanston Formation that we have been unable to recognize, or (c) possibly inadequate current standards for dating this part of the geologic sequence; that is, early Paleocene index fossils may be indicative of facies rather than age, and conditions in the Fossil basin may have been unsuitable for them. Our evidence is insufficient to choose between the three alternatives.

ORIGIN

The Evanston Formation probably is the result of both syntectonic and posttectonic nonmarine deposition. Prevalence of drab-colored mudstone, presence of lignitic beds and coal, lenticularity of individual beds, and irregular distribution of terrigenous lithologies indicate that the environments of deposition of the Evanston Formation included streams, marshes, and probably ponds. Rock colors as well as moderate abundance of ferrous carbonate and oxides indicate a chemically reducing condition, in contrast to an oxidizing condition prevalent during deposition of the overlying Wasatch Formation. Both the strata and the enclosed organic remains indicate a very humid warm-temperate climate, as suggested by Brown (1962, p. 96).

Excellent rounding and well-developed sphericity of pebbles and boulders in the Hams Fork Conglomerate Member suggest moderate transport in a large drainage system. This inference is supported by the presence of clasts that were derived from formations now exposed no closer than 60 miles to the west.

The divergence of boulder conglomerate beds from the basal contact of the formation (fig. 8) and the diversity in age of the stratigraphic units underlying the Evanston Formation are evidence that there was moderate topographic relief both within and along the edges of the basin during deposition. The persistence of relief within the area is evident at numerous localities where the Wasatch and, in places, the Green River Formations overlap the Evanston Formation.

TECTONIC IMPLICATIONS

The Hams Fork Conglomerate Member of the Evanston Formation rests unconformably on rocks both below and above the Absaroka thrust fault in T. 23 N., R. 116 W. Movement along the Absaroka thrust fault resulted in drag folding of Upper Cretaceous and older rocks beneath the fault and formed the Lazeart syncline (fig. 8). The west limb of the syncline north of Hams Fork is truncated by the Evanston Formation. Therefore, major movement along the fault at this place preceded deposition of the Evanston Formation, if the syncline did indeed form at the time of thrusting (Oriel and Armstrong, 1966, p. 2616–2617).

In at least one locality (sec. 29, T. 23 N., R. 116 W.), some beds of the Hams Fork Conglomerate Member lie beneath the fault and are deformed (fig. 8). Moreover, south of Hams Fork, basal beds of the Evanston Formation are folded and lie along the axis of the Lazeart syncline (fig. 8). These observations indicate that although major movement on the Absaroka fault preceded deposition of the Hams Fork Conglomerate Member, a minor pulse occurred after deposition of the basal Evanston strata.

Several miles south of Hams Fork, fossils from the uppermost part of the Adaville Formation and from the Hams Fork Conglomeratic Member of the Evanston Formation are assigned a Late Cretaceous (late Montana and Lance) age (J. A. Wolfe and E. B. Leopold, written commun., 1959, 1965; Dorf, 1955). Thus, all these data are evidence that major movement along the Absaroka thrust fault in the vicinity of Hams Fork took place in Cretaceous (probably early Lance) time and that deposition of the Evanston started during the deformation and ended considerably later, in late Paleocene time.

The abundance of rounded coarse detritus from formations now exposed in thrust sheets in southeastern Idaho suggests elevated source areas resulting from earlier deformation there and possibly recurrent movement along the Paris thrust fault (Oriel and Armstrong, 1966).

Basal beds of the Evanston Formation along the east side of the Fossil basin dip about 20°–40°W. Successively younger beds decrease in dip gradually upward (fig. 3) until the uppermost beds of the formation are almost horizontal and subparallel to beds of the overlying Wasatch Formation. These data indicate that the Fossil basin began taking shape in latest Cretaceous time and continued forming in Paleocene time.

WASATCH FORMATION

NAME AND USAGE

DEFINITION

The name Wasatch was first used by Hayden in 1869—considerably before currently accepted rules for definition of a new unit were formulated. Hayden's complete description of the unit (p. 91) is as follows:

> Immediately west of Fort Bridger commences one of the most remarkable and extensive groups of tertiary beds seen in the West. They are wonderfully variegated, some shade of red predominating. This group, to which I have given the name of Wasatch group, is composed of variegated sands and clays. Very little calcareous matter is found in these beds.
>
> In Echo and Weber [3] Cañons are wonderful displays of conglomerates, fifteen hundred to two thousand feet in thickness. Although this group occupies a vast area, and attains a thickness of three to five thousand feet, yet I have never known any remains of animals to be found in it. I regard it, however, as of middle tertiary age.

In a subsequent publication Hayden (1870, p. 113–114) stated of the Wasatch:

> I have included in this group all the variegated beds which we have observed west of Carter's Station, and we have noticed especially that some shade of red has prevailed in the clays and sands, as well as in the conglomerates of this group. Some of the sandstones in the upper portion of Echo Cañon are noticeable for their deep yellow hue.

[3] The sharp northwesterly bend in the railroad in fig. 1 is at the mouth of Echo Canyon where Echo Canyon Creek flows into the northwesterly flowing Weber River.

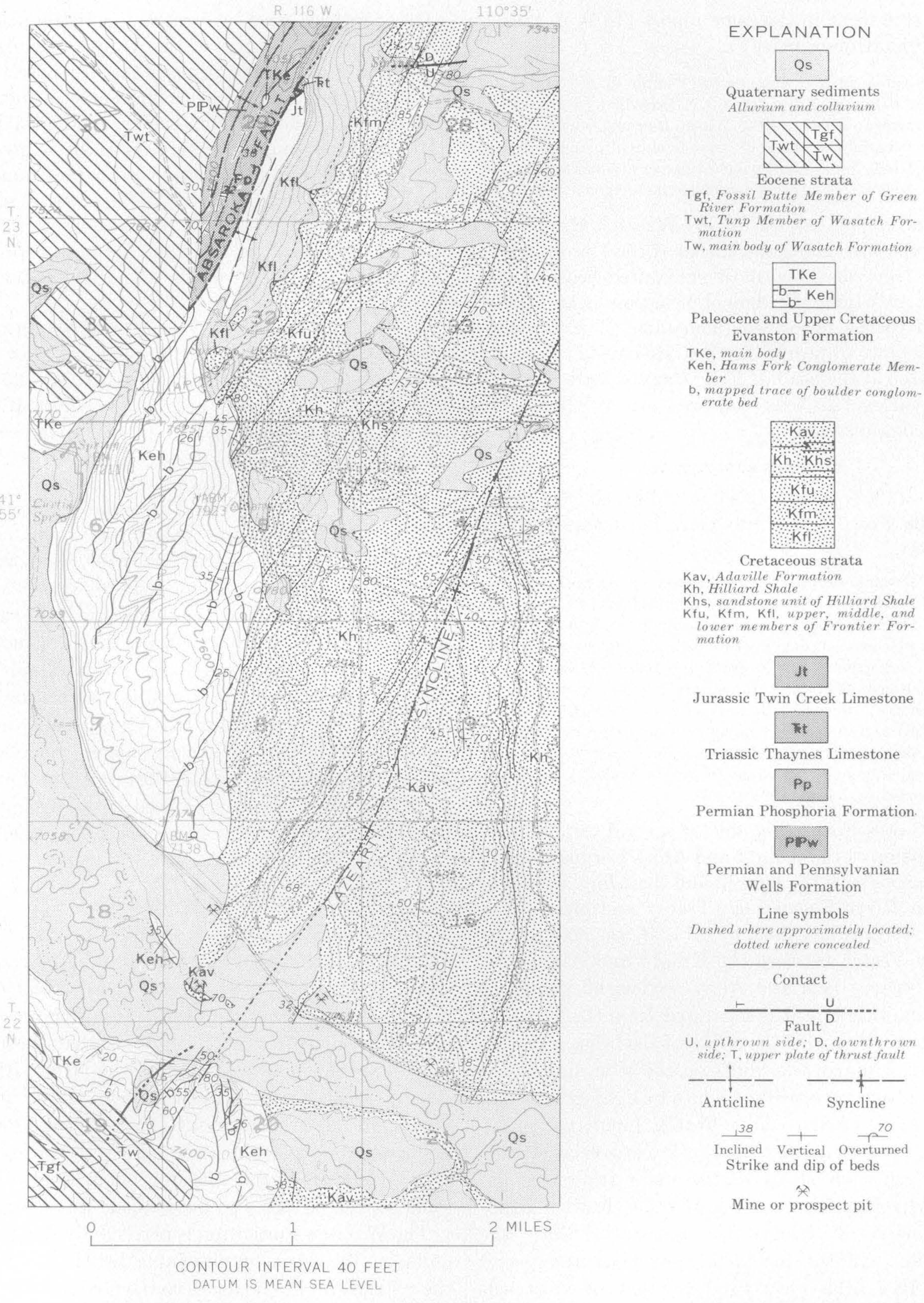


FIGURE 8.—Geologic map of part of the Kemmerer quadrangle, Lincoln County, Wyo. (from Rubey, Oriel, and Tracey, 1968), showing the divergence of boulder conglomerate beds (b) from the basal contact of the Evanston Formation.

Another statement in the same report (1870, p. 106) is somewhat more descriptive:

> * * * near Quaking Asp Summit [we] enter upon the borders of the great valley of Salt Lake * * * [in which] we have the curiously variegated beds of the Wasatch group, which present almost every variety of shade of color from white and yellow to a deep brick-red, the red and purple tints so predominating that they give a singularly curious aspect to the scenery.

Hayden's "type section" of his Wasatch Group consists of exposures along the tracks of the Union Pacific Railroad from the uppermost variegated beds in contact with overlying Bridger Formation near Carter, westward to the lowest conglomerates in Echo Canyon—a distance of nearly 70 miles. He named the group for Wasatch at the head of Echo Canyon, east of which are the variegated beds and west of which are the massive conglomerates.

VEATCH'S SUBDIVISIONS

Veatch (1907, p. 88) tried to subdivide the group within the Fossil basin into more homogeneous units as follows:

> In the Wasatch group as thus defined by Hayden the field work of the season of 1905 showed three divisions: (1) A basal member composed of reddish-yellow sandy clays, in many places containing pronounced conglomerate beds, which has been named the Almy formation; (2) a great thickness of light-colored rhyolitic ash beds containing intercalated lenses of white limestones with fresh-water shells and leaves—the Fowkes formation; and (3) a group of reddish-yellow sandy clays with irregular sandstone beds [the Knight formation] closely resembling (1) lithologically and separated from (1) and (2) by a pronounced period of folding and erosion.

The Fowkes Formation, one of several criteria used for separation of the Knight and Almy Formations, actually overlies both the Knight and the Almy, as well as the Green River Formation (Tracey and Oriel, 1959, p. 129, 130; Eardley, 1959, p, 167). It was erroneously placed by Veatch between the Knight and Almy Formations because near the Almy settlement it adjoins older rocks, although it is separated from them by normal faults that parallel the strike of the beds.

West of Almy in the bluffs on the west side of the Bear River are exposures of white to light-gray strata overlain by red beds, which Veatch (1907, p. 90) interpreted as evidence that the Fowkes is overlain by the Knight Formation. However, the white strata here, unlike the rhyolitic tuff and ash of other Fowkes exposures, consist of fresh-water limestone. Both the composition and the included gastropods and leaves (Veatch, 1907, p. 92) clearly indicate that the white beds on the west side of the Bear River are tongues of Green River limestone in the Wasatch Formation and not the younger Fowkes Formation.

Other criteria used by Veatch for distinguishing between similar lithologies of the Almy and Knight Formations were the steeper dips of the Almy strata, which he stated were overlain with pronounced angular unconformity by the Knight Formation, and the presence of conspicuous conglomerate beds in the Almy. Veatch (1907, p. 89) stated that the Almy was commonly exposed in the type region only along lines of structural disturbance and noted the presence in the Almy of crushed and cemented quartzite pebbles, a product of the great force involved in the disturbance of the strata.

Applying these concepts, Veatch and Schultz mapped extensive belts of the Almy Formation. Most of their outcrops of Almy along lines of structural disturbance, however, are the Hams Fork Conglomerate Member of the Evanston Formation. The poorly sorted calcareous conglomerate northeast of Sage mapped as Almy by Veatch belongs in the Fowkes Formation.

Many conglomerate beds within the Wasatch Formation are in a peripheral facies which can be traced laterally into basinal facies represented by the variegated dominantly mudstone beds of Veatch's Knight Formation. Where the conglomerate beds cannot be traced, as in the Almy type area, they are found to be separated from the Knight by normal faults rather than by an angular unconformity. Accordingly, there is no basis for separating the Almy and Knight Formations except if they are considered peripheral and basinal facies of the Wasatch Formation, and we recommend that the names not be used with any implication that one underlies or is older than the other (Oriel, Gazin, and Tracey, 1962).

SUBDIVISIONS USED HERE

The name Wasatch is used here in much the same manner as defined by Hayden (1869), as mapped by Peale (1879, p. 636; 1883), and as understood by Veatch, although our subdivisions of the formation are considerably different. Our usage is similar to that of others who have mapped moderate areas of the Green River and nearby basins, especially Bradley (1964, p. A20), Pipiringos (1961), Masursky (1962), Oriel (1961), and Culbertson (1965), who assigned mainly variegated red strata (fig. 10) to the Wasatch but who also included some nonred—green and gray—beds in the unit.

The Wasatch Formation is here subdivided into seven units on the basis of mappable lithologic facies and their stratigraphic relations to the Green River Formation. The units, from bottom to top of the formation, are: a local unnamed basal pebble-to-boulder conglomerate member, in places fractured and recemented; a local unnamed lower member in places unconformable with the overlying main body of the Wasatch; the unnamed main body of the Wasatch Formation; a sandstone tongue; a mudstone tongue; an upper member—the Bullpen Member; and a peripheral member—the Tunp Member, which is laterally equivalent to parts of the other units (tables 1, 3, 4).

BASAL CONGLOMERATE MEMBER

Lenticular conglomerate locally forms the basal member of the Wasatch Formation and is composed chiefly of pebbles and cobbles of tan to buff sandstone and quartzitic sandstone derived from the Triassic(?) and Jurassic(?) Nugget Sandstone. Pebbles of gray quartzite, probably from the Pennsylvanian and Permian Wells Formation, and of tan to bluish-gray limestone, from the Triassic Thaynes Formation and the Jurassic Twin Creek Limestone, are common in places. Large cobbles of gray porous conglomeratic sandstone, though sparse, are diagnostic of the unit because they are the most widespread pebbles found other than those of the Nugget Sandstone. Their source is not known, although they resemble the Triassic Higham Grit (W. W. Rubey, oral commun., 1958).

The conglomerate is exposed locally in channels and hollows in folded Mesozoic rocks at the south end of Tunp Range, northeast of Nugget, and on the extensive exposures of Nugget Sandstone south and southwest of Nugget. It ranges in thickness from a few feet, in areas where it is spread thinly over the older rocks, to several hundred feet, where it fills deep channels.

In a few places where the conglomerate is thick, it contains packed subrounded to angular blocks of quartzitic sandstone as much as several feet across. In other places, pebbles and cobbles are scattered in a fairly homogeneous quartz sand matrix that also was probably derived from the Nugget Sandstone. Beds of conglomerate with abundant limonite are common. Fractured recemented quartzite pebbles similar to the "Almy pebbles" shown by Veatch (1907, p. 16) are characteristic of the unit.

LOWER MEMBER

An irregular sequence of beds of drab-colored mudstone, sandstone, conglomerate, and limestone locally underlies typical red beds of the main body of the Wasatch along the southern part of the Tunp Range, conformably in most places and with apparent angular unconformity in others. The sequence is here assigned to the Wasatch Formation because it includes variegated beds typical of other parts of the formation, but it is not formally named pending clarification of its relation to subdivisions of the Wasatch in the southern part of the Fossil basin.

ROCKS INCLUDED

Fine-grained detrital rocks of the lower member include light- to dark-gray, brown, pink, and red sandy mudstone and black carbonaceous silty claystone, in beds generally 5–10 feet thick. These are interbedded with beds commonly 1–5 feet thick of yellow- to brown-weathering gray sandstone, flaggy irregularly cross-bedded coarse-grained sandstone, and grit and pebble conglomerate that contain abundant grains, granules, and pebbles of black chert. The flaggy beds weather to loose contorted slabs. Brown sandstone conglomerate or grit that contains small gray clay balls and angular fragments a quarter to a half inch in diameter is common.

Thin lenses of limestone are found locally. The most common kind of limestone is muddy brown, fissile, and carbonaceous. One variety is extremely hard, dark brown, and finely crystalline, and occurs in beds 1 inch to several inches thick that weather grayish brown or orange brown. Slabs of this rock ring when struck by a hammer.

In a few places, light-gray to light-brown algal limestone and pisolitic limestone form beds 5–20 feet thick that are interbedded with red to gray mudstone and red diamictite. Near Morgan Canyon in the NW¼NE¼ sec. 16, T. 22 N., R. 118 W., three beds of pisolitic limestone 5–10 feet thick (fig. 9*A*) are formed of algal pisolites (fig. 9*B*), which are mostly 1–5 inches in diameter. These beds are overlain by brown shaly limestone, gray carbonaceous mudstones, and yellow- to brown-weathering sandstone and grit that are faulted against, and apparently unconformably overlain by, red variegated mudstone of the main body of the Wasatch Formation.

The lower member grades into the main body in the small basin of North Bridger Creek, west of Elk Mountain in the northwestern part of T. 20 N., R. 119 W. Light-gray silty mudstone of the Evanston Formation is overlain with slight unconformity by a thin bed of the basal conglomerate member of the Wasatch. This conglomerate, containing rounded pebbles derived from the Nugget Sandstone, is overlain by pebble grit, containing abundant black chert pebbles, by thin beds of brown hard, ringing limestone, and by gray, red, and maroon mudstone, black carbonaceous clay, and yellow sandstone that in several hundred feet grade into variegated beds of the main body.

