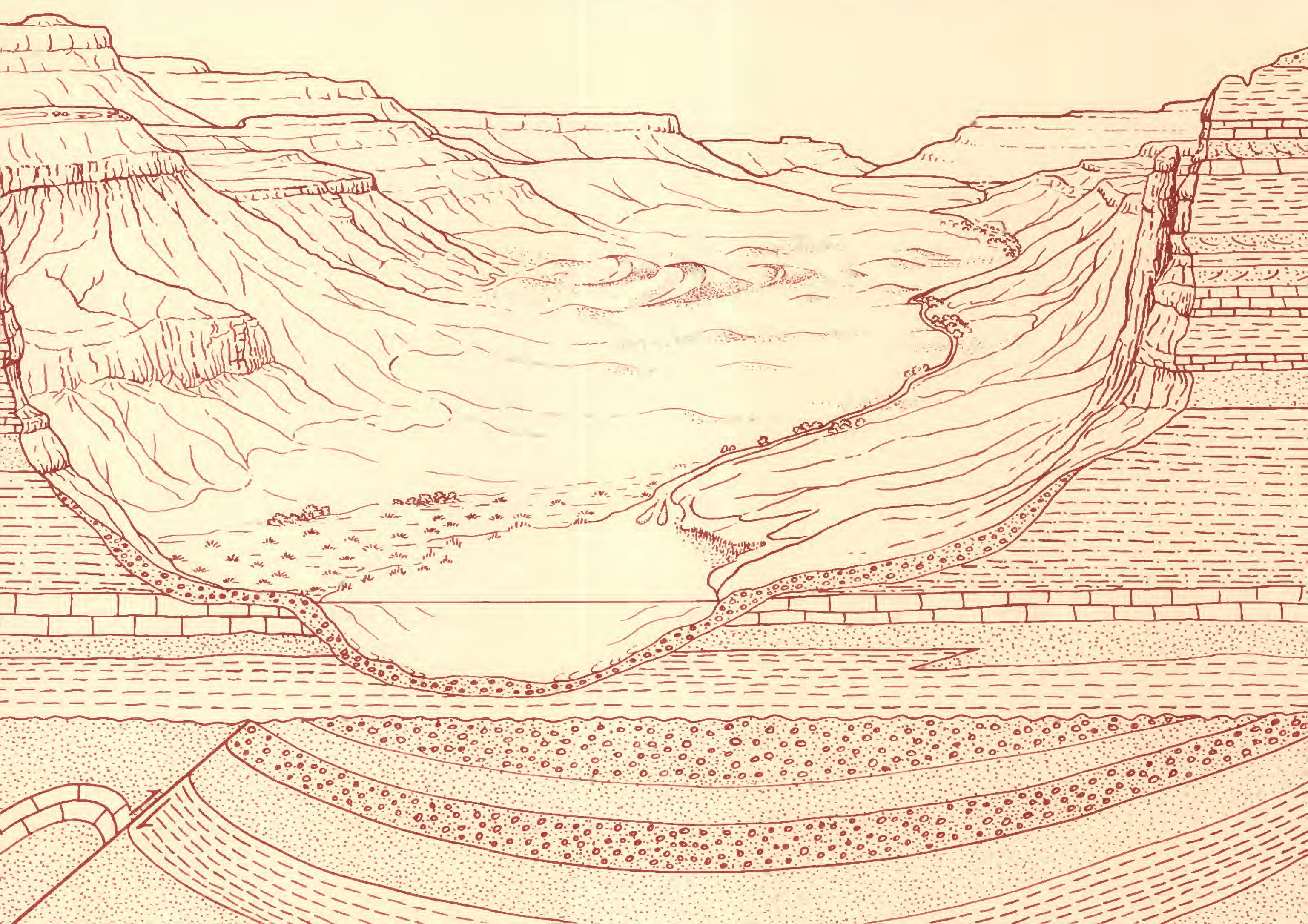
Geology of the Lower Yellow Creek Area, Northwestern Colorado

U.S. GEOLOGICAL SURVEY BULLETIN 1787–O



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Chapter O

Geology of the Lower Yellow Creek Area, Northwestern Colorado

By WILLIAM J. HAIL, JR.

A multidisciplinary approach to research studies of sedimentary rocks and their constituents and the evolution of sedimentary basins, both ancient and modern

U.S. GEOLOGICAL SURVEY BULLETIN 1787

EVOLUTION OF SEDIMENTARY BASINS—UINTA AND PICEANCE BASINS

DEPARTMENT OF THE INTERIOR
MANUEL LUJAN, JR., Secretary

U.S. GEOLOGICAL SURVEY
Dallas L. Peck, Director

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CONVERSION FACTORS FOR SOME SI METRIC AND U.S. UNITS OF MEASURE

To convert from	To	Multiply by
Feet (ft)	Meters (m)	0.3048
Miles (mi)	Kilometers (km)	1.609
Acres	Hectometers^2	0.405
Miles	Kilometers^2	2.590
Pounds (lb)	Kilograms (kg)	0.4536
Gallons	Liters (L)	3.785
Barrels	Meters^3	0.159
Tons	Metric tons	0.907
Gallons per ton	Liters per metric ton	4.171
Barrels per acre	Meters^3 per hectometer^2	0.393
Tons per mile^2	Metric tons per kilometer^2	0.350

Geology of the Lower Yellow Creek Area, Northwestern Colorado

By William J. Hail, Jr.

Abstract

The lower Yellow Creek area comprises four 7.5-minute quadrangles, an area of 229 mi^2 (593 km^2), at the northwestern margin of the Piceance Creek basin in northwestern Colorado, about midway between the towns of Meeker and Rangely. Subsurface sedimentary rocks not penetrated by drill holes, but probably present in the area, range in age from Cambrian to Pennsylvanian and may be as thick as 2,500 ft (760 m). Subsurface rocks penetrated by drill holes aggregate as much as 6,000 ft (1,830 m) in thickness and include the Morgan Formation and Weber Sandstone of Pennsylvanian age, the Park City Formation of Permian age, the Moenkopi and Chinle Formations of Triassic age, the Glen Canyon Sandstone of Triassic and Jurassic age, the Entrada Sandstone and Stump and Morrison Formations of Jurassic age, and the Cedar Mountain Formation, Dakota Sandstone, and lower part of the Mancos Shale of Cretaceous age. Exposed rocks include the Mancos Shale, Castlegate Sandstone, Iles Formation, and Williams Fork Formation of the Mesaverde Group of Late Cretaceous age and the Fort Union, Wasatch, Green River, and Uinta Formations of Tertiary age. Surficial deposits of Quaternary age (Pleistocene and Holocene) include terrace gravels, alluvium, and landslides.

Exposed rocks of the Mancos Shale consist mostly of gray to brown clay shale of offshore marine origin. The Castlegate Sandstone of marine origin separates the main body of the Mancos from the overlying Buck Tongue of the Mancos. The Buck Tongue includes the Loyd Sandstone Bed. The Iles Formation includes a marine sandstone at its base but is mostly claystone, mudstone, and sandstone and some carbonaceous shale and coal of fluvial and paludal origin. The Trout Creek Sandstone Member, probably of nonmarine origin in this area, lies at the top of the Iles. The overlying Williams Fork Formation consists of sandstone, claystone, and mudstone and lesser carbonaceous shale and coal of fluvial and paludal origin. A regional unconformity separates the Williams Fork Formation from overlying Tertiary rocks. The Williams Fork Formation thins as much as 600 ft (183 m) from east to west across the area, owing to truncation of beds beneath the unconformable surface.

The lowermost Tertiary formation is the Fort Union Formation of early or middle to late Paleocene age. It is divided into two members—a lower member consisting of fluvial sandstone, claystone, and mudstone, and an upper member consisting mostly of paludal shale, sandstone and carbonaceous shale and minor coal and siltstone. The Wasatch Formation of latest Paleocene and Eocene age is mostly varicolored alluvial claystone and lesser mudstone and fluvial channel sandstone. It includes a dark shale facies consisting of alluvial claystone and channel sandstone, lacustrine sandstone, shale and limestone, and paludal carbonaceous shale and claystone. The Eocene Green River Formation consists almost entirely of rocks of lacustrine origin and includes three members. The eastward-thinning basal Anvil Points Member consists mostly of nearshore lacustrine sandstone and lesser limestone, siltstone, claystone, and shale. The Garden Gulch Member is mostly freshwater lacustrine gray or brown clay shale and includes some oil shale and minor sandstone and limestone. The Parachute Creek Member consists mostly of dolomitic marlstone, much of which is oil shale, dolomitic shale, and clay shale, minor siltstone and sandstone, and several very thin altered tuff beds. The youngest Tertiary formation is the Uinta Formation of Eocene age, a heterogeneous mass of clastic sediments deposited in a generally southward prograding, fluvial-deltaic complex that ultimately filled Eocene Lake Uinta. The Uinta Formation is complexly intertongued with the Green River Formation.

Fold axes and faults in the area trend northwesterly. The major structural elements are (from north to south) the Crooked Wash syncline, Midland anticline, Red Wash syncline, and Yellow Creek anticlinal nose. A graben zone of small stratigraphic displacement closely parallels much of the axis of the Red Wash syncline, which forms the deepest part of the Piceance Creek basin. Maximum structural relief

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on the Precambrian surface in the area is about 15,000 ft (4,600 m).

The southern part of the area contains major oil-shale resources, estimated to be about 111 billion barrels of oil for all the oil-shale zones. Most of the oil shale is in the Parachute Creek Member of the Green River Formation. The sodium minerals nahcolite and dawsonite are abundant in the area. Resources of nahcolite, a potential source of soda ash and a gas scrubbing agent, are estimated to be about 8.9 billion tons. Resources of alumina in dawsonite are estimated to be about 6.1 billion tons.

Coal-bearing zones in the upper, middle, and lower parts of the Williams Fork Formation and near the top and base of the Iles Formation contain considerable coal. The coal-resource potential is limited, however, by the nonpersistence of the thicker coal beds.

The White River Gas Field in the northeastern part of the area has yielded small amounts of gas, about 7.5 million cubic feet as of January 1987, all of it from shallow, lenticular Tertiary sandstones. Several deep oil and gas test holes in the area have failed to find significant amounts of oil.

Large, but very low grade uranium resources are present in carbonaceous shale and claystone beds of the upper member of the Fort Union Formation.

Abundant gravel is available from Quaternary terrace deposits mostly along the White River.

INTRODUCTION

The lower Yellow Creek area is located in Rio Blanco and Moffat Counties of northwestern Colorado, about midway between the towns of Rangely and Meeker (fig. 1). It includes the Rough Gulch, Smizer Gulch, Barcus Creek, and Barcus Creek SE 7.5-minute quadrangles, an area of 229 mi² (593 km²). Paved highways, Colorado 64 along the White River and Rio Blanco County 5 along Piceance Creek, and a network of dirt roads give fair access to most of the area. The climate is semiarid, and natural vegetation is largely sagebrush, pinyon pine, and juniper. Hay, the principal crop of the area, is grown along the irrigated valleys of the White River and Piceance Creek. The area is dissected into a topography of ridges and valleys of relatively moderate relief. Dominant topographic features are the wide valleys of the White River, Piceance Creek, and Yellow Creek, the high ridges of Pinyon Ridge in the northwest, and the ridge forming the basin rim south of the White River. The ridges are 1,000–1,200 ft (300–370 m) above the valleys below. About 85 percent of the land is owned by the Federal Government and 6 percent by the State of Colorado; 9 percent is privately owned.

Geologic mapping of the area of this report was begun in 1969 as a part of a larger program of detailed geologic mapping on 7.5-minute (1:24,000 scale) topographic base maps, undertaken chiefly because of a renewed interest in oil-shale resources of the Piceance Creek basin. The study area is in the northwestern part of the Piceance Creek basin, a very deep structural and sedimentary basin that formed during the Laramide orogeny. Potentially important resources in the area are oil shale and related minerals, oil and gas, coal, and uranium. All four quadrangles of the study area (fig. 1) have been published individually, and references in this report are made to these published maps. A preliminary map of the Barcus Creek SE quadrangle was published as MF–347 (Hail, 1972) and is superseded by a revised map, GQ–1613 (Hail, 1988). The map of the Smizer Gulch quadrangle was published as GQ–1131 (Hail, 1973) and the map of the Rough Gulch quadrangle as GQ–1195 (Hail, 1974a). The map of the Barcus Creek quadrangle was published as GQ–1578 (Hail, 1984) and supersedes preliminary map MF–619 (Hail, 1974b). Some changes and modifications to the various stratigraphic units shown on the individual maps were made during the compilation of a 1:50,000-scale map of these and four other quadrangles to the east, and a modified stratigraphic terminology is used in this report.