The unit is intermediate not only in position but, except for local concentrations of algal and pisolitic lime-

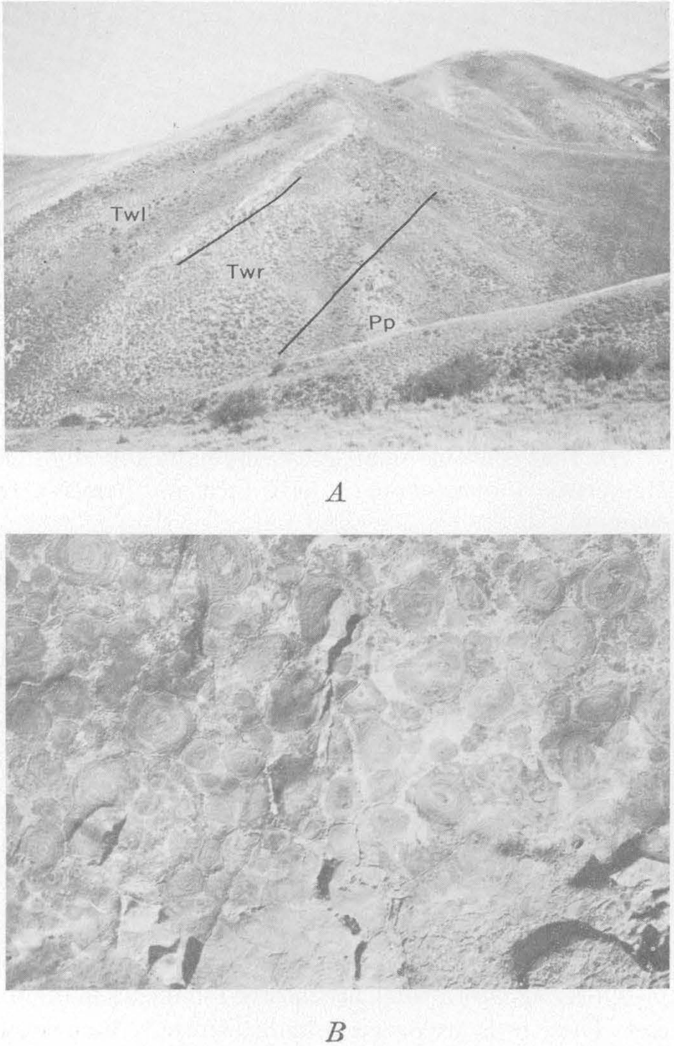


FIGURE 9.—Lower member of the Wasatch Formation. *A*, Three beds of west-dipping algal and pisolitic limestone (Twl) in the lower member of the Wasatch Formation on the north side of Morgan Canyon in the NW¼NE¼ sec. 16, T. 22 N., R. 118 W. The limestone overlies red mudstone (Twr), which rests unconformably on Permian strata (Pp). *B*, Closeup of limestone bed in *A*, showing pisolites as much as 3 inches in diameter.

stone, in composition between the upper part of the Evanston Formation and higher more typical parts of the Wasatch Formation. However, diagnostic features of the Wasatch, to which it is here assigned, prevail.

DISTRIBUTION AND THICKNESS

The lower member of the Wasatch is present on the south end of the Tunp Range in the Sage quadrangle. The strata are nearly continuously exposed along the east side of the range for 3 miles north of U.S. Highway 30N, and patches cover parts of the exposed surface and sides of the large domelike exposure of Nugget Sandstone south of the highway. The lower member overlies gray mudstone of the Evanston Formation along Collett Creek and in the basin of North Bridger Creek. Probably not more than 300 feet of beds are present at any locality. The unit varies greatly in thickness from place to place because it was deposited on an irregular topographic surface of moderate relief, because it has been variously compacted, and because it has been folded and faulted against older rocks at the edge of the basin. The lower member has not been recognized either on the east side of the Fossil basin or in drill holes.

MAIN BODY

ROCKS INCLUDED

The main body of the Wasatch Formation within the Fossil basin consists predominantly of banded, variegated mudstone (fig. 10) interbedded with claystone, siltstone, sandstone, conglomerate, and light-gray marlstone. Thin lentils of brown to dark-gray limestone are present in a few places directly below or near the margins of beds of the Green River Formation.

Colors range from deep red and maroon through various hues of red to purple, brown, yellow, tan, and light to dark gray. Horizontal color bands on weathered slopes (fig. 10) range in thickness from 1 to 10 feet and are mostly 2–5 feet thick, whereas virtually all fresh mudstone is mottled. The bands are brightest, in red, maroon, and purple hues, in the upper predominantly mudstone part of the unit not far beneath beds of the Green River Formation; in the lower sandy part of the unit, they are mostly drab shades of red, pink, tan, and gray. Colors are related to lithology in that sandy or conglomeratic strata are less intensely colored than silty or muddy strata. Nevertheless, a sequence of clearly defined bright bands is evident even in fresh exposures of virtually homogeneous mudstone. At a distance, they ap-

FIGURE 10.—Color-banded mudstone and siltstone in the main body of the Wasatch Formation. The exposure is on the southwest side of Fossil Butte in the NW¼ sec. 6, T. 21 N., R. 117 W.

pear to be sharply defined, but on close examination the color bands are exceedingly diffuse.

The upper mudstone part of the unit consists largely of bedded silt and fine sand with much clay binder. More pure claystone beds generally contain abundant disseminated grains of angular quartz sand. The clay sloughs and spalls on exposure and probably is montmorillonitic. Prominent siltstone, sandstone, and conglomerate beds are indurated with calcium carbonate. Moderately well sorted well-rounded pebble conglomerate is confined to deposits that fill channels cut into the variegated mudstone beds (fig. 11), whereas beds of gritty poorly sorted gravel conglomerate that contain abundant chips and angular fragments of black chert are laterally extensive and are not confined to channels.

Conglomerate and crossbedded sandstone are more abundant in the lower part of the section, particularly in peripheral areas of the basin. The type exposures of Veatch's Almy are not notably conglomeratic and are only moderately representative of the peripheral conglomerate facies of the main body of the Wasatch Formation. More representative conglomeratic facies can be seen west of Wasatch on U.S. Highway 30S, 9 miles west of Evanston, where the east-west gradation from basinal to peripheral facies is well exposed.

Detailed mapping may delineate the basinal muddy and peripheral conglomeratic facies of the Wasatch, at least in the south half of the Fossil basin, and demonstrate the possible validity of the Almy as a peripheral member and the Knight as a basinal member of the main body of the Wasatch Formation. Until they are mapped, however, the names Almy and Knight should not be used.

The peripheral sandy to conglomeratic facies of the Wasatch discussed here is not the same as the conglomeratic mudstone or diamictite facies of the northern part of the Fossil basin, which was mapped separately as the Tunp Member of the Wasatch, and is discussed below. In many places, however, it lies between Tunp diamictite and the basinal facies.

DISTRIBUTION AND THICKNESS

The main body of the Wasatch Formation is exposed in much of the Fossil basin. It includes most of the areas mapped as Knight Formation by Veatch (1907, pl. 3) in the northern and eastern parts of the basin. Near Evanston, on the east side of the Bear River, it includes beds mapped as both Almy and Knight Formations by Veatch.

About 1,000 feet of beds is exposed along U.S. Highway 30N from the east side of the Tunp Range to the base of the Green River Formation at Fossil Butte. About 1,100 feet of Tertiary rocks was penetrated several miles to the north, in the Amerada Petroleum Co.

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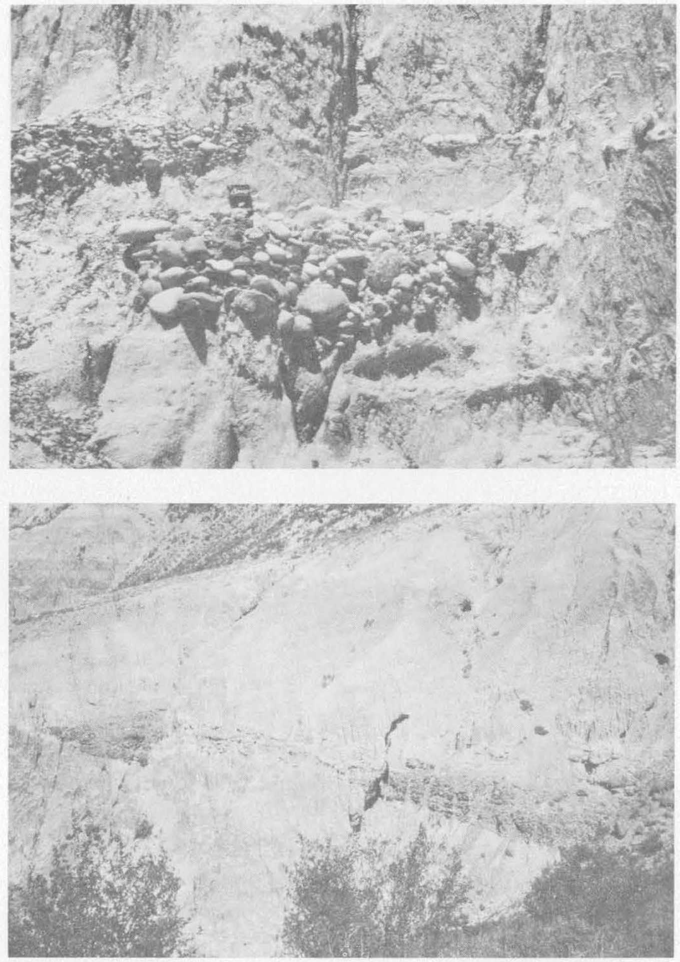


FIGURE 11.—Lenses of moderately well sorted brown conglomerate in mudstones of the main body of the Wasatch Formation. *Upper*, Conglomerate fills channels cut into red mudstone in the NE¼ sec. 12, T. 21 N., R. 117 W., near the periphery of the Fossil basin: scale is indicated by the pipe-tobacco can. *Lower*, Conglomerate fills channels cut into banded and variegated mudstone farther southwest nearer the center of the basin.

1 Chicken Creek unit well (sec. 30, T. 22 N., R. 117 W.), in a hole that started 400 feet below the base of the Green River Formation. The National Cooperative Refinery Association 1 Government-Larsen test well (sec. 33, T. 24 N., R. 117 W.) penetrated a comparable thickness. It began about 400 feet below the base of the Green River Formation and is reported to have penetrated 1,030 feet of the Wasatch Formation. The main body of the Wasatch is 1,512 feet thick in the Roy Steele 1 Government borehole, in the NE¼NE¼ sec. 29, T. 20 N., R. 118 W., 2½ miles southeast of Elk Mountain near the center of the Fossil basin.

The thickness of the Wasatch Formation near the south end of the basin may be as much as the 2,000 feet reported by Veatch (1907, p. 89) for his Almy Formation in the type area.

Toward the edges of the basin, the main body of the Wasatch generally thins. In a few places it is overlapped by beds of the Green River Formation (fig. 5) that rest directly on formations of Paleozoic and Mesozoic age. In some places, however, the Wasatch Formation may be very thick near an edge of the basin, because of high-angle faulting that dropped the basin while the Wasatch Formation was being deposited.

LOWER CONTACT

The surface upon which the Wasatch Formation was deposited had in many places considerable topographic relief. Along the margins of the basin, rocks here assigned to the main body of the Wasatch Formation rest unconformably on all older formations exposed nearby, from the upper part of the Evanston Formation down to and including the Wells Formation. In a few places, beds of the Wasatch Formation rest on older Paleozoic rock, such as the Bighorn Dolomite of Ordovician age, as in the SW¼ sec. 25, T. 21 N., R. 119 W. The considerable relief that existed during deposition of the main body is well demonstrated near the basin's margins where lower beds of the Wasatch butt against steep topographic highs of Mesozoic rocks and where both are overlapped by higher beds of the Wasatch.

The main body conformably overlies the lower unnamed member of the Wasatch Formation in relatively few parts of the Fossil basin; at these places the contact is transitional. Where uppermost beds of the Evanston directly underlie the main body of the Wasatch Formation, the contact is apparently conformable. Indeed, in a few localities, including the type sections of the Evanston and Almy Formations, the dominantly light gray mudstone beds below contain a few thin red and yellow mudstone beds, and the varicolored mudstone beds above contain several gray mudstone bands; the rocks at these localities seem to be gradational. In some of these places, however, beds within the Evanston are folded into both small and broad open folds, whereas basal strata of the Wasatch Formation dip gently and more uniformly.

SANDSTONE TONGUE

A comparatively thin tongue of sandstone with some green mudstone divides the Fossil Butte Member of the Green River Formation into two units in the southeastern part of the Sage and southwestern part of the Kemmerer quadrangles. It has been traced only a few miles south of the quadrangle boundary, as far as the north side of Elk Mountain where it is 40–50 feet thick. The tongue is well exposed within bluffs of the Green River Formation along Clear Creek and close to the Angelo Ranch, south and southeast of Fossil, but it thins and disappears to the north.

Most of the unit consists of well-bedded cross-laminated medium- to coarse-grained brown sandstone composed mostly of quartz but containing abundant black chert grains. Southeast of the southeast corner of the Sage quadrangle, the unit consists of several extensive sandstone beds, sandstone lentils, and interbedded green and gray mudstone. We regard this unit as a tongue of the Wasatch Formation because its dominantly detrital components are traceable into the thick sequence of sandstone, claystone, red mudstone, and conglomerate of Elk Mountain which we assign to the Wasatch Formation, although it is interbedded with thin laminated limestone beds of the Green River Formation.

The sandstone tongue of the Wasatch Formation probably was derived from the south and spread northward onto the laminated mudstone, siltstone, and limestone of the lower part of the Fossil Butte Member of the Green River Formation. The source of the detritus may have been the Uinta Mountains, which were shedding detritus into the Green River Basin at about the same time (Lawrence, 1963). The unit represents an encroaching dominantly sand tongue from a single source and may have formed as a delta which spread into the lake of Green River age rather than as alluvium along the southern margin of a receding lake. Despite uncertainties regarding genesis, it is assigned to the Wasatch Formation on the basis of lithology. Whether the unit is of more than local significance is not known.

MUDSTONE TONGUE

A thin but extensive tongue of the Wasatch Formation separates the Angelo Member from the Fossil Butte Member of the Green River Formation over a large part of their area of outcrop. The unit consists of dark-red to brick-red mudstone along the northwest side of the Hams Fork Plateau. Basinward the Fossil Butte and the Angelo Members of the Green River Formation thicken, and the mudstone tongue of the Wasatch thins from a maximum of about 50 feet and changes to light-red or pink and light-grayish-green to light-greenish-gray claystone. The clay is "soft" in a fresh exposure and may be montmorillonitic in that it slakes and cracks. Toward Tunp Range, the unit thickens and in places becomes conglomeratic, merging with the peripheral Tunp Member of the Wasatch Formation.

Over a large central part of the basin, where thick sections of the Green River Formation are exposed, beds equivalent to the mudstone tongue of the Wasatch Formation are represented by a few feet of light-gray to greenish-gray thin-bedded shale or claystone at the base of the Angelo Member of the Green River Formation. The equivalent of the tongue in the southern or western part of the basin is not known.

FIGURE 12.—Algal log in the mudstone tongue of the Wasatch Formation. The cylinder of limestone was probably deposited by algae as an encrustation on a fragment of a tree branch.

The mudstone tongue of the Wasatch represents muds, silts, and clays that were carried into the Green River lake chiefly from the north and west. This tongue may be related to mudflows and slides of weathered material connected with the formation of the Tunp Member of the Wasatch or possibly with an increasing amount of volcanic material over the region.

The mudstone tongue is characterized by "algal logs"—cylindrical forms that appear to be the encrustations of sticks, twigs, and logs by accretionary growth of brown laminar limestone, probably deposited by calcareous algae (fig. 12). The interior surface seems to be the mold of sticks or logs, in places preserving a grainlike or barklike surface. Small forms are one-half inch thick, several inches wide, and 4–6 inches long; the longest one is millstone shaped, 6–8 inches thick, and 18 inches in diameter and has a central opening 6 inches in diameter. The "front" and "back" surfaces are almost plane fractures.

The algal logs are locally common, are widely distributed over the northern part of the area, and in places can be used as horizon markers. They are abundant in the mudstone tongue wherever their stratigraphic positions can be accurately determined, and for this reason they have been used as indicators of the former presence of the tongue where they are abundant on a weathered surface.

BULLPEN MEMBER

NAME AND TYPE

A moderate to thick sequence of red, pink-salmon, green, and gray mudstone, extensive but thin beds of limestone, fine- to coarse-grained sandstone, and conglomerate is exposed in the central and south-central parts of Fossil basin. It is here named the Bullpen Member of the Wasatch Formation for exposures that cap bluffs of the Green River Formation south of Bullpen Creek, in the southeastern part of the Sage and the southwestern part of the Kemmerer quadrangles.

A sequence measured in the NW¼ sec. 1, T. 20 N., R. 118 W. (p. 42), is here designated the type section. Although the section is incomplete, it is moderately well exposed and contains more common lithologies than the complete sections measured to the northwest and southwest where conglomerate and diamictite along the periphery of the Fossil basin are more abundant.

Veatch recognized these rocks on Hams Fork Plateau and suggested (1907, p. 99) "* * * that they represent outlying Bridger areas. These outcrops have a reddish cast, not like typical Bridger, and the suggested correlation is based more on their position above the typical Green River than on their lithologic resemblance to the Bridger of the type locality." We assign these rocks to the Wasatch Formation because they resemble Wasatch strata elsewhere and do not resemble the Bridger Formation lithologically and because these strata above the Green River Formation grade laterally into the indivisible peripheral units also assigned to the Wasatch Formation.

ROCKS INCLUDED

The Bullpen Member of the Wasatch Formation contains layered sequences of red to pink, green, and light-gray claystone and mudstone in the central part of the Fossil basin, especially northeast and southeast of Elk Mountain. The pastel hues of the banded claystone and mudstone give a "peppermint candy" aspect to ridgetops over a wide area. The claystone is in many places soft sloughing bentonitic clay apparently identical to thinner and less widely distributed beds of the mudstone tongue of the Wasatch Formation on Hams Fork Plateau. The mudstone is both silty and sandy claystone. Siltstone beds are mainly light gray and yellow.

Cross-laminated fine- to coarse-grained sandstone and gritty granule conglomerate are abundant northeast of Elk Mountain in beds 5–40 feet thick. The beds seem to be identical in composition and texture with those of the sandstone tongue of the Wasatch Formation and are found over much the same area.

Salmon-colored to red mudstone, brown and gray sandstone beds, and pebbly conglomeratic sandstone are especially characteristic of the upper half of the member. They are dominant especially from Elk Mountain to Sillem Ridge. Toward the west edge of the basin—both northeast and southeast of Sage—sandstone and conglomerate are more abundant, coarser, and more poorly sorted, approaching the diamictite facies of the Tunp Member of the Wasatch Formation. Pebbles and boulders are well rounded to angular and apparently were derived from Mesozoic rocks exposed in nearby ridges and from Paleozoic rocks exposed west of the Crawford fault (Rubey, Tracey, and Oriel, 1968). The member may also coarsen southward toward the center of the Fossil basin, but this observation is based on reconnaissance.

The limestone is mainly slabby and thin bedded. Some beds are dark brown and petroliferous to almost black on fresh surfaces and nearly white, light tan, or brown on weathered surfaces; other beds are white to light gray and partly argillaceous to marly. Some beds are subaphanitic laminated limestone very similar to the limestone of underlying members of the Green River Formation.

Many of the limestone beds are resistant and form extensive butte and mesa caps, as well as ledges, beneath which less resistant beds of mudstone and claystone are preserved. In the Sage and Kemmerer quadrangles prominent beds of limestone and laminated siltstone, though thin, have been mapped in the Bullpen and the Tunp Members of the Wasatch Formation (Rubey, Tracey, and Oriel, 1968; Rubey, Oriel, and Tracey, 1968).

DISTRIBUTION AND THICKNESS

The Bullpen is considered a member of the Wasatch Formation on the basis of its dominant lithologies and because it grades laterally southward into the sandy and conglomeratic sequence at Elk Mountain that resembles parts of the peripheral conglomeratic facies of the Wasatch. Southeast of Bullpen Creek this member grades into claystone and mudstone, which are interbedded with increasing amounts of limestone south of the Kemmerer quadrangle, where it would be feasible to map the limestone beds as an upper member of the Green River Formation. North of U.S. Highway 30N, near the Tunp Range, the Bullpen Member merges laterally with rubbly mudstone of the Tunp Member of the Wasatch Formation. North and south of Sage, along Boulder Ridge, the Bullpen Member grades westward into blocky breccia in a matrix of salmon-colored sandstone and mudstone of the Tunp Member.

A complete section, 400 feet thick, was measured on the south side of Elk Mountain where the Bullpen Member is overlain by about 60 feet of gray tuffaceous mudstone and conglomerate of the Sillem Member of the Fowkes Formation.

Another section of the Bullpen Member, about 300 feet thick, was measured on the northeast end of Sillem Ridge, in the E½ sec. 21, T. 21 N., R. 119 W. This and other sections nearby are cut by normal faults, and the measurements required care. Eroded remnants of the unit, not overlain by younger rocks, are found north and east of Sillem Ridge at numerous localities. In the southern parts of secs. 25 and 26, T. 21 N., R. 118 W., for example, the lower 250 feet of the unit is preserved. North of U.S. Highway 30N, along the Hams Fork Plateau, a few small isolated mounds rest on the Green River Formation. The mounds range in thickness from a few feet to slightly more than 100 feet. Greater thicknesses probably are preserved to the south.

LOWER CONTACT

The contact between the Bullpen Member of the Wasatch Formation and underlying beds of the Green River Formation is, in most places, both conformable and gradational. Limestones below grade upward to gray marlstone and green mudstone, which are overlain by either sandstone or red mudstone. The base of the lowest continuous resistant sandstone or red mudstone is easily traceable in the field. In some places an uppermost white limestone of the Green River Formation is sharply and directly overlain by dark-red mudstone.

Regionally, the contact is gradational and crosses isochronous surfaces, because at least parts of the lower beds of the unit are laterally equivalent to some of the upper beds of the Green River Formation.

TUNP MEMBER

NAME AND TYPE

A peripheral lithologic unit of the Wasatch Formation in the Fossil basin ranges from conglomeratic mudstone to a rubbly breccia. It is here named the Tunp Member, for excellent exposures in the Tunp Range. No type section is given because of the rubbly and poorly stratified nature of the unit and because of extreme variability in thickness and composition; but characteristic exposures are found along Dempsey Ridge of the Tunp Range in Tps. 23, 24, and 25 N., R. 118 W., here designated the type area.

ROCKS INCLUDED

The Tunp Member is best described as diamictite (Flint and others, 1960; Tracey and others, 1961). It consists chiefly of dark-red to medium-red conglomeratic mudstone and blocky breccia in a mudstone matrix (figs. 13, 14). Fresh exposures show an extremely unsorted aggregate of small to large angular fragments, poorly rounded fragments, well-rounded pebbles to boulders, and blocks of heterogeneous lithology in an unsorted red sandy mudstone matrix. In some places, the mudstone fills spaces between packed fragments and blocks and forms only half the bulk of the material; in others, scattered pebbles, boulders, or blocks are dispersed in mudstone.

The fragments and boulders are locally derived from formations that are now exposed short distances away (fig. 13). For this reason, composition varies from outcrop to outcrop; it also varies in a vertical section indicating changes in source of the fragments during the course of deposition. In one exposure along Dempsey Ridge, NW¼SW¼ sec. 10, T. 24 N., R. 118 W., fragments and blocks were identified as gray quartzitic sandstone and sandy limestone of the Wells Formation, tan sandy Thaynes Limestone, tan quartzitic Nugget Sandstone, Twin Creek Limestone, and Preuss Redbeds. A hundred feet higher in the same section, large angular blocks of Ephraim Conglomerate are the chief constituent of the unit (fig. 14). In at least one locality, blocks of Ephraim Conglomerate have a maximum diameter of 20 feet.

East of Hams Fork and west of Commissary Ridge, in a part of the basin bounded by the Adaville, Frontier, and other formations of Late Cretaceous age, the member contains blocks of sandstone derived from these formations. Along Boulder Ridge north and south of Sage it contains abundant angular fragments and blocks chiefly of limestones from upper and lower Paleozoic formations now exposed in the Crawford Mountains a few miles to the southwest. In places the blocks are very large and may be slump or slide blocks of the older limestones. One extremely large block of Bighorn Dolo-

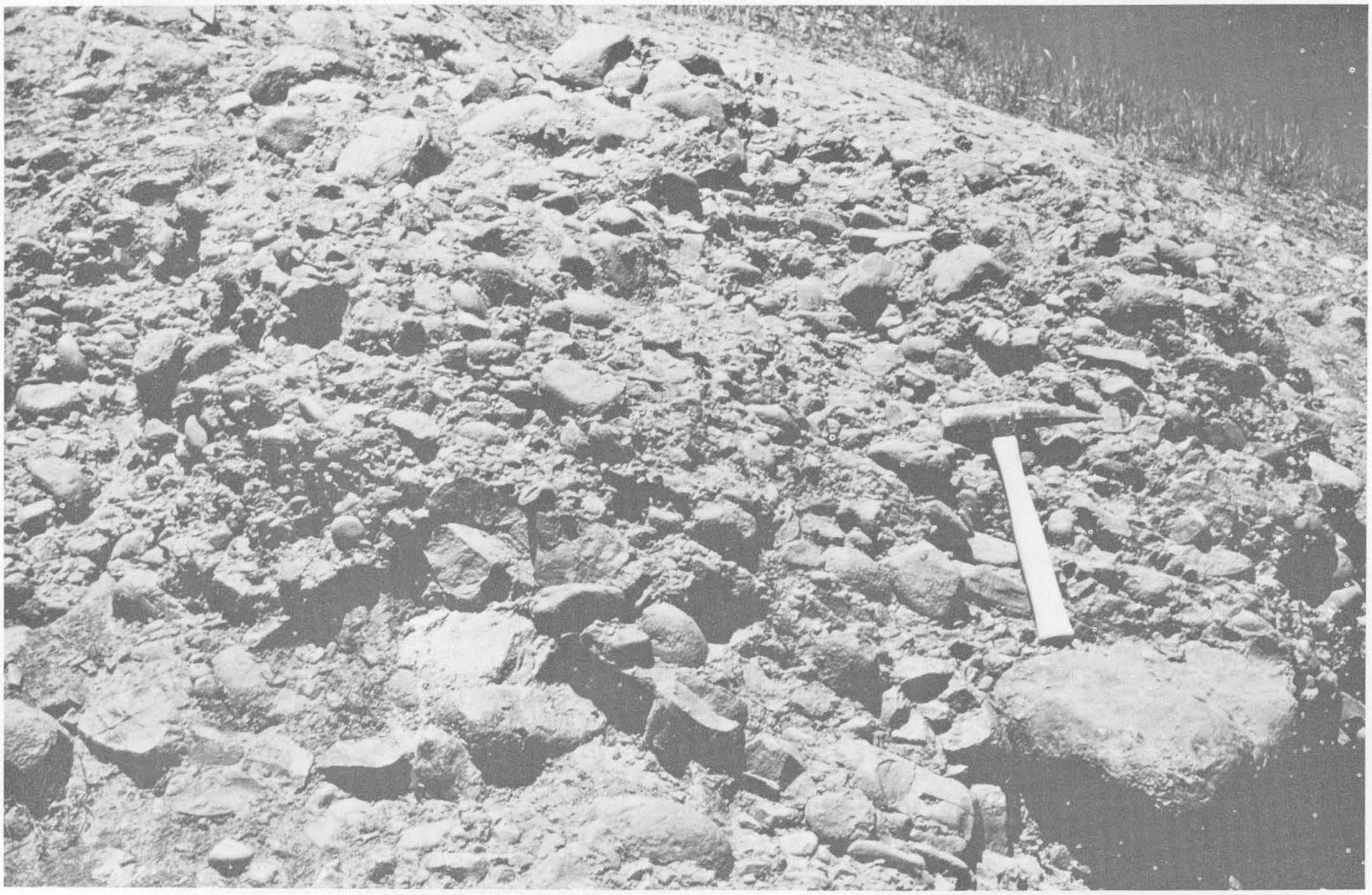


FIGURE 13.—Diamictite in the Tunp Member of the Wasatch Formation. Poorly sorted pebbles and blocks of upper Paleozoic and Mesozoic rocks in a matrix of maroon to brownish-red mudstone along the ridge east of Pole Creek in sec. 8, T. 25 N., R. 116 W.

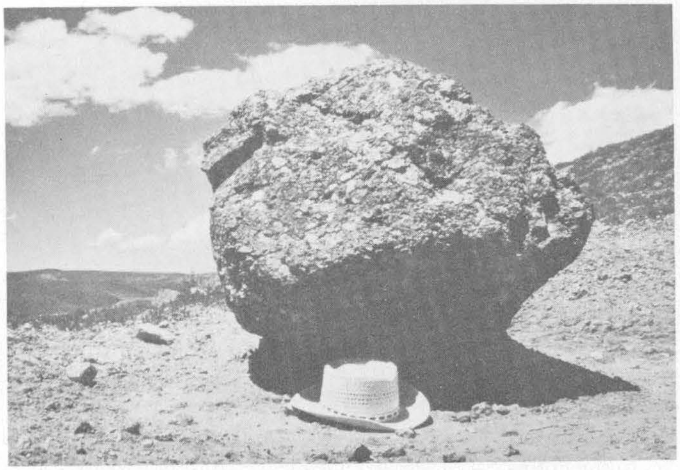


FIGURE 14.—Block of Ephraim Conglomerate in diamictite of the Tunp Member of the Wasatch Formation in the NE¼ NW¼ sec. 3, T. 21 N., R. 119 W.

mite, more than 600 feet long, lies on the ridge in the NE¼ sec. 6, T. 21 N., R. 119 W., and is surrounded by fragments and blocks of other lithology in a conglomeratic matrix containing salmon-colored sandstone and mudstone resembling and grading eastward into the mudstone of the Bullpen Member. Another much larger mass of lower Paleozoic limestone forms Eli Hill in the SW. cor. sec. 25, T. 21 N., R. 120 W. It is surrounded by Tertiary rocks and can be interpreted as a mass of bedrock that slumped onto Tertiary muds at the edge of the Fossil basin during deposition of the Wasatch Formation. It is therefore possible to interpret this hill of Paleozoic rock as a "boulder" within the Tunp Member of the Wasatch Formation, although on the geologic map Rubey, Tracey, and Oriel (1968) have accepted the alternate explanation that it is a klippe of the Crawford thrust fault, the buried trace of which lies in Bear River valley (fig. 2).

Large boulders scattered in mudstone are present in the main body of the Wasatch Formation, in the mudstone tongue of the Wasatch, and in the Bullpen Member not far from the boundary of the Tunp Member. The gradation from the Tunp Member into more typical Wasatch lithology takes place in a lateral distance of several hundred feet, although in a few places the boulders are found half a mile or more basinward and in other places the gradation takes place in less than a hundred feet.

DISTRIBUTION AND THICKNESS

The Tunp Member is exposed in a narrow belt around the periphery of the Fossil basin and in channels about normal to the belt.

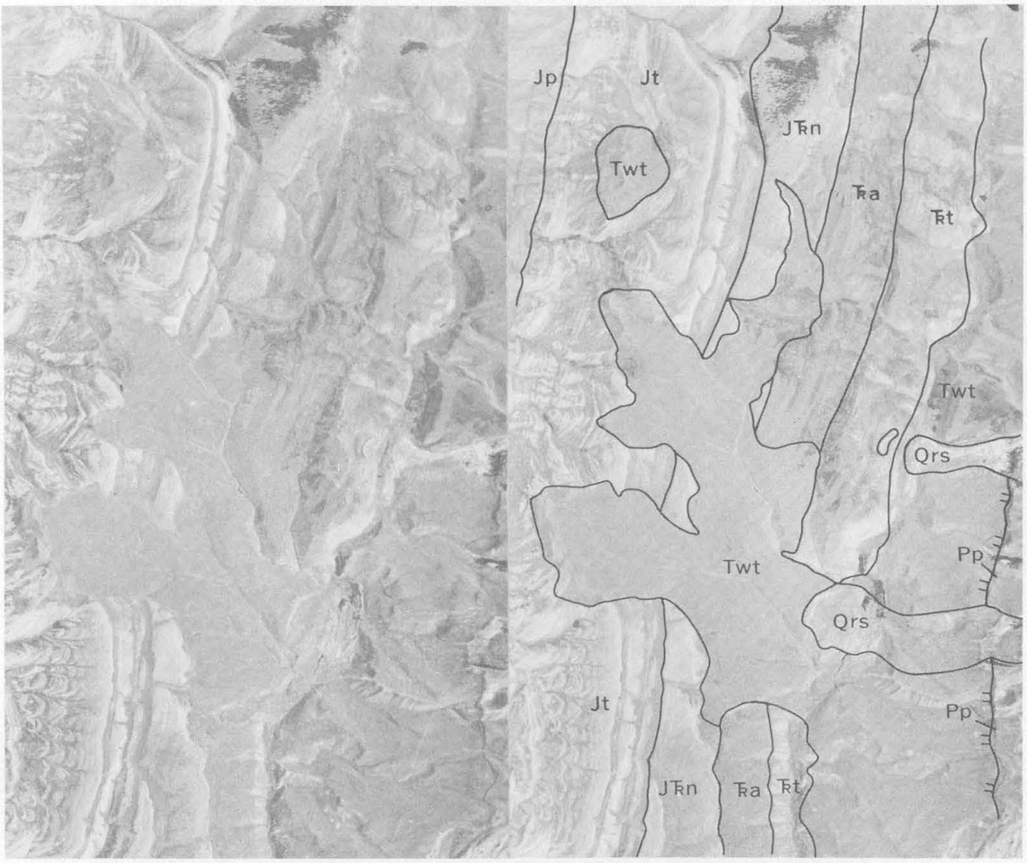
The Tunp extends along the northwest, north, and northeast sides of the Fossil basin as far north as Big Park, in the SE¼ sec. 7, T. 27 N., R. 117 W. The member is especially well exposed along the crest of Dempsey Ridge in the Tunp Range overlooking Dempsey Basin and in the Cokeville quadrangle on the northeast side of Fossil basin, west of Commissary Ridge, between Lake Creek and Pole Creek, for example, in the SW¼ sec. 8, T. 25 N., R. 117 W. Exposures on both sides of the basin are similar in the poor degree of sorting and in matrix composition but differ in the composition of coarse clasts, which reflects differences in the older rock formations exposed nearby. The member is 100–200 feet thick in most places, but exceeds 500 feet locally. The exposed width of the member ranges from a few hundred feet to several miles; in general the Tunp extends from the contact with old rocks basinward to a short distance beyond the edges of Green River limestone tongues.

Channels of this member are especially well displayed along Rock Creek Ridge. The channels along which the diamictite was transported are cut into steeply dipping mainly Jurassic strata on Rock Creek Ridge (fig. 15*A*) in the northern part of the Sage quadrangle and in the southern part of the Cokeville quadrangle. Two delta-like deposits of Tunp diamictite extended into the lake

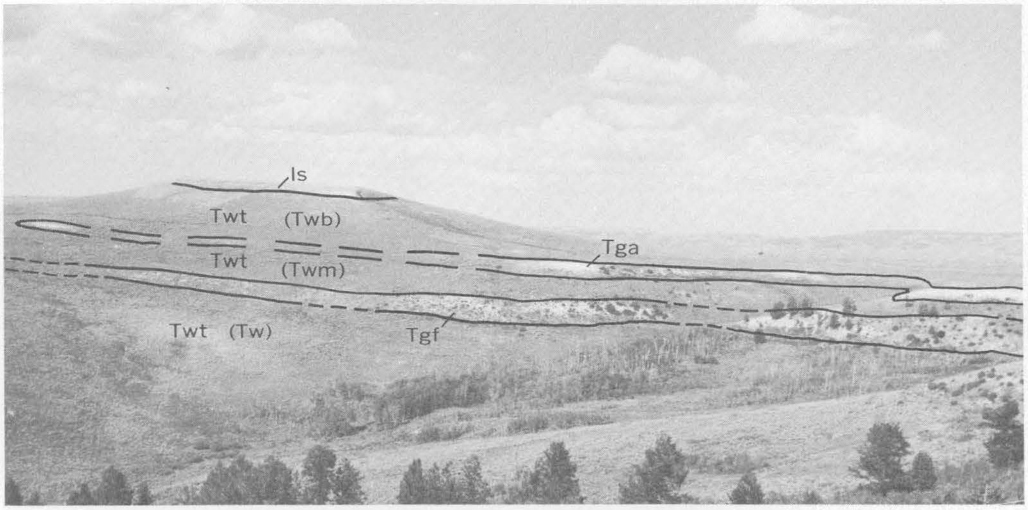
EXPLANATION OF FIGURE 15

A. Tunp diamictite (Twt) fills channels cut into Mesozoic rocks (Jp, Preuss Redbeds; Jt, Twin Creek Limestone; J̄R n, Nugget Sandstone; R̄a, Ankareh Formation; R̄t, Thaynes Limestone) on Rock Creek Ridge in western part of T. 23 N., R. 118 W. Holocene rockslides (Qrs) are associated with the fault (hachured line) on the east side of Rock Creek and dam the ponds along the stream. The Permian Phosphoria Formation (Pp) is exposed east of the fault. Stereopair of vertical air photographs (scale about 1:62,500) is from U.S. Army Map Service high-altitude photography AL–121, roll 3, negatives 401 and 402. The channels of diamictite drained eastward in Eocene time and emptied into Fossil Lake along a large apronlike delta that now forms the 8,468-foot Rock Creek bench-mark point (Sage quadrangle), in the E½ sec. 21, secs. 22 and 27, T. 23 N., R. 118 W., on Dempsey Ridge. The fault along Rock Creek dropped the channel deposits on Rock Creek Ridge at least 800 feet with respect to the delta deposits on Dempsey Ridge.

B. Intertonguing of Tunp diamictite (Twt) with limestone beds of the Green River Formation on Dempsey Ridge in view northward from about the center of sec. 3, T. 23 N., R. 116 W. The limestones include a lower bed (Tgf) that can be traced eastward into the Fossil Butte Member of the Green River, a middle unit (Tga) that is a tongue of the Angelo Member, and an upper bed (ls) that lies within the Bullpen Member of the Wasatch Formation. The Tunp grades eastward (out of the photograph) into the main body of the Wasatch (Tw), the mudstone tongue (Twm), and the Bullpen Member (Twb).



A



B

FIGURE 15.—Geometric relations of Tunp Member of Wasatch Formation.