Prior geologic studies of the area have been parts of broader, mostly reconnaissance, studies of the Piceance Creek basin and do not include any detailed large-scale geologic mapping of the area. Most of the older work has been described by Bradley (1931, p. 2–3) and Donnell (1961, p. 840). A reconnaissance geologic map at a scale of 1:125,000 was published by Gale (1910) and shows coal-bearing Cretaceous rocks in the lower White River Coal Field, including parts of the Rough Gulch and Smizer Gulch quadrangles. A report on the Tertiary geology and oil shale of the Piceance Creek basin by Donnell (1961) includes a planimetric geologic

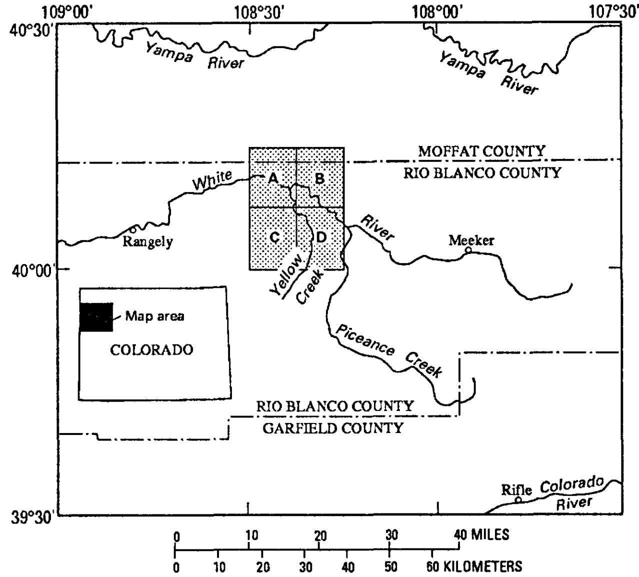


Figure 1. Location of the lower Yellow Creek area (shaded), Piceance Creek basin, northwestern Colorado. Quadrangles: A, Rough Gulch; B, Smizer Gulch; C, Barcus Creek; D, Barcus Creek SE.

map at a scale of 1:125,000. A detailed geologic map of the Elk Springs quadrangle (scale 1:48,000), which immediately adjoins the Rough Gulch and Smizer Gulch quadrangles on the north, was published by Dyni (1968). Since about 1961, many studies touching on the geology of the lower Yellow Creek area have been published and most deal with oil shale.

STRATIGRAPHY

Rocks exposed at the surface in the lower Yellow Creek area range from Late Cretaceous to late Eocene in age. Surficial deposits are Pleistocene and Holocene in age. Table 1 summarizes the bedrock stratigraphic units exposed in the study area. Cretaceous formations, aggregating about 6,600 ft (2,000 m) in thickness, include the Mancos Shale, the Castlegate Sandstone, the Iles Formation, and the Williams Fork Formation. The Castlegate, Iles, and Williams Fork compose the Mesaverde Group. The Castlegate Sandstone merges into the Mesaverde Group west of the study area and it separates the main body of the Mancos Shale from the overlying Buck Tongue of the Mancos Shale. Tertiary formations, aggregating as much as 7,000 ft (2,100 m) in thickness, include the Fort Union Formation of Paleocene age, the Wasatch Formation of Paleocene and Eocene age, the Green River Formation of Eocene age, and the Uinta Formation of Eocene age.

A major unconformity separates Cretaceous from Tertiary rocks in the study area and throughout the entire Piceance Creek basin. Structural discordance, however, is only moderate. An unknown thickness of latest Cretaceous rocks was removed by erosion during the initial stages of the Laramide orogeny. The oldest Tertiary rocks lying on the erosion surface in the study area are early to middle Paleocene in age. Within the Tertiary sequence, only minor and local erosional breaks are present.

The Cretaceous formations were deposited along the western margin of a north-trending epicontinental sea. The Tertiary formations were deposited in a variety of terrestrial environments including fluvial, paludal, lacustrine, and lacustrine-deltaic.

Subsurface Rocks

Subsurface strata in the lower Yellow Creek area above the Precambrian basement range from probable Cambrian to Cretaceous in age. Three Shell Oil Company deep drill holes within the area penetrated rocks of Pennsylvanian age: Government 31–10, sec 10, T. 2 N., R. 98 W.; Colorow 1, sec. 17, T. 2 N., R. 97 W.; and Government 22X–17, sec. 17, T. 2 N., R. 97 W. The rocks penetrated in these drill holes are exposed in nearby areas. Table 2 is an interpretive summary of the subsurface units based on drill-hole logs and on published descriptions in U.S. Geological Survey maps including the Mellen Hill quadrangle (Cullins, 1969) and the Plug Hat Rock quadrangle (Rowley and Hansen, 1979), both about 20 mi (32 km) west of the lower Yellow Creek area; the Elk Springs quadrangle (Dyni, 1968), 14–18 mi (22–29 km) north of the lower Yellow Creek area; and the Dinosaur National Monument area (Hansen and others, 1983), 8–18 mi (13–29 km) northwest of the lower Yellow Creek area.

Little is known about the rocks older than those shown on table 2, but based on descriptions of rocks that crop out in nearby areas, the following formations may be present: the Lodore Formation of Late Cambrian age, the Madison Limestone of Early Mississippian age, the Humbug Formation and Doughnut Shale of Late Mississippian age, the Round Valley Limestone of Early Pennsylvanian age, and the lower part of the Morgan Formation of Middle Pennsylvanian age. The following descriptions of the rocks are from Dyni (1968), Hansen and others (1983), and Rowley and Hansen (1979). The Lodore Formation is a largely marine unit, about 250–540 ft (76–160 m) thick, consisting of gray to green glauconitic sandstone and quartzite, conglomeratic sandstone, and varicolored glauconitic shale and siltstone. The Madison Limestone, about 500–600 ft (150–180 m) thick, is gray, cherty, locally dolomitic marine limestone. The Humbug Formation is largely marine, gray, yellow, and red sandstone, gray limestone, and red and black shale. The Doughnut Shale is dark-gray and red, mostly marine shale. The combined thickness of the Humbug and Doughnut is about 100–230 ft (30–70 m). The Round Valley Limestone, about 400 ft (120 m) thick, is gray, locally cherty marine limestone and lesser gray shale. The Morgan Formation, about 500–800 ft (150–240 m) thick, is red to brown fine-grained sandstone, gray fossiliferous cherty marine limestone, and lesser varicolored shale, siltstone, and sandstone.

Cretaceous rocks

Mancos Shale

The Mancos Shale in the lower Yellow Creek area includes the main body and the overlying Buck Tongue. The two units are separated by the Castlegate Sandstone of the Mesaverde Group. The main body includes a mapped sandstone, the B sandstone of Dyni (1968), and the Buck Tongue includes a mapped sandstone, the Loyd Sandstone Bed. Fossils from about the upper 1,500 ft (460 m) of the 2,700 ft (820 m) of exposed rocks of the Mancos are Campanian (Late Cretaceous) in age, and it is likely that all the exposed rocks are Campanian.

Table 1. Summary description of exposed bedrock units, lower Yellow Creek area
[Thickness in feet and in meters (shown in parentheses)]

Age	Unit	Thickness	Description
Eocene	Uinta Formation and tongues of Green River Formation	1,400 (430)	Intertongued sequence of deltaic clastic rocks of Uinta Formation and open-water lacustrine rocks of Green River Formation. Tongues of Uinta Formation are brown-weathering sandstone and siltstone and lesser marlstone, mudstone or claystone, conglomerate, and conglomeratic sandstone. Tongues of Green River Formation are mostly variably silty, light-gray marlstone and a considerable proportion of limestone and sandstone; very minor oil shale.
Eocene	Parachute Creek Member of Green River Formation	900-1,600 (275-490)	Dolomitic marlstone; lesser limy marlstone, clay shale, dolomitic shale, and siltstone. Several beds of siltstone and sandstone and numerous very thin beds of analcimized tuff. Much of the marlstone and some clay shale is rich oil shale that locally contains deposits of nahcolite and dawsonite. Lacustrine.
Eocene	Garden Gulch Member of Green River Formation	190-700 (58-214)	Gray to brown, mostly fissile clay shale; some variably ostracodal claystone; minor siltstone and ostracodal limestone. Oil shale in upper part. Lacustrine.
Eocene	Anvil Points Member of Green River Formation	40-300 (12-92)	Brown-weathering ostracodal or oolitic sandstone; lesser ostracodal or oolitic limestone, claystone, shale, and siltstone. Lacustrine.
Eocene and Paleocene	Upper and lower parts (main body) of Wasatch Formation	1,000-2,100 (305-640)	Gray and varicolored claystone; lesser mudstone and lenticular channel sandstone, locally conglomeratic; minor carbonaceous shale and siltstone. Fluvial.
Eocene	Dark shale facies of Wasatch Formation	0-425 (0-130)	Gray and varicolored claystone; lenticular sandstone; dark-brown or gray ostracodal shale, sandstone, and limestone; carbonaceous shale and claystone. Fluvial, lacustrine, and paludal.

Main body

The main body of the Mancos Shale is mostly brown to gray marine shale; it also contains a few nonresistant sandstone and siltstone beds and sparse yellow- to orange-weathering concretions. The Mancos is soft and nonresistant and is mostly very poorly exposed except on the steep slopes below cliffs formed by resistant sandstones of the Castlegate Sandstone and Iles Formation. The Mancos forms the low barren ground in the northwest part of the Rough Gulch quadrangle in the valley of Wolf Creek where exposures commonly weather yellowish brown. The total thickness of the main body of the Mancos, including that in the subsurface, is about 4,500–4,700 ft (1370–1430 m). The thickness of exposed rocks of the main body is about 2,200 ft (670 m).

Exposed rocks of the main body of the Mancos Shale below the B sandstone of Dyni (1968) lie in the fossil zones of *Baculites mclearni*, *Baculites obtusus*, and *Baculites sp.* (weak flank ribs) (fig. 2, U.S. Geological Survey (USGS) fossil localities D7598, D7612, D7611, D7610, D7609, D7608, and D8789).

A thin persistent marine sandstone bed lies about 150–200 ft (46–60 m) below the top of the main body of the Mancos Shale. The top of the bed is shown on the Rough Gulch quadrangle map (Hail, 1974a). The unit was informally named the B sandstone and mapped by Dyni (1968) in the Elk Springs quadrangle to the north. The B sandstone is light brown to light gray, rusty brown weathering, poorly sorted, fine to medium grained, and massive to crudely even bedded. It is moderately resistant

Table 1. Continued

Age	Unit	Thickness	Description
Paleocene	Upper member of Fort Union Formation	300-530 (92-162)	Gray shale; thin, persistent sandstone beds, carbonaceous shale; minor coal and siltstone. Paludal.
Paleocene	Lower member of Fort Union Formation	100-1,800 (30-550)	Gray to brown channel sandstone; olive-green to gray claystone and mudstone; minor siltstone, carbonaceous shale, and limestone. Fluvial.
Late Cretaceous	Williams Fork Formation of Mesaverde Group	2,000-2,600 (610-790)	Lenticular, gray sandstone; gray to grayish-green claystone and mudstone; lesser carbonaceous shale and coal. Fluvial and paludal. Regional unconformity at top.
Late Cretaceous	Main body of Iles Formation of Mesaverde Group	600-750 (180-230)	Brown sandstone at base (marine), 35-65 ft (11-20 m) thick. Higher beds of gray claystone, mudstone, and lenticular brown sandstone; minor carbonaceous shale and coal. Fluvial and paludal.
Late Cretaceous	Trout Creek Sandstone Member of Iles Formation	0-110 (0-34)	Light-gray sandstone. Nonmarine.
Late Cretaceous	Buck Tongue of Mancos Shale	440-560 (130-170)	Brown to gray shale; some siltstone and sandstone. Includes Loyd Sandstone Bed. Marine.
Late Cretaceous	Castlegate Sandstone of Mesaverde Group	40-60 (12-18)	Brown to gray sandstone. Marine.
Late Cretaceous	Main body of Mancos Shale	4,500-4,700 (1,370-1,430)	Brown to gray shale; minor sandstone and siltstone. Marine. Thickness includes subsurface.

relative to the enclosing soft shale, forms a ledge on steeper slopes, and caps some low knobs on lower ground. It is 10–35 ft (3–11 m) thick. It was mapped to the west in the Cactus Reservoir quadrangle (Barnum and Garrigues, 1980) and Rangely NE quadrangles (Garrigues and Barnum, 1980) and is apparently correlative with the lower unit of the Castlegate Sandstone as designated by Cullins (1969, 1971) in the Rangely area. Fossil evidence suggests, however, that the B sandstone is older than the lower unit of the Castlegate in the Rangely area (Gill and Hail, 1975). The B sandstone in the lower Yellow Creek area lies in the zone of *Baculites mclearni* (fig. 2, USGS fossil locality D7599).

Buck Tongue

The Buck Tongue of the Mancos Shale is mostly brown to gray marine shale and lesser siltstone and sandstone. That part of the Buck Tongue below the Loyd Sandstone Bed, about 300 ft (90 m) thick, is gray to brown, brown-weathering, locally silty, soft clay shale. It contains relatively abundant yellow-orange septarian concretions. That part of the Buck Tongue above the Loyd Sandstone Bed, about 170 ft (52 m) thick, consists of dark-gray to brown shale in the lower part; it becomes increasingly silty and sandy in the upper part and contains several soft siltstone and sandstone beds.

In the lower Yellow Creek area, the Loyd Sandstone Bed has a maximum thickness of about 70 ft (21 m). It consists of massive to thin-bedded sandstone and lesser sandy shale. Locally abundant trace fossil burrows suggest shallow-water deposition. The Loyd is relatively resistant and locally forms cliffs and ledges, but it is nonpersistent and locally phases out laterally into shale marked only by a zone of orange-weathering concretions. In the Elk Springs quadrangle to the north, the Loyd contains large limy concretions containing abundant invertebrate fossils (Dyni, 1968).

Most, if not all, of the Buck Tongue in the area lies in the fossil zone of *Baculites perplexus* Cobban (fig. 2, USGS fossil localities D7607, D7606, D7596, D7595, and D7605). In the Winter Valley area of the Elk Springs

Table 2. Description of subsurface rocks penetrated by drilling, lower Yellow Creek area

[Thickness in feet and in meters (shown in parentheses)]

Age	Unit	Thickness	Description
Late Cretaceous	Main body of Mancos Shale	4,500-4,700 (1,370-1,430)	Brown to gray shale; minor sandstone and siltstone. Marine. Thickness includes exposed rocks.
Late Cretaceous	Frontier Sandstone Member of Mancos Shale	200 (60)	Brown to gray, fossiliferous, calcareous, fine-grained sandstone and interbedded gray shale and siltstone. Marine.
Early Cretaceous	Mowry Shale Member of Mancos Shale	100 (30)	Dark-gray siliceous shale; some bentonite beds, fish scales. Marine.
Early Cretaceous	Dakota Sandstone	95 (29)	Light-gray, fine- to coarse-grained quartzose sandstone; local chert-pebble conglomerate; some dark-gray shale; local thin coal beds. Fluvial; uppermost part marine.
Early Cretaceous	Cedar Mountain Formation	70-100 (21-30)	Varicolored claystone and siltstone; some nodular limestone, sandstone, and chert-pebble conglomerate. Fluvial. Unconformity at top.
Late Jurassic	Morrison Formation	460-510 (140-155)	Varicolored claystone and siltstone and gray, fine-to coarse-grained sandstone; some chert-pebble conglomeratic sandstone and limestone. Fluvial and lacustrine. Unconformity at top.
Middle Jurassic	Stump Formation	100-200 (30-60)	Light-gray to greenish-gray, locally glauconitic, medium- to coarse-grained sandstone. Marine. Unconformity at top.
Middle Jurassic	Entrada Sandstone	150-200 (46-60)	Grayish-orange, very fine to fine grained, crossbedded sandstone. Eolian. Unconformity at top.
Early Jurassic and Late Triassic	Glen Canyon Sandstone	320-380 (98-116)	Grayish-orange, very fine to fine grained, crossbedded sandstone. Eolian.
Late Triassic	Chinle Formation	255 (78)	Varicolored, predominantly red, siltstone, shale, sandstone, and conglomeratic sandstone. Fluvial, paludal, lacustrine. Unconformity at top.
Early Triassic	Moenkopi Formation	490-600 (150-180)	Varicolored, mostly red, siltstone and shale. Shallow nearshore marine. Unconformity at top.
Early Permian	Park City Formation and related rocks	130 (40)	Light-gray, calcareous siltstone; limestone, dolomite, and sandstone. Locally phosphatic. Marine.
Middle Pennsylvanian	Weber Sandstone	800-850 (240-260)	Light-gray, fine to very fine grained, crossbedded sandstone. Eolian. Unconformity at top.
Middle Pennsylvanian	Morgan Formation	240 (73)	Red to brown, fine-grained sandstone. Lesser limestone and shale. Marine.

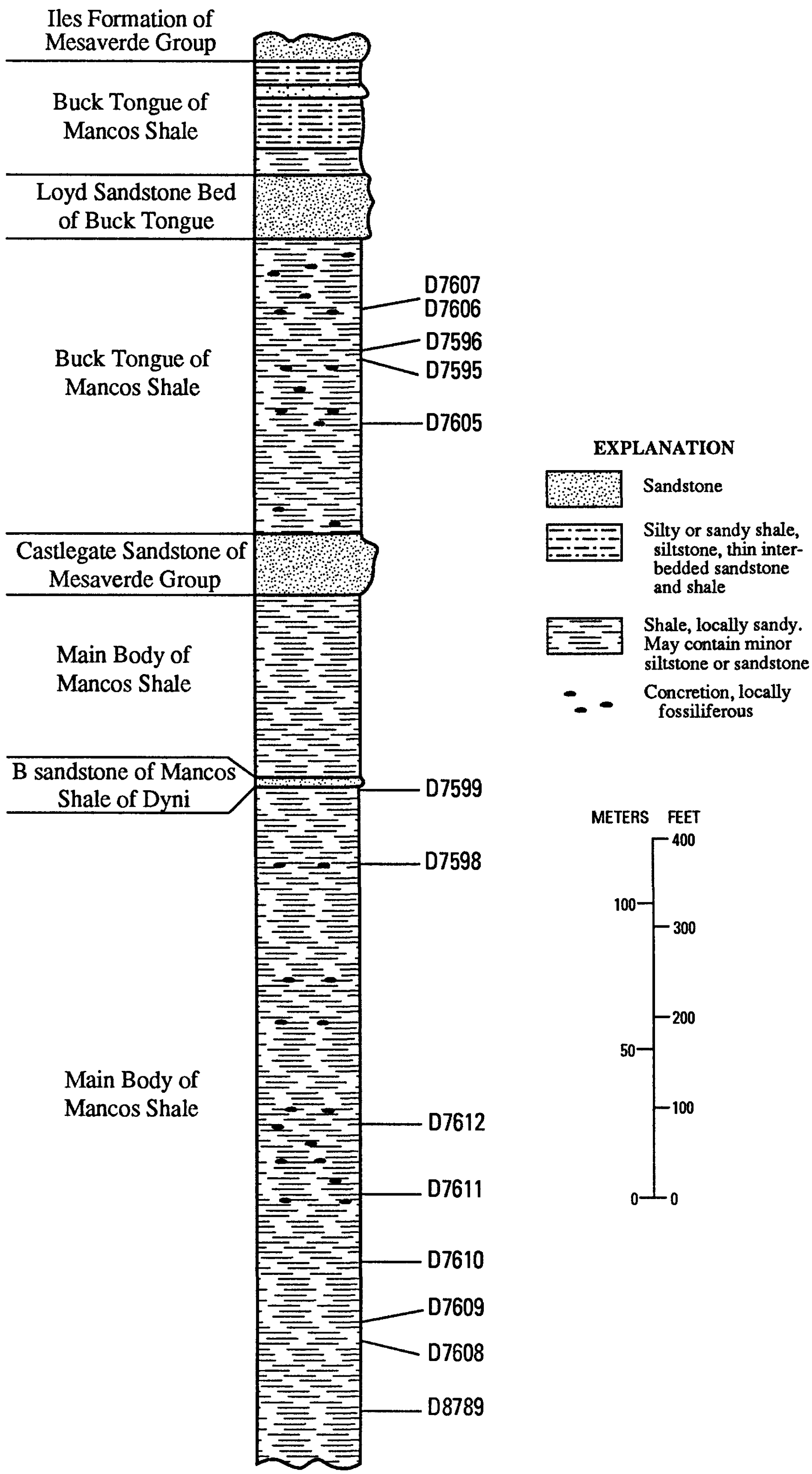


Figure 2. Measured section of Mancos Shale showing stratigraphic position of fossil collections in the report area. Collection numbers are USGS Denver catalog numbers. Adapted from Pinyon Ridge section of Gill and Hail (1975).

quadrangle, adjoining the study area to the north, *Baculites perplexus* is present in the Buck Tongue above, within, and below the Loyd Sandstone Bed (Gill and Hail, 1975).

Fossils

Figure 2 shows the approximate stratigraphic position of fossil collections taken from the Mancos Shale in the study area. Collections, except as noted, were made by James R. Gill, and identifications were made by W.A. Cobban.

USGS D7607. SW¼NE¼ sec. 19, T. 3 N., R. 98 W. *Inoceramus subcompressus* Meek and Hayden, *Baculites perplexus* Cobban.

USGS D7606. SW¼SW¼ sec. 18, T. 3 N., R. 98W. Pyriporoid bryozoan (attached to baculite), *Inoceramus subcompressus* Meek and Hayden, *Cymella montanensis* (Henderson), *Baculites perplexus* Cobban, *Placenticeras* aff. *P. planum* Hyatt.

USGS D7596. SE¼NW¼ sec. 25, T. 3 N., R. 99 W. *Inoceramus subcompressus* Meek and Hayden, *Clisocolus* sp., *Baculites perplexus* Cobban.

USGS D7595. SE¼NW¼ sec. 25, T. 3N., R. 99 W. *Inoceramus subcompressus* Meek and Hayden, *Ostrea* sp., *Anomia*? sp., *Pholadomya* sp., *Baculites perplexus* Cobban, *Hoploscaphites* n. sp., *Placenticeras* aff. *P. planum* Hyatt.

USGS D7605. NW¼SW¼ sec. 19, T. 3 N., R. 98 W. Pyriporoid bryozoan, *Baculites perplexus* Cobban.

USGS D7599. NW¼SE¼ sec. 12, T. 3 N., R. 99 W. *Baculites mclearni* Landes? (juvenile), lobster.

USGS D7598. SE¼NW¼ sec. 24, T. 3 N., R. 99 W. *Inoceramus* sp., *Baculites mclearni* Landes? (juvenile).

USGS D7612. NW¼ sec. 24, T. 3 N., R. 99 W. *Inoceramus* sp., *Pteria* sp., *Baculites obtusus* Meek.

USGS D7611. NW¼ sec. 24, T. 3 N., R. 99 W. *Baculites obtusus* Meek.

USGS D7610. NW¼ sec. 24, T. 3 N., R. 99 W. *Baculites* sp. (weak flank ribs).

USGS D7609. NW¼ sec. 24, T. 3 N., R. 99 W. *Cymbophora* sp., *Baculites* sp. (weak flank ribs).

USGS D7608. NW¼ sec. 24, T. 3 N., R. 99 W. *Baculites* sp. (weak flank ribs).

USGS D8789. SW¼SW ¼ sec. 12, T. 3 N., R. 99 W. *Inoceramus balticus* Boehm, *Cymbophora canonensis* (Meek), *Baculites* sp. (probably the weakly ribbed species), *Hoplitoplacenticeras* aff. *H. vari* (Schluter). Collected by W.J. Hail.

Mesaverde Group

The term Mesaverde Group in northwestern Colorado and northeastern Utah has been used generally to include virtually all of the Cretaceous marine sandstones and nonmarine rocks in the complex intertonguing sequence in which these rocks are separated by tongues of the marine Mancos Shale (Gill and Hail, 1975). In this area, the Castlegate Sandstone, the Iles Formation, and the Williams Fork Formation are regarded as formations of the Mesaverde Group. The Castlegate is a southeastward-thinning formation of the Mesaverde Group separating the Buck Tongue of the Mancos Shale from the main body of the Mancos. Although the Castlegate merges in eastern Utah with rocks of the Mesaverde Group owing to the pinchout of the Buck Tongue of the Mancos, it has not been consistently regarded as a part of the Mesaverde Group. Detailed maps in the Rangely, Colo., area by Cullins (1969, 1971), Barnum and Garrigues (1980), and Garrigues and Barnum (1980) do not include the Castlegate as a part of the Mesaverde Group but include only those Cretaceous rocks above the Buck Tongue of the Mancos Shale.

Separation of the Mesaverde Group above the Buck Tongue of the Mancos into the Iles and Williams Fork Formations follows the usage of Dyni (1968) in the Elk Springs quadrangle. These names are used to the east at the northeast margin of the Piceance Creek basin and in the Sand Wash basin farther north and east. The two formations are separated on the basis of the presence of the Trout Creek Sandstone Member at the top of the Iles. The Trout Creek pinches out within the lower Yellow Creek area, but the names Iles and Williams Fork are retained where the Trout Creek is absent and the contact between the two is placed at the base of the coaly carbonaceous zone that elsewhere immediately overlies the Trout Creek.

Castlegate Sandstone

The Castlegate Sandstone is a light-brown to yellowish-gray, brown-weathering, thin-bedded to massive, very fine to fine grained sandstone. It contains some interbedded dark shale, mostly in the lower part. Although no fossils were found in the Castlegate in the study area, the entire unit is believed to be marine. The Castlegate is very hard and resistant and forms persistent cliffs and dip slopes. It is the unit mapped by Dyni (1968) as sandstone unit C in the Mancos Shale in the Elk Springs quadrangle to the north. It has been mapped to the west in the Rangely area (Cullins, 1971; Barnum and Garrigues, 1980; Garrigues and Barnum, 1980). In the study area the Castlegate is about 40–60 ft (12–18 m) thick.

Iles Formation

Main Body

The Iles Formation consists of a basal marine sandstone overlain by a sequence of nonmarine fluvial and paludal rocks of which the uppermost unit is, in part of the study area, the Trout Creek Sandstone Member.