TABLE 2.—*Fossils from the lower member of the Wasatch Formation in the Sage quadrangle, Lincoln County, Wyo.*

Location	T. 22 N., R. 118 W.																	T. 21 N., R. 118 W.										T. 20 N., R. 119 W.
	Sec. 4						Sec. 9				Sec. 16						Sec. 34	Sec. 3			Sec. 10			Sec. 16	Sec. 18			Sec. 2
Sample	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Paleontologic locality numbers	21995	22001	D1685-1	D1685-2	22627	22628	22049	22623	22624	D1686	22004	22632	D1700	22630	22631		21996	22047	20915	D1684		D1683-1	D1683-2	D1687	22033	22625	22626	
CHAROPHYTA [1]																												
Maedleriella n. sp.																X											X	X
Harrisichara sp.																		X			X							
POLLEN AND SPORES [2]																												
Anemia			X																									
Alnus, pores 6																				X			X	X				
Alnus, pores 4–5										X										X		X	X	X				
**Araucariacidites australis* Cookson																						X						
Carya			X							X			X							X		X	X	X				
Cedrella type																				X			X					
Eucommia																						X						
Fremontia type																						X						
**Gleicheniidites senonicus* Ross																								X				
Juglans																				X								
**Erdtmanipollis*																								X				
Platycarya			X	X						X			X									?	?	?				
Pistillipollenites			X							X																		
Pterocarya																						X	X					
Sporites arcifer Thiergart																						X						
Retitricolpites cf. *R. vulgaris* Pierce																							X	X				
Taxodium type													X															
Ulmaceae cf. *Parasporia*				X						X			X							X		X	X	X				
Ulmaceae Ulmus or *Zelkova*													X							X		X	X					
OSTRACODES [3]																												
"*Pseudocypris*" *pagei* (Swain)																											X	
Pseudocypris? sp.																X		X										
GASTROPODS [4]																												
Land snails																												
Grangerella						X																						
Discus													X															
Oreoconus n. sp. b	X?				X		X					X?																
Glypterpes veternus	X?																											
Fresh-water snails																												
Elimia nodulifera (Meek)		X?					X	X	X																			
Biomphalaria pseudo-ammonius (Schlotheim)						X?								X											X	X	X?	
Omalodiscus																	X											
Physa cf. *P. bridgerensis*											X?						X?	X?	X?						X?			
P. pleromatis White																										X	X?	
VERTEBRATES [5]																												
Meniscotherium cf. *priscum* Granger															X													
Lepisosteus																		X										

[1] R. A. Peck, 6-12-61, 1-5-62.
[2] E. B. Leopold and H. M. Pakiser, 8-25-61, 8-20-62, 8-21-62.
[3] R. A. Peck, 1-5-62; Sohn, 4-15-59, 11-3-59, 2-12-64.
[4] D. W. Taylor, 10-5-59, 4-11-60, 4-20-60, 11-6-61.
[5] C. L. Gazin, 11-7-61; D. H. Dunkle, 10-8-58.

in which the Green River Formation was deposited and now form several large rounded peaks along the crests of Rock Creek and Dempsey Ridges.

FOSSILS AND AGE

Although the basal and upper parts of the formation are undated, the early Eocene age of most of the Wasatch in the Fossil basin is well established.

BASAL CONGLOMERATE MEMBER

Only an indeterminant planorbid fresh-water snail (USGS Cenozoic loc. 22035) has been found in the basal conglomerate member of the Wasatch Formation. The unit is tentatively assigned to the early Eocene, although it may be older.

LOWER MEMBER

Numerous fossils have been collected from the lower member, as shown in table 2; they indicate an early Eocene age. Attempts to refine the age assignment further, however, have not been entirely successful.

An earliest Eocene or Gray Bull (Granger, 1914) age is suggested by a tooth of *Meniscotherium*, although the genus has been found in uppermost Paleocene or Clark Fork Beds (C. L. Gazin, written commun., Nov. 7, 1961). The presence of the ostracode "*Pseudocypris*" *pagei* suggests either a latest Paleocene or earliest Eocene age, whereas the charophyte *Maedleriella* indicates an Eocene age (R. E. Peck, written commun., Jan. 5, 1962). The gastropods, on the other hand, are surely of Eocene age; the absence of latest Paleocene and earliest Eocene forms similar to those found in the Green River Basin suggests that the snails may be of post-Gray Bull age (D. W. Taylor, written commun., Nov. 6, 1961). All the pollen samples, except D1687, indicate an Eocene age, and four samples (D1685–1, D1685–2, D1686, and D1700) are of early Eocene age. Sample D1687 could be either Eocene or Paleocene, although a few Cretaceous forms are also present that may have been reworked from the nearby Evanston Formation exposures (E. B. Leopold, written commun., Oct. 20 and 21, 1962).

MAIN BODY

The main body of the Wasatch is of early Eocene (Gray Bull and Lysite) age in the Fossil basin—a determination based on numerous vertebrate collections from strata formerly assigned mainly to the Knight Formation by Veatch (Gazin, 1952, p. 9–10; 1959, p. 132–133; 1962).

Lowest beds of the main body, just above gray Evanston mudstone in the center of the basin west of Elk Mountain, are of earliest Eocene or Gray Bull age, as indicated by the condylarth *Haplomylus speirianus*

1. USGS Cenozoic loc. 21995, Lincoln County, Wyo., Sage quadrangle. NE¼NE¼ sec. 4, T. 22 N., R. 118 W., 1,200 ft west, 700 ft south of NE cor., elevation 7,900 ft. Shells from higher of two limestones. D. W. Taylor, 1956.
2. USGS Cenozoic loc. 22001 (field loc. 315b), a little below 1. NE¼NE¼ sec. 4, T. 22 N., R. 118 W., 1,100 ft west, 900 ft south of NE cor., elevation 7,840 ft.
3. USGS Paleobot. loc. D1685–1 (field loc. 710b), SW¼NE¼ sec. 4, T. 22 N., R. 118 W., 1,400 ft west, 2,100 ft south of NE cor., elevation 7,560 ft. Sample is gray clay, faulted against red clay of Wasatch Formation (main body).
4. USGS Paleobot. loc. D1685–2 (field loc. 710c); 30 ft north of 3. Sample is gray clay faulted against red clay.
5. USGS Cenozoic loc. 22627 (field loc. 712). SE¼SE¼ sec. 4, T. 22 N., R. 118 W., 200 ft west, 500 ft north of SE cor., on top of knob, elevation 7,480 ft.
6. USGS Cenozoic loc. 22628 (field loc. 712–B), about 30 ft lower than sample 5, south side of knoll.
7. USGS Cenozoic loc. 22049 and 22623 (field loc. 313a). SW¼SE¼ sec. 9, T. 22 N., R. 118 W. Top of peak, elevation 7,761 ft. Uppermost of three pisolitic limestone beds.
8. USGS Cenozoic loc. 22623; same location as sample 7.
9. USGS Cenozoic loc. 22624 (field loc. 313d). 500 ft SE of localities 22049 and 22623 and 150 ft lower. Middle pisolitic limestone bed.
10. USGS Paleobot. loc. D1686 (field loc. 340a–61) SW¼SE¼ sec. 9, T. 22 N., R. 118 W., 2,750 ft west and 1,000 ft north of SE cor. Gray clay from badger hole at top of saddle, 900 ft north and 150 ft higher than 11.
11. USGS Cenozoic loc. 22004 (field loc. 340). Center of north line of sec. 16, T. 22 N., R. 118 W., elevation 7,400 ft. Limestone apparently overlying pisolitic beds of samples 9 and 10.
12. USGS Cenozoic loc. 22632 (field loc. 718). 2,700 ft west and 140 ft south of NE cor. sec. 16, T. 22 N., R. 118 W.; about 300 ft SW and 80 ft lower than sample 10.
13. USGS Cenozoic loc. 22629, USGS Paleobot. loc. D1700 (field loc. 715). Center NE¼ sec. 16, T. 22 N., R. 118 W., elevation 7,380 ft. Pisolitic limestone overlying gray clay and gray slabby limestone.
14. USGS Cenozoic loc. 22630 (field loc. 716). 100 ft east and 100 ft south of center sec. 16, T. 22 N., R. 118 W., elevation 7,550 ft. Gray limestone.
15. USGS Cenozoic loc. 22631 (field loc. 717). NW¼NE¼ sec. 16, T. 22 N., R. 118 W., 2,100 ft west and 1,040 ft south of NE cor. Coarse-grained salt-and-pepper sandstone.
16. Field loc. 621, 300 ft north of 14. Slabby gray limestone in red clay.
17. USGS Cenozoic loc. 21996 (field loc. 12h). SW¼SE¼ sec. 34, T. 22 N., R. 118 W., about 500 ft NE of quarter cor. between sec. 34 and sec. 3.
18. USGS Cenozoic loc. 22047 (field loc. 12). NW¼NW¼NW¼ sec. 3, T. 21 N., R. 118 W., about 100 ft south of quarter cor. between sec. 34 and sec. 3.
19. USGS Cenozoic loc. 20915 (field loc. 12), same as sample 18.
20. USGS Paleobot. loc. D1684 (field loc. 704). SW¼SE¼ sec. 3, T. 21 N., R. 118 W., 2,000 ft west, 400 ft north of SE cor. sec. 3. Gray carbonaceous clay interbedded with coarse-grained brown sandstone.
21. Field loc. 701, SE¼SW¼ sec. 10, T. 21 N., R. 118 W., 3,500 ft west, 2,100 ft south of NE cor. Slabby limestone.
22. USGS Paleobot. loc. D1683–1 (field loc. 701a) 250 ft north of 701; gray clay in gully.
23. USGS Paleobot. loc. D1683–2 (field loc. 701a), same as sample 22. Lignite interbedded with gray clay.
24. USGS Paleobot. loc. D1687 (field loc. 703a). SE¼SE¼ sec. 16, T. 21 N., R. 118 W. 500 ft west, 1,900 ft north of SE cor. Gray silty clay and lignite.
25. USGS Cenozoic loc. 22033 (field loc. 401). NW¼NE¼ sec. 18, T. 21 N., R. 118 W. About 900 ft SE of quarter cor. between sec. 7 and sec. 18.
26. USGS Cenozoic loc. 22625 (field loc. 401d), same as sample 25.
27. USGS Cenozoic loc. 22626 (field loc. 401e), 100 yd west of sample 26. Gray limestone.
28. Field loc. 402, NW¼NE¼ sec. 2, T. 20 N., R. 119 W., 2,150 ft west, 500 ft south of NE cor. (south of Sage Quadrangle). Brown limestone.

(Cope) and associated early Eocene genera (Gazin, 1962, p. 13). Although these strata are assigned to the main body, they probably correlate with beds in the unnamed lower member.

Numerous collections from Fossil Butte (frontispiece), 40–100 feet below the lowest Green River beds, and from Knight establish the middle early Eocene (Lysite) age of these strata (Gazin, 1952, p. 9–10; 1962, p. 13–15). Additional collections of *Hyracotherium vasacciense* (Cope) have been made by us from the SE¼ sec. 5, T. 20 N., R. 117 W. (112 ft stratigraphically above the Evanston Formation), and from the NE¼ NE¼ sec. 1, T. 20 N., R. 118 W. *Coryphodon* fragments were found at both localities as well as in the following other localities: SE¼NE¼ sec. 1, T. 22 N., R. 118 W.; SE¼NW¼ sec. 22, T. 21 N., R. 118 W.; NE¼NW¼ sec. 21, T. 24 N., R. 117 W.; NW¼SE¼ sec. 3, T. 21 N., R. 118 W.; NE¼SE¼ sec. 1, T. 21 N., R. 118 W.; and the center of NW¼ sec. 32, T. 21 N., R. 117 W.

SANDSTONE AND MUDSTONE TONGUES

Only gastropods have been collected from the sandstone tongue of the Wasatch. One collection (USGS Cenozoic loc. 21999) from 2 miles south of the Kemmerer quadrangle on a butte east of South Fork of Twin Creek consists of the land snail *Oreoconus* n. sp. b? (D. W. Taylor, written commun., Apr. 11, 1960), a species found in both lower and higher units of the Wasatch. The same form was found in another collection (22048) from the SW¼SW¼ sec. 18, T. 20 N., R. 117 W. (D. W. Taylor, written commun., Oct. 5, 1959).

No fossils were found in the mudstone tongue.

The sandstone and the mudstone tongues are probably of early Eocene age; available evidence is inadequate for a more precise age assignment.

BULLPEN MEMBER

Several collections of mollusks from the Bullpen Member include the following forms (D. W. Taylor, written commun., Apr. 15 and 20, 1960):

USGS Cenozoic colln.	Locality				Mollusk
	Location in section	Section	Township (N.)	Range (W.)	
22024	NW¼NW¼SW¼	22	21	119	*Oreoconus* n. sp. b?.
22025	NW¼NW¼SW¼	22	21	119	Planorbidae indet.
22030	SE¼SW¼SW¼	21	21	119	*Valvata*?, *Elimia nodulifera* (Meek)?.
20913	NW¼NE¼SE¼	32	21	117	*Biomphalaria pseudoammonius* (Schlotheim), *Drepanotrema*?, *Physa*.
21992	NW¼	13	20	119	*Elimia nodulifera* (Meek)

The species are characteristic of those in lower and middle Eocene strata in Wyoming and Utah. The member, therefore, may be latest early or middle Eocene in age.

The limestone beds within the Bullpen Member also contain bones and scales identified (D. H. Dunkle, written commun., May 8, 1956) as *Asineops* sp. and *Lepisosteus* sp., both of which are abundant in Green River strata in western Wyoming.

TUNP MEMBER

Correlation of parts of the Tunp Member with lower or upper units of the Wasatch Formation is demonstrated in numerous places along Dempsey Ridge and especially well in the S½ sec. 3 and sec. 10, T. 23 N., R. 118 W., where three thin tongues of limestone wedge out into the Tunp Member (fig. 15*B*). The two lower limestone tongues are traceable eastward into the Fossil Butte and the Angelo Members of the Green River Formation, and the upper limestone bed is traceable into limestone beds in the Bullpen Member of the Wasatch Formation. Thus, the Tunp Member is equivalent in age to the whole Wasatch Formation in Fossil basin and is likely of early Eocene age, although parts may be slightly younger (table 4). No fossils have been found in the Tunp Member.

ORIGIN

The complex heterogeneity in composition of rocks assigned to the Wasatch Formation suggests a marked range in continental depositional environments. Most of the formation is of alluvial origin. At least some of the detritus, however, has barely been transported, if at all, and seems to be the product of residual weathering. Large volumes of detritus moved as mudflows and rockslides rather than as saltating or suspended particles in a stream. Still other detritus may have been transported by streams and deposited within the lake in which the Green River Formation was deposited.

The alluvial origin of much of the Wasatch is shown by many exposures of the main body. Extensive brightly colored bands of mudstone, which were deposited on flood plains, are cut by lens-shaped channels now filled by well-sorted conglomerate deposited as well-rounded and fairly clean gravel. Exposures are too discontinuous in the northern Fossil basin to permit mapping of these ancient stream courses.

The basal conglomerate member illustrates deposits that formed after little or no transport. The rocks consist almost entirely of Nugget detritus now resting on the Nugget Sandstone. The conglomerate matrix consists of disaggregated Nugget sand grains. Coarser clasts are rounded, but this rounding may reflect spheroidal weathering in a more humid climate than at present rather than abrasion during transport.

Around the periphery of the basin, other parts of the Wasatch also grade outward from the basin from well-sorted detrital beds through conglomerate to poorly sorted sedimentary breccia. At several places, this sedimentary breccia resembles a talus slope formed on an old surface of Mesozoic rocks; in a sense the talus represents a glimpse of an exhumed Eocene landscape. Interstices between the talus blocks are filled with red mud or pink sand like that elsewhere in the Wasatch Formation; in a few places the talus blocks are cemented by Green River limestone, thus preserving an old shoreline of the Eocene lake.

Gravitational sliding and solifluction were probably the chief agents of transport for the Tunp Member (Tracey and others, 1961). The lack of sorting and rounding, the presence of large blocks scattered in sandy mudstone, the absence of bedding, and the steep topographic slopes along which the deposits accumulated suggest that gravity predominated over running water. The deposits appear to have formed from mudflows and slides of both weathered material and fresh blocks of older rocks on steep slopes bounding the basin. The intertonguing relation between the Wasatch-Tunp diamictite and Green River limestones suggests that at least some of the mudflows may have swept into the Eocene lake as large deltas. Abundant water acting as a lubricant is likely, and inferred periods of heavy rainfall are consistent with the savanna climate commonly interpreted for the region.

At least some of the strata assigned to the sandstone and mudstone tongues of the Wasatch may also have been deposited within the lake, possibly as deltas, offshore bars, and blanket bottom deposits, but an alluvial origin can also be inferred from the available data. Numerous green mudstone beds suggest possible local reducing environments.

Thin and extensive limestone beds in the Bullpen Member indicate that the flood plains on which most of these strata were deposited were, during brief intervals, flooded by the Eocene lake. Whether these intervals of lake expansion reflect periods of especially heavy rainfall or abrupt sinking of the Fossil basin is not known.

The evidence from rock composition and fossils supports a very wet warm temperate to semitropical climate (Van Houten, 1961, p. 122) for the region during Wasatch deposition. Red upland soils formed in moderately wooded areas giving way downslope to savanna environments (Van Houten, 1964, p. 33) with abundant streams and ponds. The paucity of coal indicates that the area was moderately well drained.

TECTONIC IMPLICATIONS

The presence of considerable relief around the periphery of the Fossil basin is amply documented by the great ranges in sorting and grain size of Wasatch detritus, by the overlap of higher strata over lower strata onto older rock formations, and by channeling, as well as by observed local facies of Wasatch strata. Movement on all the thrust faults exposed north and west of the Fossil basin had ceased before Wasatch deposition, for the formation unconformably overlies traces of the faults; gross elements of present topography, reflecting structure of the western Wyoming thrust belt, had already formed by earliest Eocene time.

Many of the present topographic features are exhumed elements of an early Eocene landscape. Some, however, are not. The Tunp Member on Boulder Ridge, north and south of Sage, for example, records an apparent reversal of relief. Boulder Ridge is bounded on the west now by the wide valley of the Bear River. Yet the Tunp Member on the ridge contains enormous blocks, as much as 600 feet in maximum diameter, of Paleozoic carbonate rocks and fragments of Cretaceous rocks. The source of these clasts must have been a moderately high and steep mountain to the west, which was capped by the upper plate of the Crawford thrust fault. Post-Wasatch normal faulting likely down-dropped this mountain after Tunp deposition; erosion alone could not account for the present topography because of the greater resistance of formations above the Crawford fault than below it. Data are inadequate to date the normal faulting.

Other localities at which Wasatch detritus now stands considerably higher than the source formations include Rock Creek Ridge, where blocks of conglomerate in the Tunp Member lie on the crest of the ridge, 1,500 feet higher than present exposures several miles to the west of the Ephraim Conglomerate from which they were derived. The large exposures of Tunp diamictite that form rounded prominences on Dempsey Ridge are 800 feet or more higher than those on Rock Creek Ridge.

Deformation during the Eocene, presumably associated with block faulting, is recorded along the east side of the Tunp Range where the main body overlies the lower unnamed member of the Wasatch with angular unconformity. Some block faults of Eocene age have also been recognized farther east in the Fort Hill quadrangle (Oriel, 1969). The mudflows and rockslides believed to have formed the diamictite facies may have been triggered by earthquakes as well as by heavy rainstorms.

Broad open and gentle folds have been recognized locally in Wasatch strata. Regionally the structure of

Wasatch and Green River strata in the Fossil basin is a synclinorium to which the name Fossil syncline was applied by Veatch (1907, p. 110, pl. 4). Mapping and drilling in the Sage, Kemmerer, and adjoining quadrangles indicate that structures in Tertiary strata do not reflect deeper and tighter structures in older rocks; rather, they reflect differential compaction and draping over buried topography and, in places, primary sedimentary dips.