A persistent cliff-forming marine sandstone lies at the base of the Iles. This unit, 35–65 ft (11–20 m) thick, consists generally of a lower, cliff-forming, brown-weathering, fine-grained sandstone and an upper, light-gray-weathering, fine- to medium-grained sandstone. Sparse trace-fossil burrows, probably *Ophiomorpha*, suggest a shallow-water marine origin. This unit is the youngest known marine unit in the area. It is probably equivalent to the Sego Sandstone as mapped to the west in the Cactus Reservoir quadrangle (Barnum and Garrigues, 1980), also the youngest marine unit. Rocks of marine origin, if present in younger beds of the Iles, have not been identified.

The lower part of the main body of the Iles, above the basal sandstone, is mostly gray claystone and mudstone, relatively thin beds of fine- to medium-grained sandstone, and abundant carbonaceous shale. The sandstones are variably resistant, forming alternating soft slopes and some resistant ledges. A persistent coaly carbonaceous shale zone lies just above the basal marine sandstone. Coal beds in this carbonaceous zone are nonpersistent but locally are as thick as 3.4 ft (1 m). These beds have been locally removed by scour and the interval is now occupied by sandstone beds. Other carbonaceous shale zones in the lower part of the Iles contain only a few thin shaly coal beds. This part of the Iles reflects deposition mostly in a coastal-plain fluvial and paludal environment.

The upper part of the main body of the Iles con-sists of thick, lenticular, massive, brown-weathering sandstone that forms resistant ledges and cliffs and light-gray-weathering mudstone and claystone. Carbonaceous shale is rare except near the top of the unit where a few thin coal beds are present. These rocks repre sent deposition in a dominantly fluvial, flood-plain environment.

The main body of the Iles above the basal marine sandstone (Sego equivalent) is correlative to the west with the lower unit of the Mesaverde Group and that part of the coal unit of the Mesaverde Group below the base of the main coal zone as mapped in the Cactus Reservoir quadrangle (Barnum and Garrigues, 1980) and in the Rangely NE quadrangle (Garrigues and Barnum, 1980). The main body of the Iles above the basal marine sandstone is about 600–750 ft (180–230 m) thick.

Trout Creek Sandstone Member

A conspicuous light-gray, fine-grained, crossbedded nonmarine sandstone was mapped by Dyni (1968) in the Elk Springs quadrangle as the Trout Creek Sandstone Member. The sandstone was mapped southward into the study area to a point in sec. 17, T. 3 N., R. 98 W., where it pinches out and cannot be traced farther south as a continuous unit. In the Meeker area and farther to the east, the Trout Creek is a nearshore marine unit. The unit crops out about 12 mi (19 km) northeast of the study area in the Citadel Plateau quadrangle, where it locally contains the marine trace fossil *Ophiomorpha* (Izett and others, 1984). In the lower Yellow Creek area, the Trout Creek is a very light gray to light-brown, massive to crossbedded, fine- to medium-grained sandstone and is entirely nonmarine. The maximum thickness of the Trout Creek is about 110 ft (34 m) near the northern boundary of the area.

Williams Fork Formation

The Williams Fork Formation of Late Cretaceous age is entirely of nonmarine origin in the lower Yellow Creek area. It consists of approximately equal proportions of channel and other fluvial sandstones and fine-grained rocks, mostly claystone, shale, and mudstone. Coal beds are present in the upper and lower parts of the formation. The formation ranges in thickness from about 2,000 ft (610 m) at the west edge of the study area to about 2,600 ft (790 m) near Crooked Wash in the eastern part of its outcrop area. The rocks were deposited in environments ranging from fluvial flood plain to coastal plain.

The sandstone is mostly nonpersistent, lenticular, light to medium gray, crossbedded to massive, and very fine to medium grained; many sandstone beds are thin, even bedded, and tabular. Limy concretions are abundant in the thicker sandstones, many of which are conglomeratic and contain claystone or other soft-rock clasts. Most of the sandstone beds are relatively resistant and form strong cliffs or ledges. Claystone, shale, and mudstone are gray to grayish green and commonly contain orange-weathering limy septarian concretions, especially in the upper part of the formation. Most of the claystone and mudstone beds are soft and nonresistant and form slopes. Brown carbonaceous shale and claystone are relatively abundant.

Two major coal-bearing carbonaceous zones are present in the Williams Fork. Coal beds occur in discontinuous carbonaceous shale zones, and individual coal beds are lenticular and nonpersistent. Coal beds are locally scoured and replaced by overlying channel sandstones. The lower coal-bearing carbonaceous zone lies chiefly within the lower 300 ft (92 m) of the formation and persists throughout the area and continues westward into the Rangely area. The upper coal-bearing zone lies mostly within the upper third of the formation near Crooked Wash, where the formation reaches its maximum thickness of about 2,600 ft (790 m). The upper zone does not persist into the western part of the area, and erosional truncation from east to west may account in part for the absence of the upper coal-bearing zone in the western part of the area.

The Cretaceous-Tertiary boundary in the study area and throughout the Piceance Creek basin is an unconformity below which a considerable thickness of upper Cretaceous beds was removed. In the study area, the Williams Fork thins as much as 600 ft (180 m) from east to west below the unconformity. Much of this thinning is probably due to pre-Tertiary erosion, presumably the result of early Laramide uplift along the Douglas Creek arch to the west.

Geologic maps of the Rough Gulch and Smizer Gulch quadrangles (Hail, 1974a, 1973) show a stratigraphic unit designated Ohio Creek(?) Formation of Paleocene age. It was mapped as a thin, nonpersistent unit at the Cretaceous-Tertiary boundary and consists of very light brown to white sandstone that locally contains very sparse chert or quartzite fragments. A study by Johnson and May (1980) shows that the Ohio Creek at its type locality and elsewhere in northwestern Colorado is, for the most part, a weathered zone beneath the pre-Tertiary erosion surface. Weathered sandstone in this zone is commonly white or very light gray, owing to kaolinization of feldspars in the sandstone (Johnson and May, 1980, p. 11–12). Furthermore, the uppermost Cretaceous beds are locally pebbly, as are certain Tertiary beds above the unconformity (Johnson and May, 1980, fig. 2, p. 6, 14, 15, and 23). Thus, the Ohio Creek, as commonly used in maps and other studies, does not constitute a lithostratigraphic unit. In the lower Yellow Creek area, most of the rocks previously designated as Ohio Creek(?) Formation are herein tentatively included in the Williams Fork Formation.

Three localities in the Williams Fork Formation yielded identifiable fossils. W.A. Cobban identified the following mollusks from USGS fossil locality D7058: *Tulotomops thompsoni* (White), and *Lioplacoides* cf. *L. nebrascensis* (Meek and Hayden); the gastropod *T. thompsoni* is restricted to the Lance Formation and equivalent formations. The locality lies about 250 ft (76 m) below the top of the Williams Fork in the SW¼SE¼ sec. 31, T. 3 N., R. 98 W. Robert H. Tschudy (USGS) identified fossil pollen from USGS paleobotany localities D4773 and D4777. Locality D4773 yielded *Aquilapollenites*, *Proteacidites*, *Araucariacites*, and *Ephedra* (small), all of which indicate a Late Cretaceous age no older than Campanian. This locality lies about 520 ft (160 m) below the top of the Williams Fork Formation in the SW¼NW¼ sec. 11, T. 3 N., R. 98 W. Locality D4777 yielded *Proteacidites*, *Aquilapollenites*, *Liliacidites complexus*, *Eucommiidites*, and *Gunnera*, which also indicate a Late Cretaceous age no older than Campanian. This locality lies about 80 ft (24 m) below the top of the Williams Fork in the SE¼NW¼ sec. 30, T. 3 N., R. 97 W.

The Williams Fork Formation is correlative to the east with the Williams Fork Formation on the eastern margin of the Piceance Creek basin, although the Williams Fork in that area is considerably thicker below the pre-Tertiary unconformity and probably includes younger rocks. Near Meeker, about 20 mi (32 km) southeast of the study area, the Williams Fork is about 5,000 ft (1,520 m) thick (Hancock and Eby, 1930, p. 197). Northwest of Meeker along Strawberry Creek, about 17 mi (27 km) east of the study area, the Williams Fork is about 4,000 ft (1,220 m) thick (Pipiringos and Rosenlund, 1977b). In the Citadel Plateau quadrangle, about 10 mi (16 km) northeast of the area, the Williams Fork is about 3,800 ft (1,160 m) thick (Izett and others, 1984). To the west, in the Rangely area, the Williams Fork is correlative with the upper unit of the Mesaverde Group and that part of the coal unit of the Mesaverde Group above the base of the main coal zone (Barnum and Garrigues, 1980; Garrigues and Barnum, 1980).

Tertiary Rocks

Fort Union Formation

A lithologically distinct sequence of Paleocene rocks comprises the basal Tertiary section throughout the northern part of the Piceance Creek basin and much of the basin. In the lower Yellow Creek area, these rocks have been designated Fort Union Formation. The formation consists of a lower member of fluvial channel sandstone and claystone and an upper member of mostly paludal shale and thin sandstone.

Correlation and History of Nomenclature

A distinctive sequence of Paleocene rocks has long been recognized in both the Sand Wash and Piceance Creek basins of Colorado. Early studies, along with geologic mapping in the Sand Wash basin, recognized the distinctive character of the Paleocene beds. These strata were termed "post-Laramie" beds in most of the early studies, at a time when the now geographically restricted term Laramie was applied to the latest Cretaceous rocks in the Sand Wash basin. These post-Laramie rocks were recognized as Paleocene in age, based on fossil leaves and their stratigraphic position beneath the largely Eocene Wasatch Formation. Bass and others (1955, p. 161) used the name Fort Union Formation for these rocks in the Sand Wash basin, and the name has been used in most subsequent reports. Correlative rocks in the Piceance Creek basin, however, generally have been included with the Wasatch Formation.

In his description of the western Yampa Coal Field, Gale (1910, p. 223, and pl. 16) suggested the possibility of using the term Fort Union for the "post-Laramie" rocks in the Sand Wash basin north of Lay and Craig, Colo. Gale (1910, p. 44) described these rocks as a basal conglomeratic sandstone and massive, white or light-colored sandstone and shale that contain valuable coal beds. He retained the term "post-Laramie," however, because of the uncertainty of a Tertiary age determination. He tentatively correlated basal Tertiary beds in the northern Piceance Creek basin with the Fort Union but did not map a unit separate from the Wasatch. "On the geologic maps no attempt has been made to separate Fort Union from Wasatch in the Grand and White River region, as it is not yet clear that two such formations can be differentiated or at least are to be distinguished by any recognizable features in this region" (Gale, 1910, p. 80, 81). His map unit Tw for the Piceance Creek basin map is designated "Wasatch formation (including Fort Union?)" (Gale, 1910, pls. 10, 16, 18, and 19).

Sears (1925, p. 291–292), in his description of rocks in the Sand Wash and Piceance Creek basins, followed Gale's usage and showed "post-Laramie" rocks in the Sand Wash basin but included probably correlative rocks in the Piceance Creek basin in the Wasatch. Hancock and Eby (1930, p. 209), in their report on the Meeker quadrangle on the northeastern margin of the Piceance Creek basin, also included all pre-Green River Formation Tertiary rocks in the Wasatch Formation. They described the Wasatch as comprising two units: a lower unit, as thick as 4,180 ft (1,270 m), of sandstone, sandy shale and conglomerate, and an upper unit of varicolored clay and shale. They described the lower unit: "In lithology and stratigraphic occurrence these beds bear a striking resemblance to the post-Laramie beds of the Yampa field, which are most likely of Fort Union age."

Donnell (1961, p. 844–846) described an unnamed Paleocene unit that is probably correlative with the Fort Union and probably underlies much of the Piceance Creek basin between the Colorado and White Rivers. This unit is as thick as 500 ft (150 m) along the Grand Hogback at the eastern margin of the basin and consists of massive brown and gray sandstone beds, gray and brown clay and shale beds, and a few thin coal beds. The unit was not mapped separately but was included with the Wasatch Formation. In a later report, Donnell (1969, p. 1–11, 13–14) assigned the Paleocene beds in the southern part of the Piceance Creek basin to the Atwell Gulch Member of the Wasatch Formation.

In the White Rock quadrangle, 9–12 mi (14–19 km) east of the lower Yellow Creek area at the northeastern margin of the Piceance Creek basin, Pipiringos and Rosenlund (1977a) mapped a sandstone member of the Fort Union Formation that is about 1,200-1,400 ft (370–430 m) thick. They included in the overlying Wasatch Formation a sequence of Paleocene-age beds at least 735 ft (224 m) thick and described these beds as drab-gray and white claystone, a few ferruginous zones, and at least one brown carbonaceous shale bed. Izett and others (1984) extended the Fort Union northwestward in the Citadel Plateau quadrangle, where it is about 1,500–2,300 ft (460–700 m) thick. In the Indian Valley quadrangle, to the west of the White Rock quadrangle, Pipiringos and Rosenlund (1977b) determined from an analysis of drill-hole information that Paleocene rocks may range in thickness from about 1,500 to 2,200 ft (460–670 m).

In the Elk Springs quadrangle, immediately north of the lower Yellow Creek area at the northwestern edge of the Piceance Creek basin, Dyni (1968) designated all pre-Green River Tertiary beds, including undifferentiated rocks of Paleocene age at the base, as "Wasatch Formation and associated rocks." Both members of the Fort Union of the lower Yellow Creek area are present in the basal part of the Tertiary in the Elk Springs quadrangle (Hail, 1981), and in a drill hole at the eastern margin of the quadrangle the Fort Union is as thick as 2,200 ft (670 m).

The Fort Union extends westward and persists around the northwestern margin of the Piceance Creek basin and thence southward into the Cathedral Bluffs area. In the Cactus Reservoir quadrangle, about 8 mi (13 km) west of the lower Yellow Creek area, Barnum and Garrigues (1980) included these beds in the lower member of the Wasatch. In the Calamity Ridge quadrangle, about 8 mi (13 km) southwest of the study area, Donnell and Hail (1984) also included these beds in the basal part of the main body of the Wasatch Formation.

Lower Member

Throughout most of the study area, the lower member of the Fort Union Formation consists of approximately equal proportions of light-gray to light-brown, fluvial-channel sandstone and olive-green to gray, fluvial-plain claystone and mudstone. Minor constituents are siltstone, carbonaceous shale, and limestone. In the outcrop area north and east of the White River, the sandstones form resistant, conspicuous cliffs and ridges, but the claystones and mudstones are relatively nonresistant. The lower member is early or middle Paleocene to late Paleocene in age.

Sandstone generally is present at the base of the lower member and commonly forms the thickest sandstone sequence in the member (fig. 3). The basal contact with the Williams Fork Formation is sharp and unconformable. The basal sandstone commonly lies on

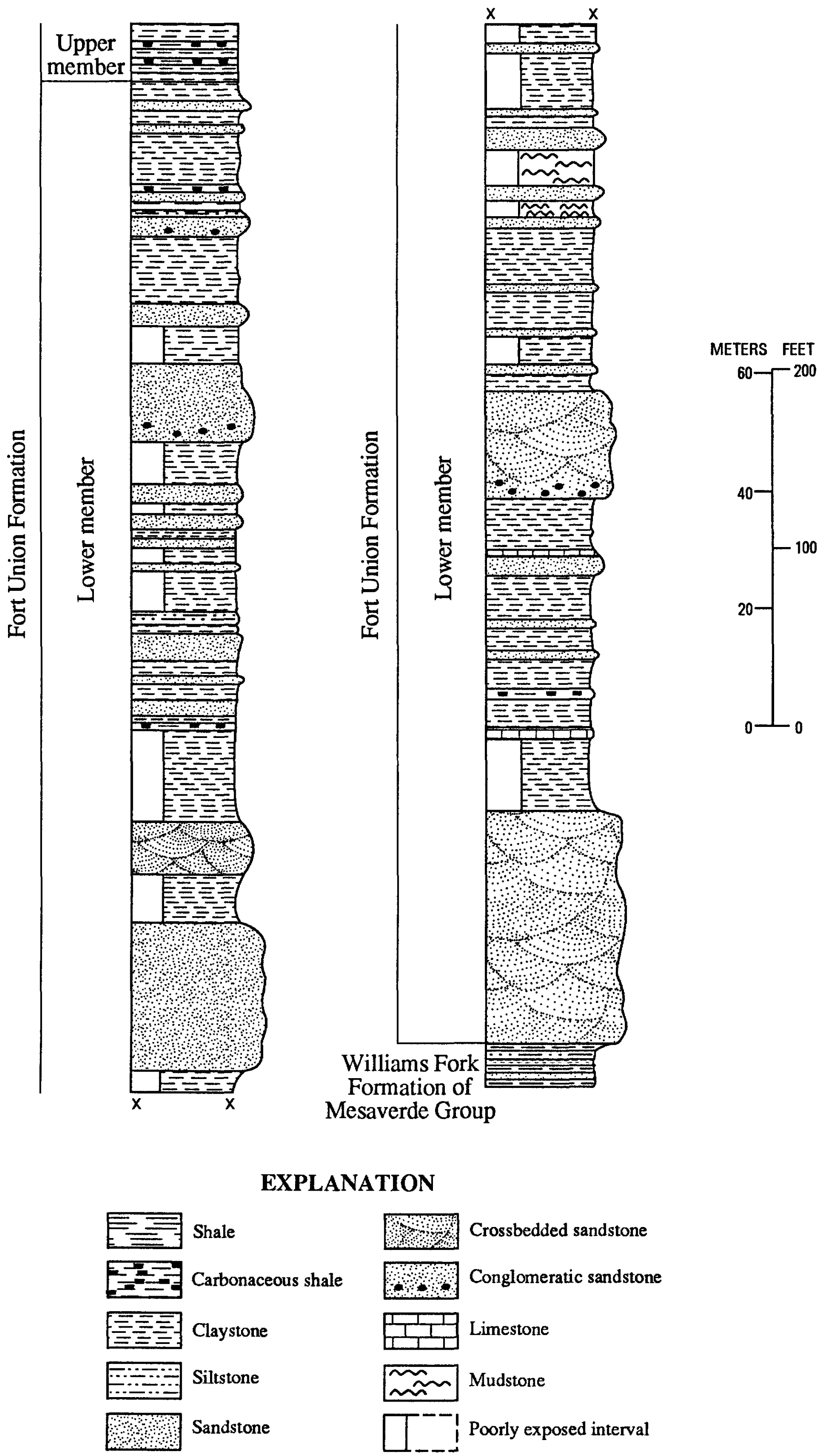


Figure 3. Measured section of lower member of Fort Union Formation. Near mouth of Crooked Wash in NW¼ sec. 1 and NE¼ sec. 2, T. 2 N., R. 98 W., and SE¼ sec. 35 and SW¼ sec. 36, T. 3 N., R. 98 W. Township-range map shown in figure 12.

eroded and locally bleached carbonaceous and other beds of the Williams Fork. Beds of the upper coal-bearing zone of the Williams Fork are truncated at the contact. Overlying beds of the lower member of the Fort Union contain only a few very thin carbonaceous beds. The basal sandstone is mostly massive but is locally crossbedded and contains limy spheroidal concretions. A few lenses of soft-pebble conglomerate are present locally, at or near the base. Most of the sand is medium grained, but grain size varies widely. Stratigraphically higher sandstone beds in the lower member also are mostly nonpersistent channel deposits. They are massive to crossbedded, mostly fine to medium grained and rarely coarse grained, and mostly calcareous. The more resistant beds are firmly cemented with calcite. A few conglomeratic lenses are present, mostly near the bases of the sandstone beds. These lenses consist of claystone clasts and lesser siltstone or sandstone clasts in a poorly sorted calcareous matrix of medium- to coarse-grained quartz sand and abundant dark rock and mineral fragments.

Claystone and mudstone of fluvial origin in the lower member are mostly olive green to greenish gray. The greenish color is a conspicuous characteristic of the member in the outcrop area north of the White River. A few red or drab-purplish beds or weathered zones are present locally. Most claystone and mudstone beds are poorly exposed and nonresistant and form valleys and covered slopes between the resistant sandstone beds. Some resistant cliff-forming mudstone beds occur locally. The claystone beds are variably silty and locally contain beds of clayey siltstone. Wherever silt or sand is abundant, the beds are termed mudstone. Bedding is mostly absent, although some shaly structure is present in the rare carbonaceous shale or dark-gray shale beds.

The lower member thins markedly to the west within the area. At the eastern edge of its outcrop area it is about 1,800 ft (550 m) thick, based on subsurface information. Near the mouth of Crooked Wash, 5 mi (8 km) to the west, it is 1,140 ft (350 m) thick (fig. 4). At the east end of Stadtman Mesa, 4 mi (6.5 km) farther west, it is only about 400 ft (120 m) thick, and at the west end of Stadtman Mesa, 3.5 mi (5.5 km) farther west, it is only about 150 ft (45 m) thick. This westward thinning of about 1,650 ft (500 m) in a distance of less than 13 mi (21 km) is believed to be the result of depositional onlap on the rising Douglas Creek arch during Paleocene time (Johnson and Keighin, 1981, p. 203). The Douglas Creek arch apparently began to rise in Late Cretaceous time and continued rising until early to middle Eocene time (Tweto, 1975, p. 34; Johnson and Keighin, 1981, p. 203). Westward thinning of the lower member of the Fort Union by onlap on the Douglas Creek arch coincides with westward erosional thinning of the underlying Cretaceous rocks. Total thinning in the Williams Fork and Fort Union Formations is as much as 2,250 ft (690 m) within the Yellow Creek area. At the western margin of the area, where the lower member of the Fort Union is thinnest, sandstone beds are mostly absent and the member consists mostly of claystone. Beds of middle Paleocene age are present at least 4 mi (6.5 km) west of the area in the Divide Creek quadrangle (R.H. Tschudy, written commun., 1975).

Two localities in the lower member of the Fort Union Formation yielded identifiable fossils. R.H. Tschudy (written commun., 1971) identified fossil pollen from USGS fossil localities D4629 and D4633. Locality D4629 "yielded a middle to early Paleocene assemblage of plant microfossils. The presence of *Maceopolipollenites* in the sample suggests, however, that it is not representative of the earliest part of the Paleocene." This locality lies about 300 ft (90 m) above the base of the member in the SW¼NW¼ sec. 29, T. 3 N., R. 97 W. Locality D4633 "yielded a good middle to late Paleocene suite of plant microfossils." This locality lies about 250 ft (76 m) below the top of the member in the SE¼SE¼ sec. 31, T. 3 N., R. 97 W. Several collections of freshwater mollusks, mostly gastropods, from the lower member were identified by W.A. Cobban (oral commun., 1970) as being of Tertiary age.

Upper Member

The upper member of the Fort Union Formation consists mostly of paludal and possibly some lacustrine deposits: gray shale, thin persistent sandstone beds, carbonaceous shale and claystone and some coaly carbonaceous shale and coal, and minor siltstone. Olive-green claystone is present in the lower part of the upper member in the transition zone between the fluvial claystones of the lower member and the overlying paludal beds of the upper member. The basal contact is arbitrarily placed within this transition zone and may not everywhere be at the same stratigraphic horizon. In the area near the mouth of Colorow Gulch (fig. 4), the contact is placed at the base of the lowest of several conspicuous carbonaceous shale beds typical of higher carbonaceous beds throughout the upper member. The distinctive darker color of the upper member is in contrast to the lighter colors of the underlying lower member and the overlying Wasatch Formation. Resistant sandstone beds locally form cliffs and ledges, but the more common shale beds are nonresistant and form a subdued topography of poorly exposed rocks. The upper member is late Paleocene in age.

The dominant lithology of the upper member is gray clay shale. This share locally grades laterally to brown carbonaceous shale and claystone with a corresponding increase in sapropelic material; some thin car-

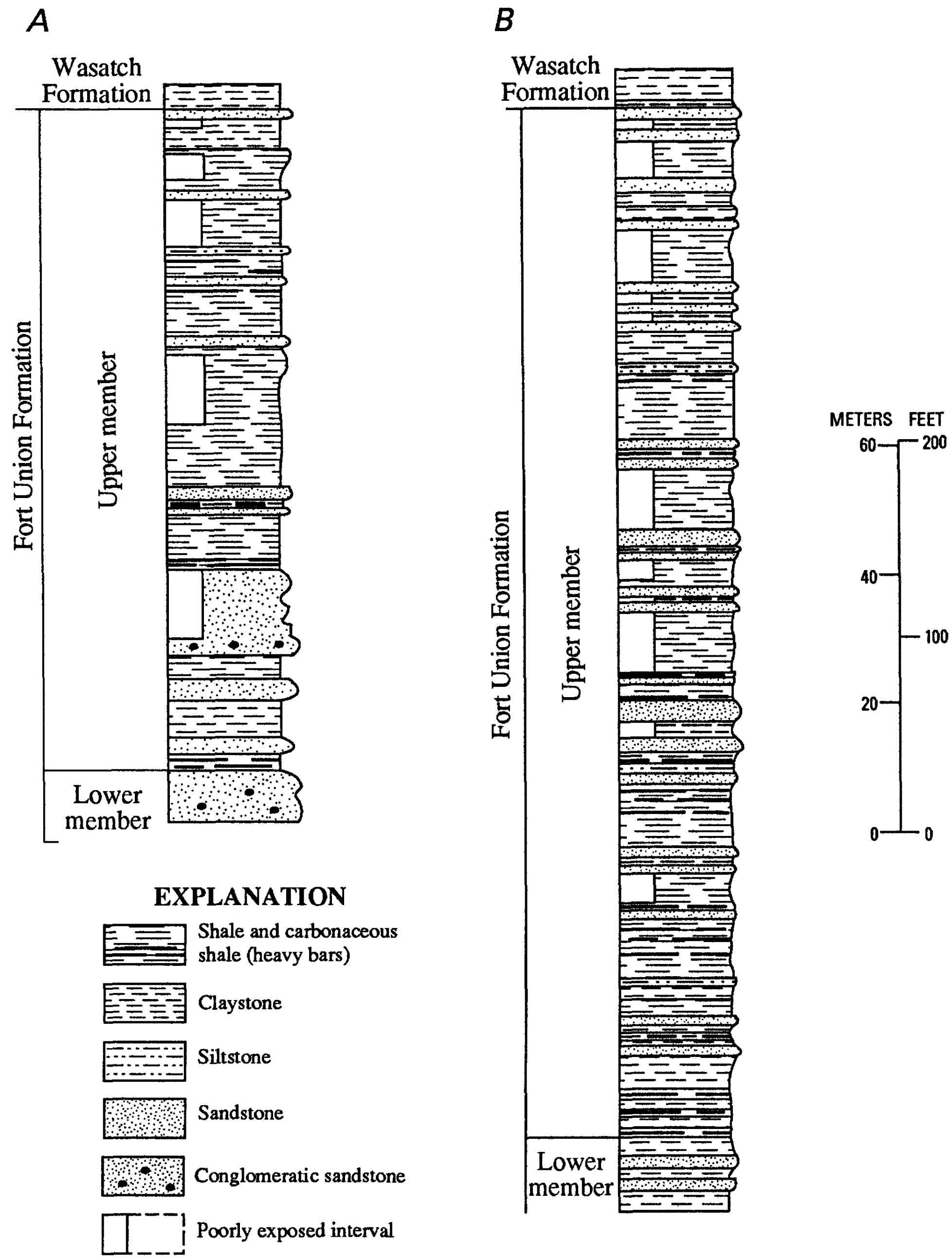


Figure 4. Measured sections of upper member of Fort Union Formation. *A*, Near mouth of Yellow Creek in SE¼ sec. 4, T. 2 N., R. 98 W. *B*, Near mouth of Colorow Gulch in NW¼ sec. 1, T. 2 N., R. 98 W. Township-rangemap shown in figure 12.