GREEN RIVER FORMATION

NAME AND USAGE

DEFINITION

The Green River Formation was named by Hayden (1869, p. 90–91) for the sequence

> * * * composed of thinly laminated chalky shales * * *, best displayed along Green River. They are evidently of purely fresh-water origin, and of middle tertiary age. The layers are nearly horizontal, and, as shown in the valley of Green River, present a peculiarly banded appearance * * *. One of the marked features of this group is the great amount of combustible or petroleum shales * * *.

Despite widespread usage, the name is still used mainly in the original sense for the light-colored laminated calcareous beds between the red-hued beds of the underlying Wasatch Formation and the green-hued beds of the overlying Bridger Formation.

LITHOLOGIC HETEROGENEITY

The Green River Formation in the Fossil basin is a heterogeneous sequence whose unity is principally in primary structure and somewhat in color. Its heterogeneity is best expressed by an inventory of rock compositions including: white, buff, and brown aphanitic relatively pure to clayey limestone; white indurated ostracode and gastropod coquina; algal limestone; marlstone; light- to dark-gray, green, and brown mudstone and claystone; light- to medium-gray and tan siltstone; white- and brown-weathering gray sandstone, which has claystone and chert fragments in places; oil shale and petroliferous marlstone and mudstone; silicified limestone and chert; volcanic ash and tuff.

Nevertheless, the sequence constitutes a mappable formation. The light shades of tan, yellow, white, green, and brown contrast markedly, even from a distance, with the more vivid shades of reds predominating in both the underlying and overlying units. Closer examination shows the overwhelming dominance throughout the unit of the thinly laminated structure and argillaceous strata mentioned by Hayden in his first published description (1869).

SUBDIVISIONS USED HERE

The Green River Formation of the Fossil basin is here divided into two units: a lower or Fossil Butte Member, characterized by tan to buff ledge-forming limestone, marlstone, and brown oil shale in which are the principal fish-bearing beds; and an upper or Angelo Member, characterized by white-weathering limestone that contains much nodular and slabby chert and by grayish-green claystone.

FOSSIL BUTTE MEMBER

NAME AND TYPE

The Fossil Butte Member of the Green River Formation is here named for the excellent exposures on the south side of Fossil Butte (frontispiece) and along the north and east sides of Fossil Ridge, 10 miles west of Kemmerer, where the most extensive fossil fish quarries have been worked. The beds near the southeast end of the butte, in the SW¼NW¼ sec. 5, T. 21 N., R. 117 W., have been selected as the type section of the member (see p. 43–44).

ROCKS INCLUDED

The Fossil Butte Member at the type section consists of four units, each characterized by several dominant rock types. A basal mudstone unit about 45 feet thick consists of beds of light-gray fine-grained to very fine grained calcareous sandstone, mudstone, and siltstone. Above this unit is a tannish-gray limestone unit about 75 feet thick, containing light-gray to tan limestone, shaly limestone, siltstone, and chocolate-colored paper shale capped by a 6-foot bed of dark-yellowish-brown mudstone. This is overlain by a buff shale unit 45 feet thick consisting of predominantly buff-weathering laminated limy shale beds, organic paper shale, and thinly laminated oil shale, alternating with beds of white to buff marlstone. Thin ash beds ¼ to 2 inches thick are scattered throughout. The main bed quarried for fossil fish is 10 feet below the top of this unit. The uppermost unit, 40 feet thick, is marked by the presence of several bands made up of thin beds of rich oil shale that weather a characteristic light-grayish white that seems bright blue in sunlight. This unit is capped by a ledge-forming limestone that weathers orange yellow, speckled by rusty spots. Several of the oil shale beds contain scattered to packed small crystals of calcite pseudomorphous after evaporite minerals, and these give the beds a coarse sugary texture.

Ash beds 1–5 mm thick are common, and beds as much as 20 mm thick are present in the upper half of the member. Some of these beds, near the fish beds, are characteristic enough to be traced over a fairly large part of the Fossil basin, but as yet we have not been able to correlate sequences of ash falls with those in the Fort Hill quadrangle in the Green River Basin.

A tongue of crossbedded sandstone which we assign to the Wasatch Formation separates the lower mudstone section of the member from the upper part in the south end of the Kemmerer and Sage quadrangles. The tongue reaches a maximum thickness of about 50 feet, and it pinches out to the north and east within Fossil Ridge. North and east of the limits of the sandstone tongue, the lower mudstone unit of the Fossil Butte Member contains only minor amounts of organic shales or laminated limestone beds. In the headwaters of Clear Creek, however, in sec. 33, T. 21 N., R. 118 W., about 40 feet of laminated carbonaceous shale, including oil shale, and buff laminated limestone with fish-bearing beds similar to those in the upper part of the Fossil Butte Member lie beneath a 40-foot ledge of the sandstone tongue. In the Roy Steele 1 Government well 4 miles to the south-southwest, in the NE¼NE¼NE¼ sec. 29, T. 20 N., R. 118 W., 323 feet of the Green River type of shale was reported in the interval 560–883 feet, above mudstone of the Wasatch Formation and below a 65-foot bed of sandstone that we interpret as the sandstone tongue of the Wasatch. Apparently the lower part of the Fossil Butte Member thickens to the south, along the trend of the Fossil synclinal axis of Veatch (1907), although very little of the lower part of the member is exposed south of the Kemmerer and Sage quadrangles.

Facies changes within the Fossil Butte Member are similar to those described for the Green River Formation in other basins. Organic-rich limestones and shales near the central, deeper parts of the Fossil basin grade laterally through ostracodal and gastropodal limestones to algal limestones, marking the near-shore shallow-water lacustrine deposits of the Green River Formation (Bradley, 1926, p. 125–126).

DISTRIBUTION AND THICKNESS

The Fossil Butte Member is the most extensive part of the Green River Formation in the Fossil basin. This member extends farther toward peripheries of the basin than other parts of the formation. Thin limestone units observed in the southern part of the basin probably represent tongues of the Fossil Butte Member that extend into detrital rocks shed by the ancient Uinta Mountains (Anderman, 1955; Lawrence, 1963).

The Fossil Butte Member is 267 feet thick in the valley of the South Fork of Twin Creek 3 miles south of the Kemmerer quadrangle. It is 208 feet thick on Fossil Butte (frontispiece) near the center of the Fossil basin.

Buff-weathering laminated limestone ledges extend northward and northwestward from the center of the basin and remain fairly uniform. Interbedded tan, brown, and gray claystone and mudstone, however, grade through shades of green into red mudstone and coarser detrital rocks of the Wasatch Formation. On Tunp Range, west of Dempsey Basin and several miles north of the Kemmerer and Sage quadrangles, the limestone ledges thin from 50 feet to an edge in red clay of the Tunp Member of the Wasatch; the horizon of the limestone is recognizable even beyond its edge for it is marked in the Wasatch Formation by a surface of abundant algal logs (fig. 12), as on the north side of Pink Butte in sec. 28, T. 24 N., R. 117 W., and east of Hams Fork along the northern part of the Kemmerer quadrangle.

LOWER CONTACT

The contact of the Green River Formation and the main body of the Wasatch Formation is apparently sharp and conformable in most places. Commonly, it is marked by a bench or by numerous slump blocks heading at the contact (frontispiece). The slumps result from water seeping down through the more permeable siltstone and sandstone beds of the Green River and through block fractures of the jointed shale and limestone of the Green River into the less permeable mudstone of the Wasatch.

In a few places, the contact at the base of the Green River is also gradational vertically. Within a few feet red mudstone below the Green River grades upward to very calcareous green mudstone, gray marlstone, and limestone.

The regional relation between the two units, however, is far more complex. Because the two formations are known to grade into one another in part laterally, the lower contact of the Green River Formation is not isochronous. Moreover, individual limestone beds of the Green River Formation overlap the lower unit of the Wasatch Formation, and in places, rest directly on Mesozoic and Paleozoic rocks with angular unconformity. The irregularity of this unconformable surface indicates a moderate amount of topographic relief around the edges of the Fossil basin even during deposition of the Green River Formation.

ANGELO MEMBER

NAME AND TYPE

Between the mudstone tongue and the Bullpen Member of the Wasatch Formation is a sequence of strata here named the Angelo Member of the Green River Formation for the excellent exposures high on the buttes overlooking the Angelo Ranch along the South Fork of Twin Creek, about 2.7 miles south of the Kemmerer quadrangle. Exposures in the type area are on these buttes and on spurs of Fossil Ridge, in the southeast corner of the Sage quadrangle. A section measured in the NW¼ sec. 1, T. 20 N., R. 118 W., is here designated the type section (see p. 44–45).

ROCKS INCLUDED

The Angelo Member consists mainly of white- to blue-white-weathering limestone, marlstone, and mudstone, but includes siliceous limestone, chert, light- to medium-gray marly mudstone and claystone, and some sandstone beds and lenses. In general, very light tan to buff limestone is dominant in the northern parts of the Sage and Kemmerer quadrangles, whereas the member is whiter and more siliceous southward. A few thin to moderately thick units of low-grade oil shale that weather to brown papery shale are in the central part of the Fossil basin. The moderately organic shales and limestones and the subaphanitic marly limestones within the basin grade laterally through ostracodal and gastropodal limestone to algal limestone near the periphery of the basin, as in the Fossil Butte Member.

DISTRIBUTION AND THICKNESS

The Angelo Member is well represented in the buttes and mesas of the Hams Fork Plateau in the central part of the Fossil basin, from about the north edges of the Sage and Kemmerer quadrangles southward. The southern limits of the member have not been determined. Reconnaissance traverses suggest that the member intertongues with conglomerates shed by the Uinta Mountain uplift in the south-central part of the Fossil basin as observed by Veatch (1907, p. 97).

The Angelo Member is about 200 feet thick in the central part of the basin but thins markedly and pinches out near the edges of the basin.

FOSSILS AND AGE

The Fossil Butte Member contains one of the best preserved and most extensive fossil assemblages known in North America. Fish, insects, and leaves abound, and even rays, bats, and birds are represented. Yet the precise age of the unit is not known. This reflects partly the absence of comparable forms in the standard and reference sections used to subdivide the North American continental Tertiary and partly the neglect, until very recently, of modern studies of the faunas and floras.

Fossils previously reported from strata here assigned to the Fossil Butte Member include several forms of fish (Cope, 1877, 1878, 1884; Leidy, 1873; Thorpe, 1938; Hesse, 1939), a sting ray (Schaeffer and Mangus, 1965), bats (Jepsen, 1966), snakes (Schaeffer and Mangus, 1965), birds (Wetmore, 1933), insects (Scudder, 1890; Cockerell, 1920), and plants (Lesquereux, 1883; Brown, 1929, 1934), as well as abundant fresh-water mollusks, ostracodes, and algal deposits.

Fragments of similar fossils (fish, birds, insects, plants, mollusks, and ostracodes) have been found by us in the overlying Angelo Member, but these are far less abundant and more poorly preserved than in the Fossil Butte Member.

Mollusks found by us in both members at numerous localities include *Physa pleromatis* White, *Elimia? nodulifera* (Meek), *Bellamya paludinaeformis* (Hall), *Oreoconus* n. sp. b, and *Plesielliptio?* (D. W. Taylor, written commun., Apr. 11 and 20, 1960). In addition, the fresh-water snail *Biomphalaria pseudoammonius* (Schlotheim) was found in several exposures of the Angelo Member.

Ostracodes found in both members at several localities have been identified (I. G. Sohn, written commun., Apr. 15, 1959, Feb. 12, 1964) as "*Hemicyprinotus*" *watsoensis* Swain, *Procyprois ravenridgensis* Swain, and *Pseudocypris* sp. undescribed.

Despite the abundance of well-preserved fossils, age assignments of the Green River Formation have been based on mammalian faunas from Wasatch strata that intertongue with the formation (Gazin, 1959, p. 135). The absence of diagnostic fossils from the overlying Bullpen Member of the Wasatch Formation precludes a precise age assignment for the Green River Formation in the Fossil basin. Although it commonly has been assigned a late early Eocene age (Gazin, 1959; McGrew and Roehler, 1960; Schaeffer and Mangus, 1965), the topmost strata may be younger or older than Lost Cabin.

ORIGIN

The lacustrine origin of the Green River Formation, recognized by Hayden (1869), has been amply demonstrated by the studies of Bradley (1926, 1929a, 1929b, 1930, 1931, 1948, 1959, 1963, 1964, 1966) in his notable contributions to paleolimnology.

The abundance of varves, organic matter, and oil shale and the excellent preservation of abundant fish in exposures near the central part of the Fossil basin indicate that the lake in which the strata accumulated, named Fossil lake by Jepsen (1966, p. 1338), was thermally stratified and possibly deeper than 100 feet (Bradley, 1930, p. 101–103; 1963, p. 636). The abundance of algal, gastropodal, and ostracodal limestones, indices to shallow-water shore phases of the lake (Bradley, 1926), indicates that the shores of Fossil lake were along the present margins of the Fossil basin, although the lake may have been connected briefly with the Eocene Gosiute lake in the Green River Basin (fig. 16). Eocene talus deposits of older rocks cemented by Green River limestone preserve the ancient lake shore at several lo-

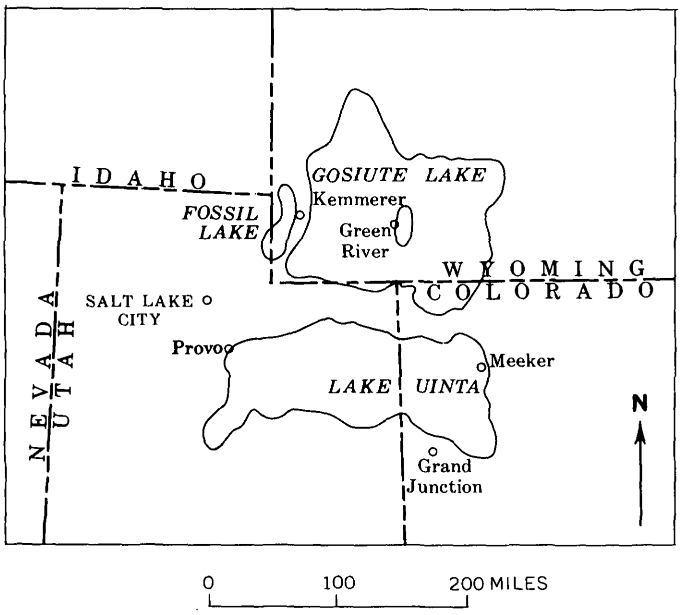


FIGURE 16.—Locations of the Eocene lakes (showing maximum extent of each) in which the Green River Formation was deposited. (Modified from Schaeffer and Mangus, 1965.)

calities. Fluctuations in the lake size are recorded in intertongues of Green River beds with Wasatch strata around the margin of the basin. The Wasatch tongues indicate (a) drops in lake level, (b) mudflows and rockslides into the lake, and (c) several "floods" of detritus that may have been deposited within the lake as deltas and bottom sediments.

Although Green River strata are now more than 1 mile above sea level, they were likely deposited at elevations of 1,000 feet or less (Bradley, 1930, p. 93–95; 1963, p. 633). The climate was humid subtropical to tropical (Bradley, 1966) and had a mean annual temperature of about 65°F and a rainfall of about 40 inches (Bradley, 1930, p. 93–95; 1963, p. 633). The paucity of evaporites (Fahey, 1962) indicates that Fossil lake did not undergo as great a saline cycle as did nearby lakes Uinta and Gosiute; whether this reflects continuous replenishment of the smaller lake by abundant streamflow or the ending of lacustrine deposition in the Fossil basin before the onset of a somewhat drier climate is not known.

TECTONIC IMPLICATIONS

The moderate depths at which the varied organic-rich fish-bearing strata near the middle of the Fossil basin must have been deposited indicate a continued downwarp of this part of the earth's crust. Fossil basin, formed by latest Cretaceous time, continued to sink through the middle and late early Eocene.

Gentle folds and moderately steeply dipping strata along the flanks of the basin do not necessarily indicate postdepositional compressional deformation. Observed structures probably reflect, as in the Wasatch, differential compaction, draping over buried topography and, in places, primary dips. The overlap of underlying strata by Green River beds, which in places rest directly on older rocks, as well as other observed relations along the periphery of the basin, indicates that the area continued to be one of moderate relief.

FOWKES FORMATION

NAME AND USAGE

DEFINITION

The Fowkes Formation was named and defined by Veatch (1907, p. 90) as

a thick series of light-colored beds composed largely of rhyolitic ash and containing thin layers of white limestone. These beds are well exposed [2 miles east of Almy] in the valley east of the Almy Hills and thence northward to the Narrows [of the Bear River]. This formation is named for the Fowkes ranch, about 9 miles [north] from Evanston, around which these beds are well exposed.

Veatch (1907, p. 88) defined the Fowkes Formation as the middle formation of the Wasatch Group. He believed it was underlain by the dominantly reddish yellow beds of the Almy Formation and overlain by the dominantly reddish yellow beds of the Knight Formation, all of the Wasatch Group.

SUBSEQUENT USAGE

Since Veatch's definition of the Fowkes, the unit has been a source of perplexity, if not confusion, to geologists working in the region. Almost nowhere has such a unit been found to subdivide the Wasatch Formation (or Group). For this reason and possibly because of the limited areal extent of the unit, the name has not been used except in brief reviews of Veatch's report. An exception was the erroneous use of the name for another unit in the northern Wasatch Range (Eardley, 1944).

SUGGESTED USAGE

Because of the structural complexity of the Almy area along the east side of the Bear River, Veatch failed, in his reconnaissance study, to recognize all the faults in the vicinity of his type locality. He therefore emerged with an erroneous interpretation of the stratigraphic sequence.

Detailed study of Fowkes exposures farther north and reconnaissance studies in the type locality have established beyond question that rocks assigned by Veatch to the Fowkes Formation overlie, and are therefore younger than, rocks assigned by him to both the Almy and the Knight, as well as to the Green River. The

Fowkes Formation is, in fact, the youngest formation of unquestioned Tertiary age (Tracey and Oriel, 1959, p. 130) mapped by us in the region.

The name Fowkes is retained, despite Veatch's erroneous interpretation of the position of the formation in the section, because the rocks assigned to the formation constitute a rock-stratigraphic unit easily distinguished from others on the basis of lithologic characteristics.

SUBDIVISIONS USED HERE

The Fowkes Formation is here divided into three new members: the Sillem Member at the base, consisting of pale-gray and pinkish-gray mudstone and gray conglomerate; the Bulldog Hollow Member in the middle, consisting of green tuffaceous mudstone and sandstone; and the Gooseberry Member at the top, consisting of light-gray to white calcareous and tuffaceous puddingstone.

SILLEM MEMBER

NAME AND TYPE

Directly above the Bullpen Member of the Wasatch Formation is a distinctive rock unit that was not mapped consistently by Veatch (1907, pl. 3) in the few places in which it is exposed. Some exposures were assigned to the Fowkes Formation, others to the Almy, and still others to Quaternary units. The composition of the rocks differs from that of the typical Fowkes. However, because we have studied the unit only locally, because the upper part of the unit grades upward into typical Fowkes strata, and because Veatch included the unit, in at least a few places, in his Fowkes Formation (as in the NE¼ sec. 8, T. 17 N., R. 120 W.), it is assigned here to the Fowkes Formation.