bonaceous shale grades laterally into coal. Coal beds are sparse and very thin, generally only a few inches thick. Most of the sandstone is gray to dark brown, fine grained and calcareous, and contains much non-quartz mineral or rock constituents. The sandstone beds are thin, commonly even bedded, and relatively persistent. Most are firmly calcite cemented, hard, and resistant. A few crossbedded sandstones are present, and from near Yellow Creek westward the upper member contains several apparent channel sandstones, some containing soft-pebble conglomeratic lenses.

The upper member is about 330–530 ft (100–160 m) thick and exhibits no consistent thinning trend. Differences in thickness may be due in part to the indefinite lower boundary

Three localities yielded identifiable fossils in the upper member of the Fort Union. R.H. Tschudy (written commun. 1971) identified palynomorphs from USGS fossil localities D4631, D4632, and D4637. Locality D4631 yielded *Carya*, *Abietineaepollenites*, *Maceopolipollenites tenuipolis*, *Pediastrum*, *Botryococcus*, and *Pistillipollenites*, a late Paleocene assemblage. This locality is

65 ft (20 m) above the base of the upper member in the SW¼NW¼ sec. 1, T. 2 N., R. 98 W. Locality D4632 yielded *Carya*, *Ulmus-Zelkova*, *Inaperturopollenites*, *Abietineaepollenites*, *Pistillipollenites*, and *Erdtmanipollis*, a definitive late Paleocene palynomorph assemblage. This locality is about 50 ft (15 m) below the top of the upper member in the NE¼SW¼ sec. 1, T. 2 N., R. 98 W. Locality D4637 yielded the same forms as D4632, as well as *Alnus*, *Pediastrum*, and *Botryococcus*, a late Paleocene pollen and spore assemblage. Locality D4637 is about 150 ft (46 m) below the top of the upper member in the SE¼SE¼ sec. 4, T. 2 N., R. 98 W.

Wasatch Formation

The Wasatch Formation in the lower Yellow Creek area consists mostly of alluvial claystone and sandstone. Throughout much of the study area, a dark shale and claystone facies is present in the upper part of the Wasatch and consists of rocks of alluvial, paludal, and lacustrine origin. The Wasatch lies conformably on the upper member of the Paleocene Fort Union Formation. The boundary marks the change across a narrow interval from paludal rocks of the upper member of the Fort Union to alluvial rocks of the Wasatch. The contact commonly is placed at the base of the lowermost beds of red or purple claystone or of fluvial sandstone of the Wasatch above the dark-gray clay shale or brown carbonaceous beds of the Fort Union. The lowermost beds of the Wasatch are late Paleocene in age and do not exceed a few tens of feet in thickness. All higher beds of the Wasatch are Eocene in age.

The diverse rock types of the Wasatch form a varied topography. In general, the lower part of the main body of the Wasatch contains thicker and more resistant sandstone beds than does the upper part and forms prominent ledges and ridges. The higher ground of the divide between Smizer and Colorow Gulches is formed mostly on these beds. The claystones are relatively nonresistant and form slopes, valleys, or badland topography. The strike valley of Smizer Gulch is cut into the nonresistant claystones above the more resistant sandstone sequence. Resistant thin sandstones of the dark shale facies form strong ledges and dip slopes that dominate the topography of the outcrop area just east of the White River. In the southeastern part of the area, in the drainages of Kissinger, Short, and Tom Little Gulches, a rough topography of gullies, benches, and badlands is cut on the main body of the Wasatch.

Main Body

The following description applies to all alluvial beds of the Wasatch, above, below, and lateral to the dark shale facies. The dominant rock type in the main body is gray, greenish-gray, brown, and varicolored claystone. The varicolored rocks are green, purple, red, and yellowish brown and generally are more abundant in the upper part of the main body than in the basal few hundred feet. The brighter colored, red or purple varicolored rocks are the most conspicuous feature of the main body of the Wasatch. Some of the claystone especially near the base, locally has shaly bedding. For the most part, however, the claystone lacks shaly bedding and weathers out into blocky fragments. It is locally silty or sandy and grades into mudstone. Abundant fluvial channel sandstone beds are mostly fine grained, but some of the thicker beds are medium to coarse grained. A few contain soft-pebble conglomerate beds. Concentrations of freshwater mollusks are locally abundant in some of the sandstone beds. Most of the sandstone beds are lenticular and nonpersistent and show little or no discernable bedding; some, however, are locally crossbedded or even bedded. The sandstone beds are mostly light gray to light brown, locally concretionary, and highly calcareous and form resistant ledges where firmly calcite cemented. The thickest sandstone beds generally are in the lower part of the main body and are as thick as 50 ft (15 m). The lithology of the Wasatch, as exposed along the east side of Yellow Creek, is shown in figures 5 and 6.

Other rock types in the main body of the Wasatch are sparse. They include a few beds of brown carbonaceous shale and siltstone, very thin beds of ostracodal sandstone or limestone, and beds of dark-gray shale of probable lacustrine origin.

The rocks of the main body of the Wasatch were probably deposited on an arid fluvial plain that contained a few small ponds and swamps. The Wasatch, including the dark shale facies, ranges in thickness from about 1,000 ft (300 m) at the western edge of the area to about 2,100 ft (640 m) in the northeastern part of the area; it apparently continues to thicken east of the area. Equivalent strata in the eastern parts of the Indian Valley and White River City quadrangles, just east of the lower Yellow Creek area, are about 3,400 ft (1,040 m) thick (Pipiringos and Johnson, 1976; Pipiringos and Rosenlund, 1977b).

Dark Shale Facies

On the geologic maps of the Rough Gulch and Smizer Gulch quadrangles (Hail, 1973, 1974a), a separate map unit (Twl) of the Wasatch was described as containing some probable lacustrine beds. The unit was mapped separately only west of the White River.

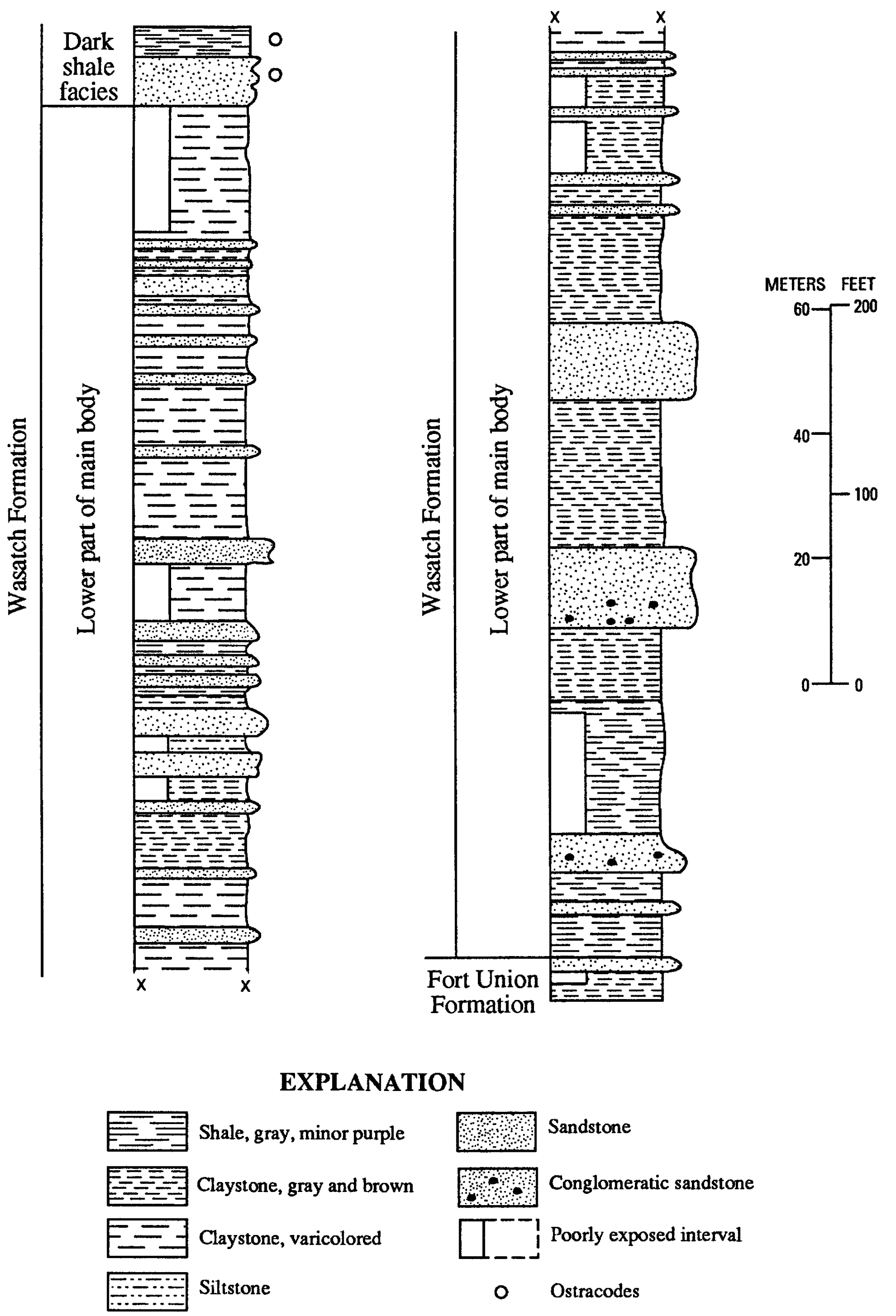


Figure 5. Measured section of lower part of main body of Wasatch Formation. East side of Yellow Creek in SE¼ sec. 4, SW¼ sec. 3, NW¼ sec. 10, and NE¼ sec. 9, T. 2 N., R. 98 W. Township-range map shown in figure 12.

Subsequent mapping (Hail and Pipiringos, in press) extends the unit for several miles east of the White River, almost to the east boundary of the area, insofar as the unit can be separated from the main body of the Wasatch

The dark shale facies comprises a wide variety of rock types including green or gray, locally varicolored, alluvial claystone; fluvial channel sandstone; lacustrine ostracodal sandstone, shale, and limestone; and paludal carbonaceous shale and claystone. The unit lacks the prominent light-colored and varicolored claystones of the main body of the Wasatch and generally presents a relatively dark aspect. The even-bedded shale and thin, persistent lacustrine sandstone and limestone give the unit a layered appearance.

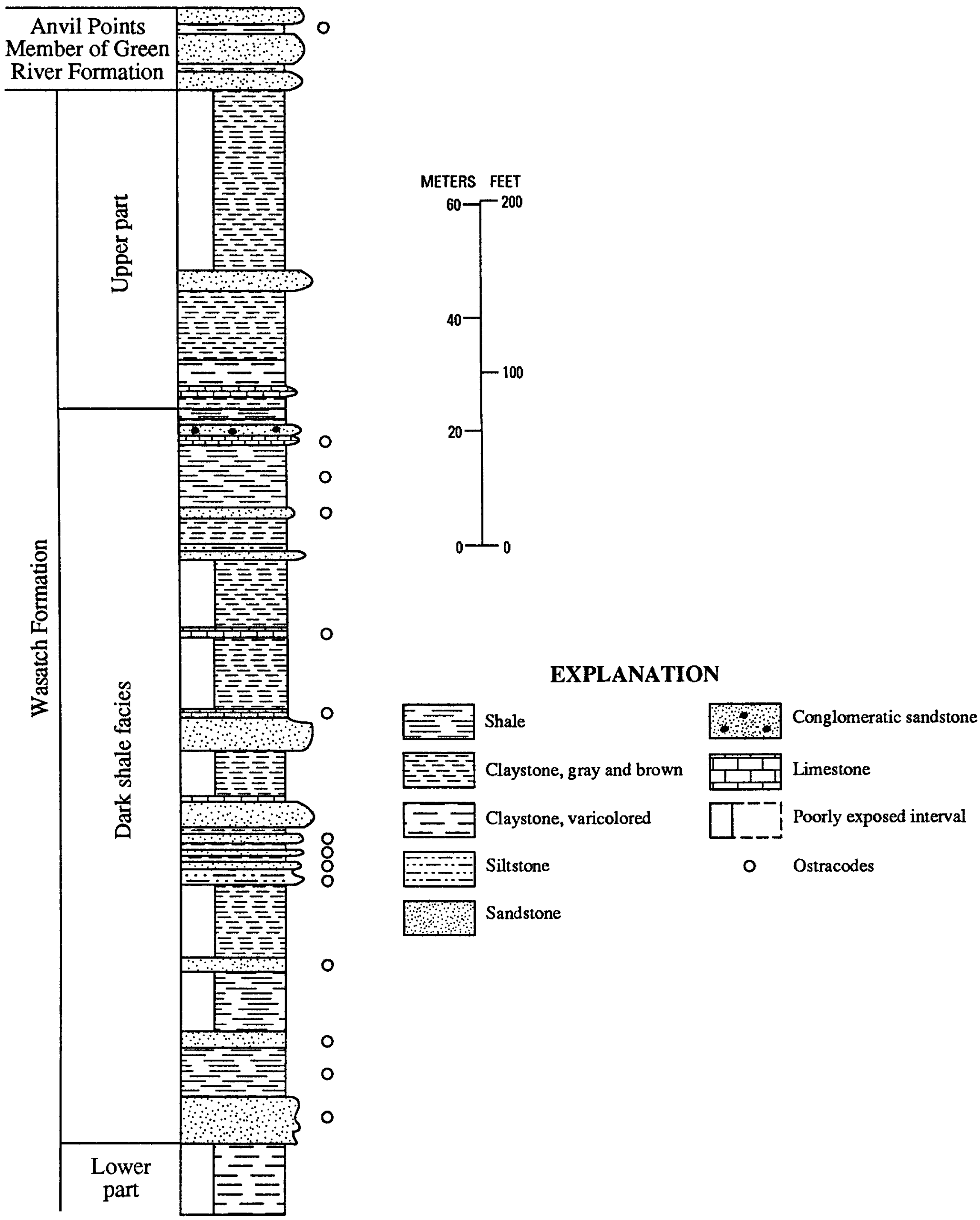


Figure 6. Measured section of part of Wasatch Formation and Anvil Points Member of Green River Formation. East side of Yellow Creek in NE¼ sec. 9 and NW¼ sec. 10, T. 2 N., R. 98 W. Township-range map shown in figure 12.

Johnson (1984, p. 13–19, pl. 1) correlated the dark shale facies with the newly named Cow Ridge Member of the Green River Formation and designated the exposure on the east side of Yellow Creek (Rough Gulch quadrangle) as a reference section of the Cow Ridge. The Cow Ridge is the oldest member of the Green River Formation and represents an early Eocene to early middle Eocene freshwater stage of Lake Uinta (Johnson, 1984, p. 4).

At Yellow Creek, the dark shale facies includes ostracodal, probably lacustrine, brown to gray shale in the lower part and near the top. Thin ostracodal limestone and limy sparsely ostracodal sandstone are present throughout the unit and form resistant ridges and dip slopes. Nonostracodal, gray to greenish-gray claystone beds comprise almost half of the unit and appear to be typical Wasatch alluvial claystone.

In the outcrop area east and north of the White River, the dark shale facies contains abundant lacustrine ostracodal sandstone, limestone, and shale as at Yellow Creek. It contains a greater proportion of paludal carbonaceous shale and dark, locally purple weathering, alluvial claystone than at Yellow Creek. Several massive to crossbedded channel sandstone beds also are present.

The dark shale facies is about 425 ft (130 m) thick at Yellow Creek but thins abruptly to the west. It was traced as a map unit to a point about 3 mi (5 km) west of Yellow Creek in sec. 1, T. 2 N., R. 99 W., where it is only a few feet thick. In the area north and east of the White River, it reaches a maximum thickness of about 250 ft (76 m) and, because the base is not exposed, may be thicker. Near the eastern edge of the mapped exposures, where top and base are both present, the unit is only about 100 ft (30 m) thick. Presumed outliers of the unit are present as far east as the eastern boundary of the area.

Pipiringos and Rosenlund (1977b) mapped a possible tongue of the Green River Formation in the extreme northern part of the Indian Valley quadrangle and suggested its possible equivalence to the unit mapped as the dark shale facies in this study; however, similar beds were not observed elsewhere in the Indian Valley quadrangle and the correlation remains doubtful.

The dark shale facies appears to terminate rather abruptly in a southwesterly direction parallel with and just northeast of the White River in secs. 7, 17, 18, and 20, T. 2 N., R. 97 W. Firm evidence of post-Wasatch faulting was not found, and the abrupt change from dark shale facies to the main body of the Wasatch near the eastern edge of section 18 is probably depositional, possibly owing to relief on a local Eocene erosion surface or on an Eocene eroded fault scarp.

Fossils and Correlation

Three localities yielded identifiable fossils in the Wasatch Formation. R.H. Tschudy (written commun., 1971, 1972) identified fossil palynomorphs from USGS fossil localities D4636, D4775, and D4626. Locality D4636 yielded *Carya*, *Abietineaepollenites*, *Alnus*, *Ulmus-Zelkova*, *Pediastrum*, *Botryococcus*, and *Pistillipollenites*, a good late Paleocene assemblage. This locality lies just above the base of the Wasatch east of Yellow Creek in the SE¼SE¼ sec. 4, T. 2 N., R. 98 W. Locality D4775 yielded *Araucariacites*, *Juglanspollenites*, *Ulmipollenites*, *Chenopodipollis*, *Alnus*, *Carya*, *Abietineaepollenites*, *Classopollis*, *Ephedra*, *Erdtmanipollis*, *Momipites*, *Zlivisporis*, *Polypodiumsporites*, *Onagraceae*. "It is probably of latest Paleocene age. The presence of *Chenopodipollis* in abundance and *Onagraceae* pollen suggests an Eocene age, but other forms heretofore characteristic of the Eocene were not observed." This locality lies about 80 ft above the base of the Wasatch in the SE¼NW¼ sec. 5, T. 2 N., R. 97 W. Locality D4626 yielded *Platycarya*, *Carya*, *Ulmus-Zelkova*, *Inaperturopollenites*, *Tilia*, *Abietineaepollenites*, and *Gleicheniidites*. "The presence of *Platycarya*, and a questionable grain of *Tilia* identifies this sample as definitely Eocene." This locality lies about 60 ft below the top of the dark shale facies in the SW¼NW¼ sec. 7, T. 2 N., R. 97 W.

The Wasatch Formation of the study area is correlative to the east and northeast with the mostly Eocene part of the Wasatch, as mapped by Pipiringos and Rosenlund (1977a) in the White Rock quadrangle and by Izett and others (1984) in the Citadel Plateau quadrangle. It is equivalent to the upper part of the Wasatch of the Elk Springs quadrangle (Dyni, 1968) to the north. It is correlative westward generally with the Eocene part of the Wasatch, as mapped by Barnum and Garrigues (1980) in the Cactus Reservoir quadrangle and by Garrigues and Barnum (1980) in the Rangely NE quadrangle.

Green River Formation

The Green River Formation of Eocene age consists almost entirely of rocks of lacustrine origin deposited in the long-lived Eocene Lake Uinta. The Green River conformably overlies and intertongues with the Wasatch Formation and is conformably overlain by and intertongues with the Eocene Uinta Formation. An early phase of lacustrine deposition is represented by some rocks of the previously described dark shale facies of the Wasatch Formation that Johnson (1984, p. 13–19, pl. 1) correlated with the Cow Ridge Member of the Green River. The main body of the Green River in the lower Yellow Creek area is early to middle Eocene in age and includes (in ascending order) the Anvil Points, Garden Gulch, and Parachute Creek Members. Rocks of the Anvil Points Member are laterally equivalent to the lower part of the Garden Gulch Member. The Parachute Creek Member is extensively intertongued with the Uinta Formation.

Anvil Points Member

The Anvil Points Member of the Green River Formation is present in the eastern and southeastern parts of the Piceance Creek basin and represents a westward-thinning wedge of nearshore lacustrine rocks including abundant sandstone beds and other sandy and silty units. The coarser clastic rocks of the member have an easterly or southeasterly source, and to the west rocks of the Anvil Points intertongue with and grade into deeper water lacustrine rocks of laterally equivalent units. On the geologic maps of the Smizer Gulch and Rough Gulch quadrangles (Hail, 1973, 1974a), the Anvil Points Member was designated basal sandstone member of the Green River Formation.

In the lower Yellow Creek area, the Anvil Points is made up mostly of sandstone and lesser amounts of limestone, siltstone, claystone, and shale. It is gradational, across a narrow interval, with the underlying Wasatch Formation. Cliff-forming sandstone beds of the Anvil Points lie on relatively nonresistant claystone beds of the Wasatch.

Sandstone beds of the Anvil Points are mostly brown weathering, fine to medium grained, massive to even bedded, and calcareous to firmly lime cemented; they commonly form conspicuous timber-covered cliffs, benches, or ledges. The prominent butte in sec. 27, T. 2 N., R. 97 W., just north of the White River, is capped by resistant cliff-forming beds of the Anvil Points. Some sandstone beds are as thick as 30 ft (9 m). The sandstones are variably ostracodal or oolitic, and many are abundantly ostracodal at the top, such that they are essentially ostracodal limestones. Concentrations of mollusks, mostly gastropods, are present locally. The Anvil Points also contains light-brown-weathering ostracodal or oolitic limestone beds interbedded with the sandstones. Many such beds are grainstone or calcarenite composed almost entirely of ostracodes or oolites. These also are resistant and form ledges and cliffs. They are thinner than the sandstone beds, seldom thicker than 2–3 ft (0.5–1 m). Claystone, shale, and clayey siltstone beds are variably ostracodal, soft, and nonresistant and generally are poorly exposed between the dominant sandstone and limestone beds.

The Anvil Points thins to the northwest along its outcrop by pinchout of sandstone beds in the upper part. Sandstone beds in the lower part persist farther westward than do sandstone beds in the upper part. The member is arbitrarily terminated at Yellow Creek, west of which lacustrine sandstone beds are not clearly identifiable or are too thin to map. Interbedded ostracodal limestone beds and a few sandstone beds persist far to the west, however, within and beyond the study area, and are included in the lower part of the Garden Gulch Member. The Anvil Points pinches out southwestward in the subsurface within the study area. The member ranges in thickness from about 280 ft (85 m) near the east edge of the Barcus Creek SE quadrangle to about 40 ft (12 m) at Yellow Creek in the northwest.

The Anvil Points contains a distinctive black coquina in the outcrop area in the southwestern part of the Smizer Gulch quadrangle. In this area the member is as thin as 40 ft (12 m). The coquina comprises the upper part of a limy, cliff-forming, coarse-grained, sparsely ostracodal sandstone bed. It consists mostly of broken fragments of mollusks in a black, sandy, bituminous matrix that contains much recrystallized calcite.

The Anvil Points Member is correlative eastward with the lower part of the Anvil Points as mapped in the White River City quadrangle (Pipiringos and Johnson, 1976) adjacent to the east. In the White River City quadrangle, the lower part (map unit Tgal) is one of two westward-thinning units of Anvil Points and the upper part (map unit Tgau) is a tongue that pinches out several miles east of the lower Yellow Creek area.

The Anvil Points Member occupies a stratigraphic position analogous to that of the Douglas Creek Member of the Green River Formation in the western and southern parts of the Piceance Creek basin. Both reflect an early nearshore phase of Green River lacustrine deposition. The abundant sandstone and siltstone of the Anvil Points were derived mostly from bordering highlands to the east and southeast, however, and are lacking in the largely shallow-water shelf deposits of the Douglas Creek Member.

Garden Gulch Member

In his original definition of the members of the Green River Formation in the Uinta and Piceance Creek basins, Bradley (1931, p. 9–15, pls. 3, 7, 8) established four members (in ascending order), the Douglas Creek, Garden Gulch, Parachute Creek, and Evacuation Creek. Bradley (1931, p. 9) stated, "These members persist throughout most of this area, though they vary in thickness from place to place and lose their identity where they merge into a shore facies." Geologic mapping since 1931 does not substantiate the basinwide extent of these members as proposed by Bradley but instead shows complex lateral facies changes that have resulted in a confusing application of map-unit names, especially for those strata below the Mahogany ledge of the Parachute Creek Member. This problem is demonstrated by a comparison of maps showing the geology in the southern part of the Piceance Creek basin in the upper drainages of Parachute Creek and Roan Creek (Waldron and others, 1951; Donnell, 1961; Cashion, 1973; Johnson, 1977, 1981a; Hail, 1978, 1982). This area includes the type locality of the Garden Gulch Member.