The unit is here named the Sillem Member of the Fowkes for the best exposures seen on Sillem Ridge and in the badlands 1–2 miles north-northeast of Sage, here designated the type area. The type section was measured north of Sage, from about the center of sec. 5, T. 21 N., R. 119 W., to about the center of sec. 33, T. 22 N., R. 119 W. (see p. 46).

ROCKS INCLUDED

The Sillem Member consists of a basal conglomeratic unit and an upper pale mudstone unit. The conglomerate is absent from some sections examined by us, and in a few others its lithologic distinctiveness is equivocal. The most extensive, though rather poor, exposures of the unit are along butte and ridge tops, as on the crest of Sillem Ridge, where the concentration of pebbles probably is exaggerated by the ablation of finer particles.

The basal conglomeratic unit includes conglomerate, sandstone, mudstone, and claystone. The conglomerate consists dominantly of very well rounded pebbles and boulders, some of which exceed 1 foot in diameter although most are less than 8 inches. The composition of the pebbles is distinctive and differs from that of the conglomerates in underlying and overlying formations. In the Sillem, they are largely medium- to dark-gray, in part black-flecked conglomeratic quartzite, dark-colored chert, and dark-colored Paleozoic limestone, at least some of which was derived from the Madison Limestone. The source of the conglomeratic quartzite may be the Brigham Quartzite in southeastern Idaho. Sandstone in the unit ranges from crossbedded coarse- to medium-grained very calcareous light-gray "salt-and-pepper" (dark-gray and black chert is the "pepper") beds to very poorly indurated muddy pale-tan, pink, and light-gray beds that may contain some volcanic ash. The mudstone and claystone is also pale pink, tan, and gray.

The upper unit of the Sillem Member consists dominantly of mudstone and claystone that grade from very pale pink, yellow, and gray in the lower part through predominantly pale gray in the middle to pale green and gray in the upper part. Green and purple mottling and thin bands are common, as are reworked chips of volcanic ash. The upper part of the unit includes some coarser volcanic debris comparable to that in the overlying unit, such as scattered biotite flakes, magnetite, amphibole laths, glass, and secondary silica in the form of opal. Interbedded with the mudstone and claystone are thin beds of marlstone, ostracodal and algal limestone, and pale-gray to greenish-gray and brown sandstone, containing lentils of chert conglomerate locally. Beds of poorly indurated pale-pinkish-tan sandstone with angular pebbles and chips of white to very light gray ash are abundant. The lower part of the middle unit also includes scattered lentils, at different stratigraphic horizons, of conglomerate comparable in pebble composition to the basal conglomeratic unit.

DISTRIBUTION AND THICKNESS

The Sillem Member is 100–400 feet thick in the Sage quadrangle. Remnants of the member have been observed, but not measured, at many other localities. The unit is exposed along the east side of Boulder Ridge in a south-southeastward-trending belt and on Sillem Ridge. The member is also present west of the Bear River, along the east side of the Bear Lake Plateau, and it has been recognized near the mouth of Acock Canyon, about 14 miles north of Evanston. The exposure at Acock Canyon is only a few hundred feet thick.

LOWER CONTACT

The basal contact of the Fowkes Formation is not well exposed in most of the formation's area of distribution. It is moderately well exposed at four localities where the position of the Fowkes Formation on beds within the Bullpen Member of the Wasatch Formation can be demonstrated. These localities include the northeastern part of sec. 5, T. 21 N., R. 119 W.; the central part of sec. 22, T. 21 N., R. 119 W.; sec. 19, T. 21 N., R. 119 W.; and the northeastern part of sec. 8, T. 17 N., R. 120 W.

At all these localities, the basal beds of the Fowkes Formation seem to rest conformably on Bullpen strata. The contact, however, may be a disconformity and the stratigraphic range of beds directly beneath the contact may be considerable for the region.

The contact between the Fowkes and Almy Formations as mapped by Veatch (1907, pl. 3) was examined by us in several reconnaissance traverses along the belt on the east side of the type Almy exposures. Because Veatch's implied conformable stratigraphic contact truncates individual beds on both sides of it, we tentatively interpret the contact as a fault.

BULLDOG HOLLOW MEMBER

NAME AND TYPE

The middle part of the Fowkes Formation, here named the Bulldog Hollow Member for extensive exposures along Bulldog Hollow, includes most of the rocks assigned to the Fowkes by Veatch (1907, pl. 3) and most exposures in the formation's type locality. It is the most extensively exposed and probably thickest part of the formation.

The section here designated (with some misgivings) as the type section for the Bulldog Hollow Member is that measured in the western part of sec. 33, T. 22 N., R. 119 W. (see p. 46). The member is thinner and more poorly formed and exposed in this section than at many other localities along Bulldog Hollow, south of Sage, and along the east side of the Crawford Mountains; however, the member has both a base and a top in the selected unfaulted section, whereas structural relations have not been determined farther south.

ROCKS INCLUDED

The member is dominantly pale- to dark-green, blue-green, and white tuffaceous and ashy mudstone and green to buff and brown tuffaceous calcareous sandstone. These rocks contain amphibole laths, biotite plates with well-preserved crystal faces, minute feldspar crystals, quartz, and glass. Both tuff and ash are of rhyolitic composition. Disaggregation of the poorly to moderately indurated sandstone facilitates the testing of the grains with a magnet. All samples examined in this unit contain at least some magnetite; a few contain 5, possibly as much as 10, percent, in sharp contrast to all underlying formations which contain virtually no magnetite. In addition, the matrix of some sandstone beds weathers to a distinctive blue efflorescence; the composition of the matrix was not determined. In a few places, tuffaceous sandstone contains an opaline cement. The Bulldog Hollow Member also contains some lenses of light-gray calcareous conglomerate similar to that in the overlying Gooseberry Member.

DISTRIBUTION AND THICKNESS

The Bulldog Hollow Member is more extensively exposed than the other two members of the Fowkes Formation. It has been mapped in a south-southwestward-trending belt from the west-central part of the Sage quadrangle to its southern edge. It has also been recognized in discontinuous belts along the east side of the Bear River almost as far south as Evanston. Almost all the exposures mapped as Fowkes by Veatch (1907, pl. 3) are assigned to the Bulldog Hollow Member; the exposures on the west side of the Bear River, west of the old Almy settlement, however, are here assigned to the Green River Formation.

The member is only 200 feet thick north of Sage but thickens greatly southward. It may be as much as several thousand feet thick (Veatch, 1907, table opposite p. 50) south of the Sage quadrangle.

LOWER CONTACT

The base of the Bulldog Hollow Member is apparently gradational downward into the underlying Sillem Member. The proportions of volcanic tuff and ash in sandstone and mudstone decrease downward, and the greens and whites of the Bulldog Hollow Member grade to pale gray and very pale greenish gray. The base of the Bulldog Hollow Member is placed at the base of the lowest moderately tuffaceous sandstone that contains observable biotite, amphibole, and magnetite grains.

GOOSEBERRY MEMBER

NAME AND TYPE

The uppermost part of strata provisionally included in the Fowkes Formation is a puddingstone[4] here named the Gooseberry Member for exposures near Gooseberry Springs in the west-central part of the Sage

[4] The term "puddingstone" is used here for conglomerate that differs from all others in the Fossil basin sequence. The rock consists of very well rounded and spherical pebbles and cobbles so sparsely packed in a matrix of white ashy marl that very few are in contact with one another. Pebbles and cobbles in all the other conglomerates, in contrast, are tightly packed and have numerous points of contact. Diamictite differs from puddingstone in the extreme angularity and lack of size sorting of coarse clasts.

quadrangle. The unit is tentatively retained in the Fowkes Formation because the underlying Bulldog Hollow Member contains lenses of somewhat similar conglomerate. However, it is possible that the Gooseberry puddingstone is an easternmost remnant of the Salt Lake Formation.

The type area of the Gooseberry is the conglomerate ledge exposures about 2 miles northeast of Sage. The section here designated the type section is that measured in the N½ sec. 33, T. 22 N., R. 119 W. (see p. 45), although the section is incomplete.

ROCKS INCLUDED

The Gooseberry Member consists of light-gray to white puddingstone, calcareous rhyolitic ash, and tuff and ash bearing very finely crystalline to subaphanitic limestone.

The puddingstone consists of sparsely to moderately tightly packed cobbles and pebbles in a matrix of white to pale-buff silty and tuffaceous highly calcareous sandstone, marlstone, and sandy limestone. Most clasts are 6 inches or less in diameter, but a few are as much as 1 foot. Packing of the well-rounded to subangular coarse clasts in most beds is so poor that few cobbles are in contact with others; most beds, therefore, are puddingstone. The cobbles and pebbles are mainly of quartzite, chert, and limestone from Paleozoic formations but are also volcanic rocks of unknown derivation that range in composition from rhyolite to vesicular basalt. The presence of volcanic pebbles, the poor packing, and the white to light-buff calcareous matrix distinguish this conglomerate from those in all other stratigraphic units.

DISTRIBUTION AND THICKNESS

The extent of the Gooseberry Member as mapped by Rubey, Tracey, and Oriel (1968) is confined to the area northeast of Sage that was mapped as the Almy Formation by Veatch (1907, pl. 3). Rocks of similar composition, however, have been observed at many localities to the west on the Bear Lake Plateau (fig. 1). Somewhat similar rocks have been noted southward at some localities mapped as Fowkes by Veatch (1907, pl. 3), but whether they are exposures of the Gooseberry or simply conglomerate lenses in the Bulldog Hollow Member has not been ascertained.

The member, though incompletely represented (it has no stratigraphic top), is about 200 feet thick in the Sage quadrangle.

LOWER CONTACT

The nature of the base of the Gooseberry Member has not been ascertained. Where examined locally, the upper part of the underlying Bulldog Hollow Member apparently grades into the Gooseberry. Moreover, the presence in the Bulldog Hollow Member of Gooseberry-like conglomerate lentils also suggests a gradational contact. However, a moderately great range in thicknesses of the Bulldog Hollow Member suggests that the base of the Gooseberry may be an angular unconformity. Regional dips of the members of the Fowkes Formation (the Bulldog Hollow Member south of Sage, dips mainly south, whereas the Gooseberry exposures north of Sage dip gently northward) also make an angular unconformity likely.

FOSSILS AND AGE

The Fowkes Formation in the Fossil basin is of Eocene and possible early Oligocene age. The uppermost part, however, may be as young as Pliocene.

Only ostracodes and gastropods have been found in the Sillem Member. Ostracodes were collected in the NE¼NW¼NE¼ sec. 5, T. 21 N., R. 119 W. (Tertiary loc. 21741), and in the NW¼ sec. 4, T. 21 N., R. 119 W. (Tertiary loc. 21704), and were identified as "*Hemicyprinotus*" *watsoensis* Swain, *Procyprois ravenridgensis* Swain, and *Pseudocypris*? sp. undescribed (I. G. Sohn, written commun., Apr. 15, 1959, Feb. 12, 1964); these fossils indicate only an Eocene age. The gastropods, though too poorly preserved to be useful for age determinations, included three forms of fresh-water snails and were collected from USGS Cenozoic localities 22621 and 22622 in sec. 12, T. 24 N., R. 120 W.; the first is 650 feet west and 550 feet south of the northeast corner of the section, and the second is 2,000 feet west and 1,000 feet south of the northeast corner.

On the basis of fossils and stratigraphic position, the age of the Sillem Member is more probably middle than late Eocene.

Both gastropods and leaves have been collected from the Bulldog Hollow Member. The gastropods have been identified as *Biomphalaria pseudoammonius* (Schlotheim) and *Oreoconus planispira* Taylor (McKenna) and have been assigned a late middle to late Eocene age (D. W. Taylor, written commun., May 29, 1957; McKenna and others, 1962). The collections were made at the following localities:

USGS Cenozoic loc.	20082, 300 ft E., 1,900–2,400 ft N. of SW cor. sec. 20, T. 21 N., R. 119 W.
	20083, 250 ft W., 600 ft N. of SE cor. sec. 19, T. 21 N., R. 119 W.
	20084, NW¼ sec. 16, T. 20 N., R. 119 W.
	20146, north side, Fowkes Canyon, sec. 33, T. 17 N., R. 120 W.
	22198, NE¼NE¼NE¼ sec. 29, T. 16 N., R. 120 W.

The leaves were collected near the top of the Bulldog Hollow Member in sec. 4, T. 21 N., R. 119 W., and were identified as *Equisetum* sp. and *Lygodium kaulfussi* Heer, to which an Eocene age is assigned (R. W. Brown, written commun., Sept. 23, 1958). The age of the member, therefore, is middle or late Eocene.

The radiogenic age of the hornblende in a sample of the Bulldog Hollow Member has been determined, by means of the potassium-argon method, by Richard Lee Armstrong (written commun., Mar. 5, 1967) of the Kline Geology Laboratory at Yale University. The sample was collected in the SE¼NE¼SE¼ sec. 19, T. 21 N., R. 119 W. The following data were furnished by Armstrong:

Percent
K: 0.72, 0.72
Ar: 1.39×10^{-6} cc radiogenic Ar^{40}
70 percent air Ar in analyzed sample
Constants used: $K\lambda\beta = 4.72 \times 10^{-10} yr^{-1}$
$K\lambda e = 0.584 \times 10^{-10} yr$
$K^{40}/K = 0.0119$ atm (atmosphere) percent

Date: 47.7 m.y. (million years) ±1.5 m.y., or middle Eocene (Evernden and others, 1964, p. 165, 189)

The result probably should be considered a maximum possible age because of possible contamination by older material, although such contamination seems unlikely in this sample.

Although the Bulldog Hollow Member may be as young as late Eocene, it probably is of middle Eocene age.

Fossils have not been found in the Gooseberry Member within the Sage quadrangle. Reconnaissance west of the quadrangle in the Bear Lake Plateau, however, resulted in a collection of some fossil bones west of Pegram Creek in the NE¼NE¼ sec. 29, T. 15 S., R. 45 E., in Idaho, from puddingstone similar to that in the Gooseberry, despite the previous assignment of these rocks to the Wasatch Formation (Mansfield, 1927, pl. 9). The bone fragments included Leporidae teeth identified (Mary Dawson, written commun., Mar. 31, 1967) as probable *Hypolagus* of possibly late Miocene or early Pliocene age. This fossil from strata that can be assigned only with uncertainty to the Gooseberry and the inferred angular unconformity at the base of the member in the Sage quadrangle suggest that the Gooseberry may be considerably younger than the Sillem and Bulldog Hollow Members of the Fowkes Formation. Perhaps Gooseberry strata should be assigned to the Salt Lake rather than to the Fowkes Formation or established as a new formation. Tentative assignment here of the Gooseberry Member to the Fowkes Formation is based on the close association areally of the Gooseberry with other members of the Fowkes and on the similarities in composition of the conglomerates in both the Bulldog Hollow and the Gooseberry Members.

The apparent disparity in ages for members of the Fowkes, suggested by the tenuous available data, closely parallels that determined for the Salt Lake Formation in its type locality in northern Utah. A lower tuff unit there, which closely resembles the Bulldog Hollow Member in composition (Eardley, 1959, p. 167), is also considerably older than other Salt Lake strata. This tuff unit, named the Norwood Tuff and assigned an early Oligocene age by Eardley (1944), contains vertebrates which, when reexamined, were assigned (C. L. Gazin, written commun., Nov. 9, 1959) a late Eocene age. The overlying Salt Lake strata, in contrast, are assigned a Pliocene and possibly a late Miocene age. Geologists working in the region have found the contact between the two formations extremely difficult to map because of similarity in composition.

ORIGIN

The Fowkes Formation probably was deposited mainly as alluvium but also in small lakes and ponds during a time of increasing volcanic activity in the region. Heterogeneity of detrital fragments, moderately good size sorting and rounding of coarse clasts, and sedimentary structural features suggest that the bulk of the material was deposited in fresh water. The poorly sorted puddingstone in the Gooseberry Member may have been deposited as a mudflow. Some interbedded ash layers in the formation may have been deposited subaerially. The source and direction of transport of the great volume of volcanic debris are not known.

TECTONIC IMPLICATIONS

The Fowkes Formation is limited in distribution to a belt along the western part of the Fossil basin (Veatch, 1907, pl. 3). Although deposition of the unit may possibly have been confined to a downwarp or trough formed within the Fossil basin in middle or late Eocene time, the evidence suggests otherwise. Faults that cut underlying Tertiary strata also cut the Fowkes Formation, and gentle folds of both are concordant. The present distribution, therefore, seems to reflect post-depositional normal faulting that dropped Fowkes strata, thereby preserving them. Strata that formerly were more extensive and that remained elevated were no doubt removed by erosion. This erosion probably also accounts for extensive lag concentrates of pebbles and cobbles that were assigned a Quaternary age by Veatch (1907, pl. 3), both north and south of Sage.

The relations of the units assigned here to the Fowkes to those mapped farther west, such as Norwood Tuff and

Salt Lake Formation, are too imperfectly known to permit detailed tectonic reconstructions. In general, however, deposition of these units seems to have reflected basin-and-range faulting, particularly farther west, and extensive volcanism.

The composition of the Sillem Member in exposures both west and east of Boulder Ridge suggests that the mountain of Paleozoic and Cretaceous formations (p. 28) that supplied detritus for the Tunp Member of the Wasatch was downfaulted by middle to late Eocene time.

SOME REGIONAL RELATIONS

The precise relations of the Fossil basin rock units to comparable units in adjoining areas remain somewhat enigmatic. Most of the units cannot be traced continuously from this basin to others. Although almost all the units seem to have lithologic counterparts in the stratigraphic sequences of nearby areas (table 3), current age assignments deny or make questionable precise temporal equivalence. The age assignments, however, are not unequivocal, for they are based in large part on different fossil forms in the different areas.

TABLE 3.—*Dominant rock types and sequences of Upper Cretaceous and Tertiary stratigraphic units in the Fossil basin and adjoining areas*

[Most of the units are not temporal equivalents]

Dominant rock types	Northeastern Utah, Echo Canyon area	Fossil basin, northern part	Green River Basin, Fort Hill area
Light-gray and buff tuffaceous conglomerate.	Salt Lake Formation.	Gooseberry Member of Fowkes Formation.	
White to green tuffaceous and ashy sandstone, mudstone.	Norwood Tuff of Eardley (1944).	Bulldog Hollow and Sillem Members of Fowkes Formation.	Bridger Formation.
	Unconformity		
Red and salmon mudstone and gray and brown sandstone, thin buff limestone.		Bullpen Member of Wasatch Formation.	
Laminated marlstone and limestone, algal limestone.		Angelo Member of Green River Formation.	Upper tongue of Green River Formation.
Gray-green and pink mudstone.		Mudstone tongue of Wasatch Formation.	Upper tongue of Wasatch Formation.
Laminated organic marlstone, limestone, oil shale, ash.		Fossil Butte Member of Green River Formation (upper part).	Middle tongue of Green River Formation.
Brown sandstone and green mudstone.		Sandstone tongue of Wasatch Formation.	New Fork Tongue of Wasatch Formation.
Light-gray and buff laminated limestone and marlstone.		Fossil Butte Member of Green River Formation (lower part).	Fontenelle Tongue of Green River Formation.
Red, purple, and tan, banded and variegated mudstone.	Wasatch Formation.	Main body of Wasatch Formation.	La Barge Member of Wasatch Formation.
	Angular unconformity		
Boulder conglomerate and gray sandstone and mudstone.	Evanston(?) Formation.	Evanston Formation.	Chappo Member of Wasatch Formation. Hoback(?) Formation.
Red conglomerate and sandstone.	Echo Canyon Conglomerate of Williams and Madsen (1959).		Basal part, Chappo Member of Wasatch Formation.
	Angular unconformity		
Tan sandstone, gray mudstone, some coal.	Wanship Formation of Eardley (1952).	Adaville Formation.	Adaville(?) Formation.
Dark-gray marine mudstone.		Hilliard Shale.	Hilliard Shale.
Gray sandstone and mudstone and coal.	Frontier Formation.	Frontier Formation.	Frontier Formation.

In general, the Fossil basin units seem to be intermediate in age between somewhat older comparable units to the southwest, in northeastern Utah, and younger units to the east, in the western Green River Basin (table 4). There being a progressively younger age, from west to east, for analogous rock units in the region both is predicted by and supports the conclusion that orogeny and thrust faulting in the cordilleran region progressed from west to east (Oriel and Armstrong, 1966, p. 2619). The generalization, however, is by no means true for all the units.

LOWER STRATA OF THE WASATCH

Progressively younger ages from west to east are perhaps best illustrated by strata that have been assigned to the Wasatch Formation beneath the Green River Formation.

The main body of the Wasatch Formation is well dated in the Fossil basin. The base of the main body is no older than earliest Eocene (Gray Bull) and the top no younger than middle early Eocene (Lysite). Comparable rocks in the Green River Basin, where they are assigned to the La Barge Member of the Wasatch (Oriel, 1962, p. 2168–2170), are younger. Although most of the La Barge Member is late early Eocene (Lost Cabin age), the basal part may be as old as middle early Eocene (Lysite).

West of the Fossil basin, strata formerly assigned to the Wasatch Formation in part of its extended type locality at Echo Canyon, Utah (Hayden, 1869, p. 91), are now subdivided into several units in northeastern Utah (Mullens and Laraway, 1964; Williams and Madsen, 1959). A basal unit of red conglomerate, sandstone, and shaly sandstone underlies with angular unconformity other strata previously assigned to the Wasatch. The red strata beneath the unconformity are now assigned to the Echo Canyon Conglomerate; they contain Cretaceous fossils of late(?) Niobrara age near the base (Williams and Madsen, 1959, p. 123). The Echo Canyon Conglomerate is overlain by brown conglomeratic sandstone and gray sandy siltstone assigned to the Evanston(?) Formation (Mullens and Laraway, 1964). These beds are overlain by other mainly brownish red beds still assigned to the Wasatch Formation and to the Eocene. Thus, the deposition of the Wasatch-like strata began earlier (in the Late Cretaceous) in the Echo Canyon area than it did in the Fossil basin area and seems to have continued until well into the Eocene.

RELATIONS OF LOWER UNITS

The Evanston Formation, too, has lithologic counterparts both to the east and to the west. Evanston strata in the Fossil basin are of latest Cretaceous to late, but not latest, Paleocene (Tiffany) age. Similar strata assigned to the Evanston(?) Formation in the Echo Canyon area in Utah (Mullens and Laraway, 1964) are probably also of very late Cretaceous age, according to pollen identified by E. B. Leopold (written commun. to T. E. Mullens, Mar. 27, 1963).

Drab-colored, mainly gray to pale-green-gray, strata are also extensive to the east, in the Green River Basin. Extensive exposures in the Hoback area were initially assigned to the Evanston Formation (Schultz, 1914, p. 69, pl. 1) but are now included in the Hoback Formation (Eardley and others, 1944; Dorr, 1952, p. 64–71). Similar strata have been drilled farther south, in the La Barge area and southward, where they are assigned to the Hoback(?) and are believed to intertongue with the Chappo Member of the Wasatch Formation, which underlies the La Barge Member with angular unconformity (Oriel, 1969). The drab-colored Hoback strata in the Green River Basin are, in general, somewhat younger than the Evanston in the Fossil basin. The Hoback is assigned a middle to late Paleocene and very early Eocene age (Dorr, 1952, p. 68; 1958, p. 1229–1232). The Chappo Member of the Wasatch, with which the Hoback intertongues, is assigned a latest Paleocene (Clarkforkian) [5] and earliest Eocene (Gray Bull) age (Oriel, 1962, p. 2168).

RELATIONS OF TONGUES OF THE WASATCH AND GREEN RIVER FORMATIONS

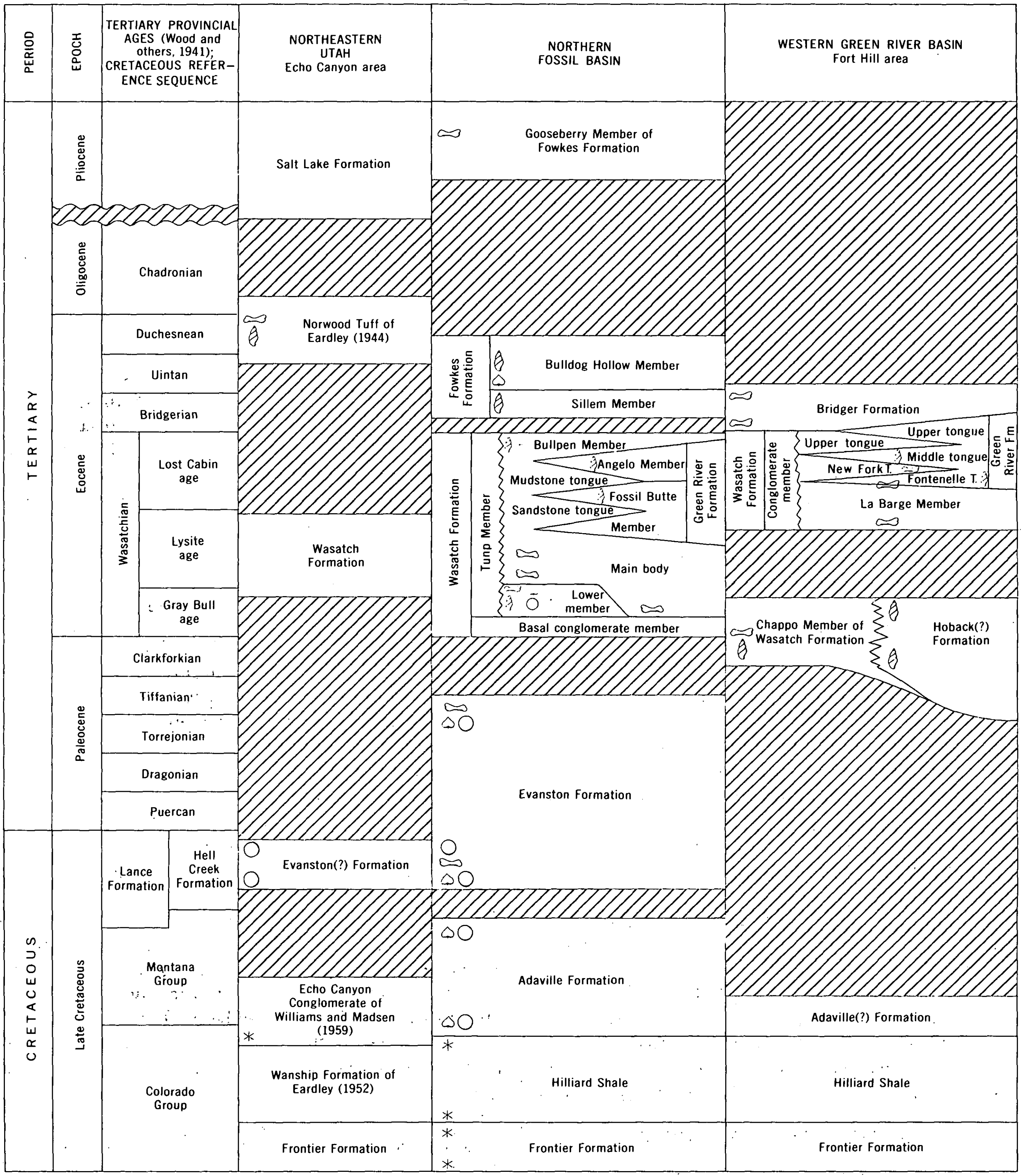
Subdivision of the Green River Formation by two Wasatch tongues in the Fossil basin, as in the western part of the Green River Basin, raises the question of possible contemporaneity: Although the tongues resemble each other in stratigraphic position and lithology, available fossil evidence indicates that the Fossil basin tongues probably are older.

The sandstone tongue of the Wasatch in the Fossil basin is similar in both composition and apparent stratigraphic position to the New Fork Tongue of the Wasatch in the Green River Basin (table 3; Oriel, 1961). Moreover, the Wasatch mudstone tongue in the Fossil basin somewhat resembles the upper tongue in the Green River Basin. The analogous Green River Formation units, therefore, are the lower and upper parts of the Fossil Butte Member and the Angelo Member in the Fossil basin and the Fontenelle, middle, and upper tongues, respectively, in the Green River Basin (table 3).

[5] Although the validity of the Clarkforkian as the latest Paleocene provincial age has been questioned (Wood, 1967; D. W. Taylor, written commun., 1967), a generally accepted revision of the classification of the North American continental Tertiary is not available. Even if rocks previously dated as Clarkforkian prove to be of Gray Bull age, the fact that the Chappo and parts of the Hoback are younger than the upper part of the Evanston is not invalidated.

TABLE 4.—*Approximate ages of the stratigraphic units in the Fossil basin and adjoining areas*

Paleontologic dates are indicated by: , vertebrates; , mollusks; , leaves; ○, pollen; *, other forms



Note: T., Tongue

The Fossil basin and Green River Basin are separated by the moderately continuous Oyster Ridge barrier. At one locality, however, in the west-central part of T. 15 N., R. 118 W., Wasatch strata can apparently be traced from one of the basins into the other (Veatch, 1907, pl. 3). We have noticed a few thin Green River limestones in this area. It seems likely that detailed mapping of these limestones northward along both sides of the Oyster Ridge barrier will determine their positions within the established stratigraphic sequences in the two basins.

In the Green River Basin, the various tongues are moderately well dated. The Fontenelle Tongue is of latest early Eocene age, for the underlying La Barge Member and overlying New Fork Tongue of the Wasatch both contain mammals of Lost Cabin age (Gazin, 1952, 1962). Upper strata of the Green River intertongue with the Bridger Formation of middle Eocene age (Bradley, 1964).

In the Fossil basin, the tongues are not as well dated. The presence of Lysite age mammals in Wasatch strata just a few feet below Green River strata suggests that the basal part of the Fossil Butte Member may be of Lysite or middle early Eocene age. Although available fossil control does not require it, the topmost Green River strata have been regarded as probably older than middle Eocene (Gazin, 1959, fig. 1; Schaeffer and Mangus, 1965, p. 12–13). This interpretation is supported by the presence of Wasatch strata above the highest Green River beds, although these Wasatch beds are not dated more precisely than as latest early or middle Eocene.

Current interpretations, therefore, though better supported by the dating of units below the Green River than by the dating of those above, suggest that the Green River tongues in the Fossil basin are somewhat older than those in the Green River Basin.

FOWKES-NORWOOD-BRIDGER RELATIONS

The abundance of tuff and ash in strata above the Wasatch and Green River Formations in northeastern Utah and in the Fossil basin and Green River Basin suggests that the tuff and the ash reflect the same period of volcanic activity in the region. Yet the available bases for dating the several units are both intriguing and perplexing. Although the Fowkes Formation, the Norwood Tuff, and the Bridger Formation may prove to be of the same age, the likelihood now is that they are not. The relations of these units are among the least understood.

The Bulldog Hollow Member and underlying Sillem Member of the Fowkes in the Fossil basin resemble strata assigned to the Norwood Tuff in Utah. Mollusks from the Bulldog Hollow Member indicate a middle or late Eocene age; leaves, an Eocene age; hornblende, an age of 47.7±1.5 m.y. (middle Eocene), from a potassium-argon determination.

The similar Norwood Tuff contains vertebrates of late Eocene age (Gazin, 1959, p. 137), gastropods of late early to middle Eocene age (D. W. Taylor, written commun., to T. E. Mullens, Jan. 16, 1963), biotite of 37.5 m.y. at the type locality (Evernden and others, 1964, p. 161, 183), and biotite of 68±8 m.y. and 74±8 m.y. at the south end of Cache Valley (Williams, 1964, p. 271; Heylmun, 1965, p. 13).

The Bridger Formation in the Green River Basin differs in appearance and composition from the dominantly rhyolitic Bulldog Hollow Member of the Fowkes. It is considerably darker in color, ranging from neutral-gray to dark-green and chocolate-brown tuffaceous mudstone and gray to brownish-gray tuffaceous mudstone. Moreover, it consists dominantly of andesite tuff, although it also includes rhyolite (Bradley, 1964, p. A49). Abundant fossil mammals establish the age of most of Bridger as middle Eocene, although the upper part may be younger (Bradley, 1964, p. A48). Biotites have not been dated from the Bridger Formation, but some from approximately correlative beds elsewhere in Wyoming are 45.4–49.0 m.y. old (Evernden and others, 1964, p. 165).

Thus, our earlier belief that the Bulldog Hollow Member of the Fowkes is equivalent to the Norwood Tuff and is younger than the Bridger Formation is not well supported. Conflicts among the data remain to be resolved.

The probably younger age of the Gooseberry Member of the Fowkes Formation and the possible equivalence of the Gooseberry to many strata assigned to the Salt Lake Formation are discussed on a previous page. The range in ages of strata that have been assigned to the Salt Lake Formation and other stratigraphic problems are discussed by Heylmun (1965).

TYPE SECTIONS FOR MEMBERS DEFINED IN THIS REPORT

Evanston Formation at type section for Hams Fork Conglomerate Member

[Measured near middle of eastern part of sec. 36, T. 21 N., R. 117 W., 1½ miles northwest of Elko]

	Ft	in
Wasatch Formation (partial):		
Main body:		
Mudstone, sandy and silty; mottled red, green, light gray, and yellow; partly covered at top of hill by blocks of Green River limestone float	62	
Sandstone, medium-grained, light-gray; calcareous with salt-and-pepper texture; forms dark-brown crossbedded ledge	14	

Evanston Formation at type section for Hams Fork Conglomerate Member—Continued

	Ft	in
Wasatch Formation (partial)—Continued		
Main body—Continued		
Sandstone, medium- to fine-grained, clayey, yellow; forms yellow slope	16	
Angular unconformity.		
Partial thickness, Wasatch Formation	92	
Evanston Formation:		
Main body:		
Claystone, slightly to moderately silty, light-gray to pale-pinkish-gray; yellow stains along fractures	15	
Sandstone, fine- to medium-grained, very calcareous, dark-brown to very dark gray; forms ledge	1	6
Claystone, light-gray	9	
Claystone, slightly silty, dark-gray	5	
Claystone, silty, light-gray	3	
Siltstone, light-pinkish-gray	20	
Sandy siltstone and silty very fine grained to fine-grained sandstone; light gray with random yellow streaks	3	
Sandstone, clayey, fine-grained to very fine grained, yellow; interbedded with mottled light-gray, pinkish-gray, and yellow siltstone	6	
Claystone, medium- to dark-gray and partly silty; grading downward to light-gray siltstone	10	
Sandstone, fine- to medium-grained, light-gray salt-and-pepper; very thinly cross laminated with abundant carbonaceous streaks in some cross laminae	3	6
Siltstone, light-gray to pinkish-gray; yellow to orange mottling and bright-orange laminae of clayey siltstone	15	
Claystone and silty and clayey siltstone, light-gray	10	
Sandstone, mainly fine to very fine grained; contains some medium sand grains and silt; noncalcareous, carbonaceous; fossil leaves, limonite concretions, and yellow staining	2	6
Claystone, medium-gray; grades downward to light-gray siltstone	18	
Sandstone, fine-grained, silty, noncalcareous, light-gray; weathers to light gray and yellow with dark-red-brown ferruginous layers; contains some limonite nodules	3	
Claystone, slightly silty in part, medium- to light-gray	13	
Siltstone, somewhat clayey, light-gray; yellow splotches	10	
Mudstone, light-gray; yellow and yellow-brown mottling	8	
Sandstone, fine-grained, very calcareous, salt-and-pepper; light gray but weathers to mottled brown, yellow, dark gray and purplish gray	1	
Siltstone and slightly to very silty claystone, light- to medium-gray; yellow and yellow-brown mottling; forms small badland	40	
Siltstone to very fine grained sandstone with scattered medium sand grains, noncalcareous, salt-and-pepper, light-gray; some yellow along bedding and joints	5	
Siltstone, poorly indurated, pinkish-gray; yellow and yellow-brown splotches; grades downward to slightly silty light- to medium-gray claystone	8	
Lignite, very thinly laminated to papery	2	
Conglomerate, containing well-rounded clasts as much as 8 in. in diameter; mainly light-gray quartzite; some black to gray chert and pink conglomeratic quartzite	5	
Siltstone, quartzitic, light-gray; contains scattered dark-gray chert grains	4	
Interbedded yellow-brown siltstone and light-gray mudstone; yellow and brown mottling	14	
Interbedded light- to medium-gray, yellow-weathering claystone and pinkish-gray clayey siltstone; laminae of red-mottled dark-gray and dark-brown silty claystone	8	
Claystone, black, very slightly to moderately silty; weathers light to medium gray	15	
Thickness, main body of Evanston	257	6
Hams Fork Conglomerate Member:		
Sandstone, poorly sorted, medium-grained to very fine grained; thin layers of coarse-grained to conglomeratic sandstone; very light gray; weathers to yellow orange; forms prominent ledge	13	
Sandstone, fine- to medium-grained; some gritty beds and highly carbonaceous to lignitic laminae near middle; poorly indurated; greenish gray	15	
Claystone, medium-gray; tan-weathering streaks and layers of light-gray siltstone	15	
Claystone, slightly silty, black	8	
Interbedded light-gray mudstone, tan siltstone, and light-gray to brown fine-grained to very fine grained sandstone, partly covered	26	
Ironstone, dark-chocolate to reddish-brown; weathers to purple		6
Claystone, medium- to dark-gray	1	

Evanston Formation at type section for Hams Fork Conglomerate Member—Continued

Evanston Formation—Continued

Hams Fork Conglomerate Member—Continued

	Ft	*in*
Sandstone, very fine grained, buff to gray; weathers yellow to tan; very calcareous and thinly crossbedded	4	
Interbedded very dark gray claystone, brown slightly silty claystone, and tan to gray siltstone	40	
Covered, probably claystone and siltstone as above	85	
Sandstone, fine- to medium-grained; crossbedded with abundant conglomeratic cross laminae; most well-rounded clasts are less than 1 in. in diameter but a few are larger	30	
Interbedded fine-grained sandstone and conglomerate with well-rounded quartzite and chert pebbles as much as 3 in. in diameter in matrix of medium- to coarse-grained sandstone	5	
Sandstone, medium- to fine-grained, light-gray salt-and-pepper; lenses of coarse-grained to gritty sandstone; thinly laminated and cross laminated	35	
Covered, probably fine-grained to very fine grained sandstone	4	
Sandstone, poorly sorted, coarse- to fine-grained, crossbedded; weathers olive light brown with abundant irregularly shaped calcareous nodular light-gray sandstone	6	
Covered	6	
Sandstone, moderately well sorted, medium-grained, salt-and-pepper, crossbedded, yellow to yellow-brown	5	
Covered, probably tan to light-brown fine-grained sandstone	5	
Sandstone, very well laminated, tan; weathers to light brownish gray; forms ledge	1	
Covered, probably sandstone	14	
Sandstone, fine-grained, salt-and-pepper, very light gray; abundant scattered medium and coarse grains; moderately well laminated with 2-inch layers of cross laminae	7	6
Covered, probably sandstone	13	
Sandstone, medium- to coarse-grained, partly gritty, crossbedded	3	
Covered, probably sandstone and conglomerate with pebbles and cobbles of well-rounded quartzite	70	
Sandstone, medium-grained, and boulder conglomerate with quartzite clasts, crossbedded; weathers yellow, olive, and brown	10	
Boulder conglomerate; consists mainly of light-gray quartzite but includes boulders of medium- to dark-gray quartzite, pink conglomeratic quartzite, black chert, and dark-gray limestone	18	
Boulder conglomerate as above; matrix of medium- to coarse-grained sandstone; weathers light olive drab	15	
Total thickness, Hams Fork Conglomerate Member	455	
Total thickness, Evanston Formation	712	6

Adaville Formation (partial):

	Ft	*in*
Covered, probably interbedded yellow to greenish-yellow sandstone and medium- to dark-gray mudstone	43	
Mudstone, medium-gray; abundant chips of ironstone	10	
Covered, light-gray- to yellow-gray-weathering slope, probably sandstone and siltstone	10	
Interbedded gray mudstone, yellow siltstone, and very fine grained light-gray, brown-weathering salt-and-pepper sandstone	25	
Coal	1	
Covered	44	
Mudstone, medium-gray; capped by iron-stained yellow-brown sandstone	5	
Interbedded dark-gray mudstone, dark-brown-stained sandstone with leached calcareous nodules, and light-yellow to tan sandstone; thin interbeds of reddish-brown ironstone	40	
Total measured thickness, Adaville Formation	178	

Base of measured section.

Wasatch Formation (partial) at the type section for Bullpen Member

[Measured in the NW¼ sec. 1, T. 20 N., R. 118 W.]

Wasatch Formation:

Bullpen Member:

Top of butte.

	Ft	*in*
Limestone, finely crystalline, buff; weathers to yellow, tan, and brown chips and slabs on tan silty slope at top of butte	10	
Limestone, finely crystalline to sublithographic, tan; contains sparse ostracodes; forms ledge	1	
Claystone, green, partly marly; some interbeds of mudstone; green with tan and brown mottling	13	
Mudstone and claystone, mottled brownish red, brown, green, and tan	14	
Claystone, green; contains thin layers of green mudstone and very calcareous claystone and light- to medium-gray marlstone and calcareous claystone	11	

Wasatch Formation (partial) at the type section for Bullpen Member—Continued

	Ft	in
Wasatch Formation—Continued		
Bullpen Member—Continued		
Siltstone, brown; grades downward to tan and brown limestone and upward to brown mudstone	6	
Limestone, chalky, white to pale-yellow; thinly laminated to 3-inch-thick beds; forms ledge	1	
Mudstone and claystone, green	4	
Mudstone and claystone, red and brown; thin layers of green and gray	9	
Mudstone and claystone, mainly green but partly yellow and brown mottled	9	
Limestone, buff, tan, and brown; weathers to small chips in brown silty soil	4	
Limestone, grading downward from tan, well indurated, very finely crystalline, and partly algal to white and chalky	4	6
Mudstone, green; contains green and tan slightly silty claystone and tan marly mudstone	9	
Mudstone, maroon; a little green and purple mottling	4	
Mudstone, brown; some layers of brown- and green-mottled claystone and very thin layers of tan limestone	25	
Sandstone, fine-grained to very fine grained, very calcareous, light-gray; forms tan spheroidally weathering ledge	1	
Limestone, mainly very finely crystalline; some ostracodal coquinas in tan, brown, and buff laminae; forms brown silty slope with abundant limestone chips	10	
Limestone, recrystallized ostracodal coquina, tan; forms ledge	1	
Mudstone and siltstone, brown	6	
Sandstone, ranging from brown, very fine grained, and very calcareous to medium gray, slightly calcareous, fine grained, and poorly indurated	7	
Sandstone, brown, medium-grained, moderately well sorted; contains scattered dark chert; moderately well and evenly laminated and cross laminated; forms ledge	6	
Sandstone, brown, fine-grained and muddy; poorly exposed	8	
Claystone, partly silty, shaly, mainly dark brown; some yellow with thin seams of purple	14	
Incomplete thickness, Bullpen Member	177	6
Green River Formation:		
Angelo Member (partial):		
Thinly interlaminated claystone and marlstone, tan, yellow, and pink, and limestone, finely crystalline, well-indurated, light-gray and buff	5	
Limestone; forms brown, orange, and yellow chips in brown silty soil	4	
Limestone, very finely crystalline and thinly laminated, medium-brown; fossil fish fragments		6
Limestone, very finely crystalline, tan to purplish-tan; abundant flat gastropods	7	
Oil shale, low-grade		6
Partial thickness, Angelo Member (185 ft thick at this locality) of Green River Formation	17	

Green River Formation at the type section of the Fossil Butte Member

[Measured at the east end of the south-facing scarp of Fossil Butte, SW¼NW¼ sec. 5, T. 21 N., R. 117 W.]

	Ft	in
Green River Formation:		
Angelo Member (partial):		
Top of butte.		
Limestone, marly, light-gray to white, thin-bedded; contains chert nodules; thin as bed 2 feet above base of unit	7	
Shale, limy, grayish-tan, laminated; contains some oily beds	9	
Limestone, marly, light-gray, thin-bedded	1	
Shale, silty, greenish-gray and rust-colored; contains plant fragments	1	
Limestone, marly, and calcareous shale, light-gray to white; contains chert nodules and evaporite crystal cavities	10	
Oil shale, laminated		8
Limestone, shaly, light-gray	2	
Shale, greenish-gray, crumbly	3	6
Limestone, shaly, light-gray, massive to laminated; ash beds near top	3	
Shale, green- and olive-gray, mottled	1	6
Partial thickness (rounded), Angelo Member	39	
Fossil Butte Member:		
Limestone, chalky to white, pale-orange-yellow; laminated in top foot; marly; weathers to yellow below, grayish tan on fresh fracture; contains small ironstone blebs that weather to rusty spots	6	6
Shale, marly, grayish-tan, laminated	5	6
Oil shale, brown; weathers bluish gray at top and light tan below; contains evaporite crystal pseudomorphs of calcite	4	6
Chalk, white, soft		6
Shale, marly, and siltstone, tan to light-gray	4	6

Green River Formation at the type section of the Fossil Butte Member—Continued

Green River Formation—Continued

Fossil Butte Member—Continued

	Ft	*in*
Oil shale, brown, soft to limy and hard; contains beds with abundant evaporite pseudomorphs	5	
Shale, limy, pink to tan	2	
Limestone, porous; contains ash bed	1	6
Shale, light-tan, varved	1	6
Oil shale; weathers light bluish gray; fissile	1	
Marlstone, light-grayish-tan, soft	1	
Shale, light-tan to buff, papery; and blue-weathering oil shale; thin ash beds	7	6
Oil shale, low-grade; weathers light gray	1	6
Shale, laminated, buff-weathering	1	6
Ash, calcareous, pink		6
Shale, laminated, buff-weathering	4	
Ash, calcareous, pink-weathering; bright yellow on fracture		8
Shale, laminated; contains fossil fish	2	
Limestone, chalky, pinkish-tan	2	
Shale, laminated, calcareous, buff; thin ash beds	5	6
Limestone, chalky, light-buff; rust-colored ash zone at base; unit is very irregular	2	
Shale, limy, laminated, carbonaceous; in beds 1–3 ft thick alternating with 6-in. beds of carbonaceous siltstone	10	
Shale, light-tan, papery; contains thin beds of dark-brown oil shale	7	
Shale, light-tan to light-gray, laminated	7	6
Limestone, chalky, white		6
Shale, laminated; limy at top	2	6
Limestone, buff, chalky, massive, irregular; fish fragments	2	6
Mudstone, calcareous, dark-yellowish-brown to gray; thin gypsum veins	6	
Shale, papery; chocolate colored on fresh surface	9	
Limestone, chalky, yellow-weathering	2	
Shale and shaly limestone, rusty-tan to gray, laminated	5	
Limestone, light-gray, bluish-gray-weathering, massive, fossiliferous	3	6
Limestone, light-gray to buff, chalky to blocky, brecciated	21	6
Limestone, shaly, light-gray to buff	3	
Limestone, shaly, rusty-tan, brecciated	4	
Limestone, light-tan, hard, silty, medium-bedded	5	
Siltstone, shaly, light-bluish-gray; purplish gray at top	4	
Limestone, silty, pale-buff, brecciated	3	6
Siltstone, shaly, buff to gray, yellow-weathering, oolitic	1	6
Limestone, light-tan to buff, chalky, sandy	6	
Siltstone, light-bluish-gray to greenish-gray, oolitic; gypsum veins	6	6
Sandstone, light-gray to tan, fine-grained	4	
Siltstone, limy, light-gray, ledge-forming, massive to brecciated; veined with gypsum	1	
Siltstone, medium- to light-bluish-gray	4	
Mudstone, sandy, light-gray; rusty colored near base; calcareous	5	6
Sandstone, light-gray, fine-grained to very fine grained, calcareous	1	
Siltstone and claystone, gray to pale-olive-gray; muddy partings	5	
Covered zone above terrace (assumed top of Wasatch Formation)	17	
Total thickness (rounded), Fossil Butte Member of Green River Formation	208	

Green River Formation at the type section of the Angelo Member

[Measured on bluff overlooking the Angelo Ranch, west of South Fork Twin Creek, in the NW¼ sec. 1, T. 20 N., R. 118 W.]

Wasatch Formation:

Bullpen Member (partial):

	Ft	*in*
Covered at top of butte; tan slope of weathered marlstone and thin-bedded yellow, brown, and tan limestone	10	
Limestone, brown, blocky	1	
Interbedded chalky-white marlstone and greenish-gray claystone	9	
Claystone, green, soft	4	
Claystone, mottled brownish red, brown, green, and tan; forms reddish band	14	
Claystone, greenish-gray	8	
Claystone, silty, brown to red	5	
Marlstone, tan; and greenish-gray claystone	4	
Limestone, tan, flaggy, thinly laminated; forms 1-ft ledge above chalky-white marlstone	3	
Claystone, green	4	
Claystone, mottled red, brown, and green; forms pink band	13	
Mudstone, buff-weathering	4	6
Limestone, tan, aphanitic, hard; 6-in ledge at top of white marlstone	3	6
Claystone, greenish-gray, soft	12	
Claystone, maroon; green and purple mottling	4	
Covered; brown soft slope; variegated purple, brown, and green claystone	25	
Sandstone, quartz, calcareous, thin-bedded	1	
Covered; mudstone	7	
Limestone, sandy, thin-bedded; ostracode coquina grading down to brown sandy mudstone	3	
Covered; brown mudstone and fine-grained poorly indurated sandstone	9	
Sandstone, brown, laminated	1	

Green River Formation at the type section of the Angelo Member—Continued

	Ft	in
Wasatch Formation—Continued		
Bullpen Member (partial)—Continued		
Sandstone, brown, coarse-grained; crossbedded in places	15	
Partial thickness, Bullpen Member of Wasatch Formation	160	
Green River Formation:		
Angelo Member:		
Oil shale, low-grade, brown, papery; and brown claystone	10	
Limestone, yellow- to buff-weathering, thinly laminated	6	
Covered; brown soil; yellow, brown, orange limestone chips on surface	4	
Limestone, brown, petroliferous, thinly laminated; fish fragments		6
Covered; purplish-tan limestone fragments; flat gastropods	6	6
Oil shale, low-grade, brown		6
Claystone, brown	2	6
Claystone, greenish-gray	2	
Limestone, shaly, soft		6
Claystone, greenish-gray; thinly bedded limestone that weathers to orange, brown, and dark-brownish-gray chips	9	6
Limestone, tan, buff-weathering, ledge-forming	1	
Covered; tan and greenish-gray banded slope; alternating green claystone and tan calcareous shale with thin beds of sandy limestone	23	
Covered; white slope containing chips and slabs of tan limestone	14	
Marlstone, hard, dark-brown, ledge-forming; weathers orange; banded	1	
Covered; white to light-tan slope with abundant limestone chips; mostly fissile greenish-gray calcareous shale	23	
Limestone, light-brown, hard, crystalline; weathers tan	2	
Claystone, olive-brown, hackly, hard	17	
Sandstone, gray, fine-grained, poorly sorted; grains of angular chert and clay	1	
Covered; tan slope; fissile limy grayish-white shale with thin beds of brown hard limestone	30	
Limestone, algal or concretionary, slabby to thin-bedded, white-weathering; hard, ledge forming to soft, covered	10	
Oil shale, papery, brown	1	

Green River Formation at the type section of the Angelo Member—Continued

	Ft	in
Green River Formation—Continued		
Angelo Member—Continued		
Shale, calcareous, white-weathering; contains chalky limestone and chert	4	
Limestone, tan to brown; weathers white	1	
Mudstone, gray, calcareous	4	
Limestone, tan, thin-bedded	5	
Mudstone, bluish-green; and claystone; gray to white limestone chips	15	
Total thickness, Angelo Member of Green River Formation	194	
Fossil Butte Member (top only):		
Shale, calcareous, buff- to white-weathering	10	
Oil shale, dark-brown; weathers blue; 3-cm beds of "sugar oil shale," filled with 1-mm calcite pseudomorphs after evaporite crystals	1	

Fowkes Formation at type sections for its members

[Measured from the SE¼ sec. 5, T. 21 N., R. 119 W., to the NE¼ sec. 33, T. 22 N., R. 119 W.]

	Ft	in
Fowkes Formation:		
Gooseberry Member (incomplete):		
Covered interval at top of hill; loose gravel float; possibly puddingstone conglomerate	60	
Covered interval on hillslope; limy sandstone and silt in float	60	
Puddingstone; pebbles as much as 4 in.; light-gray chert dominant, set in white sandy limestone matrix; flat pebbles parallel bedding. 1-ft lenticular calcareous sandstone bed	8	
Limestone, light-gray to white, very sandy to calcareous sandstone; biotite and dark mineral grains abundant. Forms rounded weathered surface. Contains five lentils of "puddingstone" about 2 in. thick, 1 ft to several feet in length; lentils grade laterally and vertically into limestone	6	
Puddingstone; conglomerate in sandy limestone matrix	1	6
Limestone, white; contains thin layers of sparse granule-and-pebble conglomerate 1–3 in. thick near base. Upper 3 ft is white. Massive limestone with beds as much as 1 ft thick of laminated pinkish-tan limestone. Cross laminated and contorted in places; separated in others to form calcite-filled vugs as much as 1 in. high and 1 ft long. Resembles travertine	5	

Fowkes Formation at type sections for its members—Continued

	Ft	in
Fowkes Formation—Continued		
Gooseberry Member (incomplete)—Continued		
Puddingstone, coarse-grained; light-gray at a distance; white limestone matrix. Contains crude beds 2–6 in. thick of finer and coarser pebbles floating in a limestone matrix. Pebbles well rounded and cobbles to as much as 4 in. of white, gray, black, and tan quartzite; brown, black, and gray chert and pinkish-white porcellenite(?); sparse volcanic pebbles; flat to well-rounded pebbles of dark-gray limestone	9	
Approx. thickness (incomplete; rounded), Gooseberry Member of Fowkes Formation	150	
Bulldog Hollow Member:		
Sandstone, light-green to olive-brown, medium- to fine-grained; clayey matrix; abundant biotite, magnetite, dark chert grains; interbedded very fine grained sandstone, mudstone, and coarse-grained sandstone. Topmost beds crossbedded, dipping 20° E; 3-ft pebble conglomerate 20 ft below top; white tuffaceous claystone bed 50 ft above base	131	
Sandstone, medium-green to dark-green, very fine grained to medium-grained; dark-green clay matrix; very abundant magnetite	5	
Sandstone, light-green to olive-brown, medium- to coarse-grained; biotite and magnetite	48	
Sandstone, light-grayish-green, medium-grained	5	
Covered interval; unit consists chiefly of soft dark-green sand that contains magnetite grains	40	
Gravel, black, tan; and gray chert and quartzite pebbles to as much as 6 in. in diameter; broken limestone-indurated puddingstone with pebbles floating in sandy limestone matrix	2	
Sandstone, greenish-tan, very fine grained to medium-grained; magnetite, chert grains and black mineral grains	3	
Gravel, as above	5	
Total thickness, Bulldog Hollow Member of Fowkes Formation	239	
Sillem Member:		
Mudstone, clayey, pale-tan to greenish-gray; pink mottling; thin beds of white tuffaceous claystone	15	
Claystone, calcareous silty, light-gray; brown calcareous concretions	1	
Sandstone, pale-gray to pale-tan, fine-grained, poorly sorted, clayey; moderately abundant dark grains and mica; angular fragments of claystone	5	

Fowkes Formation at type sections for its members—Continued

	Ft	in
Fowkes Formation—Continued		
Sillem Member—Continued		
Claystone, pale-green to pale-tan, silty; biotite flakes	9	
Mudstone, pale-tan to light-greenish-gray; weathers to gray and pink bands; silty and sandy; micaceous 10 ft above base	14	
Mudstone; pale-greenish-gray siltstone and fine-grained muddy sandstone; weathers to gray with pink mottling	15	
Sandstone, muddy, very fine grained, pale-greenish-gray; contains brown and tan beds. Very silty and muddy at top of unit. Slope weathers to an encrusted mud surface	20	
Mudstone, shaly; and siltstone, pale-greenish-gray	1	
Sandstone, light-greenish-gray; fine grained grading down to coarse grained	2	
Mudstone, silty, shaly; mottled pink, tan, and brown		6
Sandstone, olive-drab, green to light-green, coarse-grained; clayey matrix; grains dominantly quartz and black chert	4	6
Sandstone, coarse-grained, crossbedded, light-gray "salt and pepper"; about 10 percent dark grains, black chert, minor magnetite, and interbedded thin mudstone and conglomerate beds; lenticular conglomerate as much as 2 ft thick; granules and pebbles of chert and quartz; some clay balls as much as 6 in. in diameter	21	
Covered below.		
Total thickness, exposed Sillem Member of Fowkes Formation	108	
Total thickness (rounded), exposed Fowkes Formation	497	

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