The type section of the Garden Gulch was measured by Bradley (1931, p. 10) in sec. 8, T. 6 S., R. 96 W., near the mouth of Garden Gulch along Parachute Creek, and he stated, "The greater part of the Garden Gulch consists of flaky shale and more thinly laminated marlstone." He showed a considerable proportion of non-oil-shale marlstone in the upper part of the type Garden Gulch and apparently established its contact with the overlying Parachute Creek Member at the base of the lowest group of conspicuous oil-shale beds, although the type Garden Gulch does contain a few papery oil-shale beds. Elsewhere in the Piceance Creek basin, including the lower Yellow Creek area, the Garden Gulch generally is defined on the basis of its dominant lithology of fissile to papery or thin-bedded, dark clay shale. It lacks the indicators of nearshore lacustrine deposits that characterize laterally equivalent parts of the Douglas Creek Member such as numerous algal beds, abundant siltstone and sandstone, nonbedded claystone and mudstone, abundant ostracodal shale, and a relatively low content of organic material. It generally does not include the barren marlstone of the upper part of the type section; this lithology is included in the overlying Parachute Creek Member. The shale of the Garden Gulch was deposited in relatively deeper, quieter water of Lake Uinta during its early freshwater phase.

In the study area, the Garden Gulch Member consists mostly of dark-gray or brown clay shale and some oil shale, minor siltstone, sandstone and limestone, and a few analcimic tuff beds. It is a nonresistant slope-forming unit between overlying resistant steep cliffs of the carbonate marlstone of the Parachute Creek Member and underlying resistant cliff- and bench-forming sandstone and limestone of the Anvil Points Member. Figure 7 shows a section of the Garden Gulch Member as measured near Yellow Creek. West of Yellow Creek, the Anvil Points is absent and the Garden Gulch lies directly on alluvial rocks of the Wasatch Formation.

On the original 7.5-minute quadrangle maps of the area the Barcus Creek SE, Smizer Gulch, and Rough Gulch quadrangles (Hail, 1972, 1973, 1974a), the Garden Gulch–Parachute Creek contact was placed at the top of the highest sequence of dark fissile clay shale, a sequence overlain by carbonate marlstone of the Parachute Creek Member. As then mapped, the Garden Gulch included a sequence of light-gray-weathering dolomitic shale and siltstone. This dolomitic shale is probably the earliest indication of deposition from an alkaline-water environment in Lake Uinta. In general, shales of the Garden Gulch were deposited during the early freshwater phase, and carbonate-rich rocks of the Parachute Creek Member were deposited during the late alkaline and saline phases. An interpretation of USGS oil-shale test core hole 78–5 drilled in sec. 32, T. 2 N., R. 97 W. (Smith and O'Sullivan, 1982, p. 68–81) shows that the base of the R–2 oil-shale zone was penetrated at 232 ft. This horizon, the top of which is indicated by an electric-log marker commonly known as the Blue marker, generally is regarded as the break between freshwater and alkaline deposition and saline deposition in the northern part of the Piceance Creek basin. This break generally is selected as the boundary between the Garden Gulch and Parachute Creek Members in this area (Trudell and others, 1970, p. 4, 8, figs. 4, 5, 6; Dyni, 1974, fig. 3; Donnell and Hail, 1984). For this reason, the Garden Gulch–Parachute Creek boundary is herein moved downward to the base of the dolomitic shale and all overlying beds are included in the Parachute Creek. The dolomitic shale unit can be easily mapped and crops out as a relatively resistant, locally timber-covered band between smooth slopes of nonresistant shale.

The dominant dark clay shale of the Garden Gulch Member is mostly fissile to papery; locally it contains some nonbedded claystone that weathers blocky. The claystone beds are resistant relative to the fissile shale and locally form ledges. Claystone beds are variably ostracodal. The shale is dark gray to dark brown and weathers medium to light gray. Siltstone beds in the lower part of the member locally contain abundant ostracodes. Limestone beds, mostly ostracodal grainstone or calcarenite, are present only in the basal part of the Garden Gulch. East of Yellow Creek, these beds commonly are thin, generally no thicker than 1–2 ft (30–60 cm), but are resistant and form ledges. West of Yellow Creek, the basal part of the Garden Gulch contains several ostracodal limestone beds that are included in the Anvil Points Member to the east. These are as thick as 2–3 ft (60–90 cm) and form ledges. They are interbedded with thin, discontinuous sandstone beds that are also laterally equivalent eastward to some of the sandstones in the basal part of the Anvil Points Member.

The Garden Gulch Member, as now defined for the lower Yellow Creek area, is correlative eastward with about the lower three-fourths of the Garden Gulch as defined in the White River City quadrangle (Pipiringos and Johnson, 1976). The Garden Gulch continues westward and then southward along the west rim of the Piceance Creek basin, with essentially the same lithology and upper and lower boundaries (B.E. Barnum, written commun., 1980; Donnell and Hail, 1984).

The Garden Gulch Member ranges in thickness on the outcrop from about 190 ft (58 m) near the eastern edge of the area to about 700 ft (210 m) near the western edge. This westward thickening is largely at the expense of the westward-thinning Anvil Points Member. The Garden Gulch is about 400 ft (120 m) thick in the U.S. Bureau of Mines AEC–1 drill hole in the SE¼ sec. 13, T. 1 N., R. 98 W.

Parachute Creek Member

The Parachute Creek Member is the youngest member of the Green River Formation and is present throughout most of the Piceance Creek basin. It contains

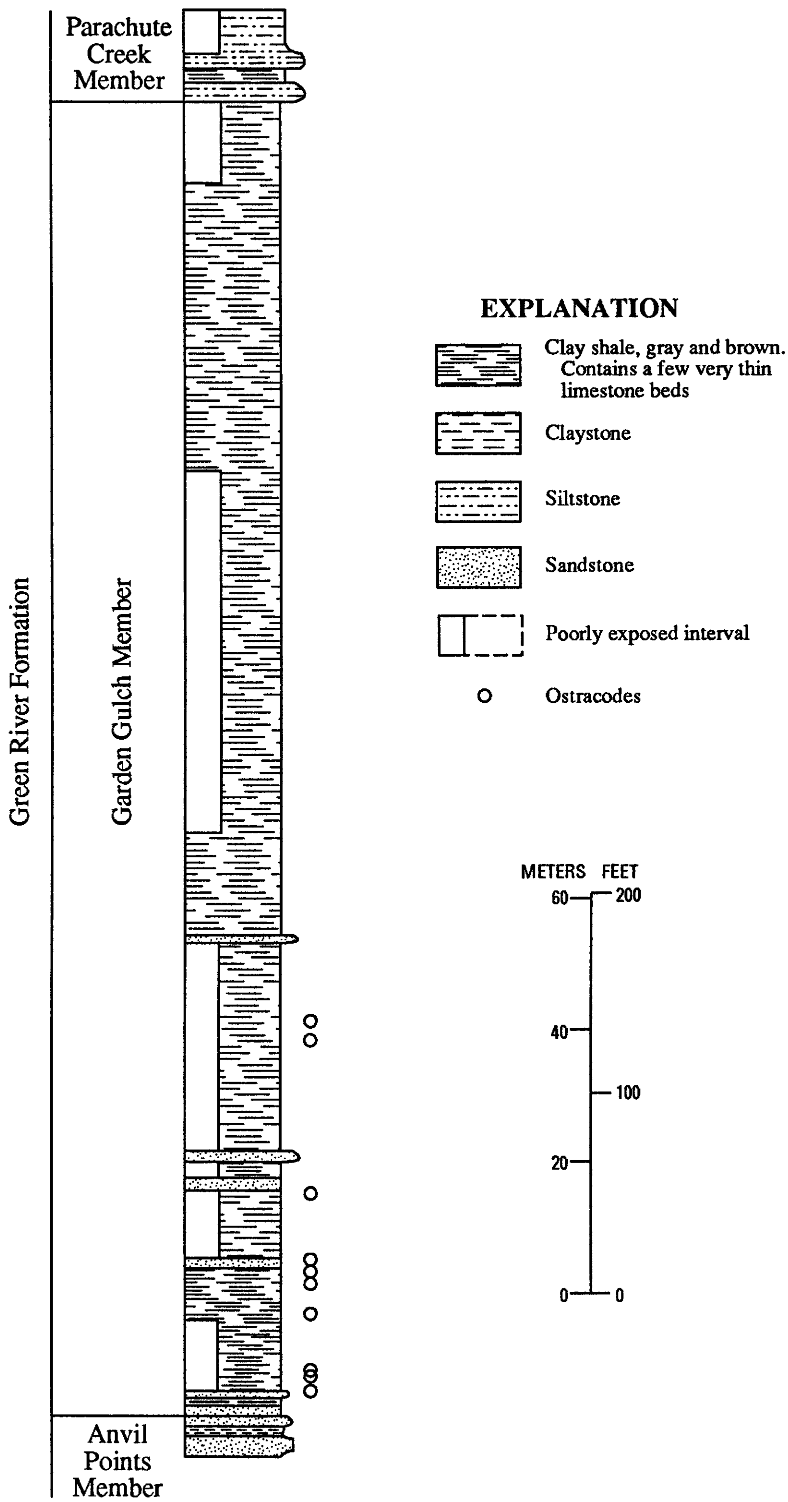


Figure 7. Measured section of Garden Gulch Member of Green River Formation. West side of Yellow Creek in NW¼ sec. 9, T. 2 N., R. 98 W. Township-range map shown in figure 12.

most of the potentially valuable oil-shale deposits of the Green River and in the study area also contains large deposits of nahcolite and dawsonite. The Parachute Creek consists mostly of dolomitic marlstone and lesser amounts of limy marlstone; in its lower part it includes a considerable proportion of clay shale and dolomitic shale and siltstone. It also contains several beds of siltstone, sparse sandstone, and numerous very thin beds of analcimic tuff. It conformably overlies the Garden Gulch Member and is complexly intertongued with the overlying Uinta Formation. It includes the rich oil-shale zones R–2, R–3, R–4, R-5, R–6, and the Mahogany zone.

The Parachute Creek Member was named by Bradley (1931, p. 11–14, 17) for exposures along Parachute Creek in the southeastern part of the Piceance Creek basin. Bradley defined the member chiefly on its content of oil-shale beds. At the type locality, he placed the base of the Parachute Creek at the base of the lower oil-shale group and the top of the member at the top of the upper oil-shale group. Subsequent studies have shown that visual estimation of oil content of outcropping beds is not a reliable basis for stratigraphic correlation. The use of drill-hole logs, especially Fischer assay logs, shows that rocks low in oil-shale values and possibly perceived to be barren in outcrop exposures can be correlated with considerable precision with high-yield oil shale elsewhere. This problem of correlation was discussed by Cashion and Donnell (1974) in their revision of correlations and nomenclature for the upper part of the Green River Formation. They showed by means of assay logs of nearby drill holes that the upper part of the type Parachute Creek is laterally equivalent to part of the type Evacuation Creek Member of the Green River (Cashion and Donnell, 1974, p. 4, 5). Most mapping and other stratigraphic studies since Bradley's work have based stratigraphic correlation involving the Parachute Creek on lithologic studies and oil-shale assay and other drill-hole logs. In the vicinity of the mouth of Yellow Creek, the Parachute Creek Member seems largely barren of oil shale. On lower Piceance Creek, a considerable thickness of rocks that Bradley (1931, pl. 4A) assigned to the Garden Gulch is herein included in the Parachute Creek.

The lithologic terminology used by Bradley (1931, p. 6–8, 22) for rocks of the Green River Formation generally has been followed in subsequent studies, but the terms marlstone and oil shale have been used with little consistency among various writers.

Bradley (1931, p. 7) adopted the term marlstone from the European terminology of H. Rosenbusch to refer to a hard variety of marl consisting of an intimate mixture of calcite (occasionally dolomite) and clay. The term marlstone has been widely applied to carbonate rocks of the Parachute Creek Member in which dolomite is generally more abundant than calcite. In much of the Parachute Creek marlstone, however, the clay content generally is low; quartz, feldspar, analcime, and saline minerals, where present, are significant constituents (Brobst and Tucker, 1973, p. 28–34).

The term oil shale has been used both as a lithologic term and as an economic resource term, and both kerogen-rich marlstone and kerogen-rich clay shale have been termed oil shale. Bradley (1931, p. 7) defined oil shale as "***a fine-grained sedimentary rock containing organic matter which was derived chiefly from aquatic organisms or waxy spores and pollen grains, which is only slightly soluble in ordinary petroleum solvents, and of which a large proportion is distillable into artificial petroleum." Bradley pointed out that most rich oil-shale beds are not shale but rather are more or less magnesian marlstones rich in organic matter. He set no lower limit on oil yield but set 10 gallons per ton as the boundary between low-grade and high-grade oil shale. Many workers, however, have set a lower limit on oil yield below which the rock is not termed an oil shale; this limit varies widely, generally from 3 to 15 gallons per ton. Visual estimates of oil yield in the field are based primarily on the pervasive brown color imparted by the organic material. Color seldom is seen in outcropping marlstone containing less than about 3 gallons per ton. The limits of 10–15 gallons per ton are probably based on a concept of foreseeable economic value. Fischer and other assays can detect very low oil-yield values, approaching zero, values useful in stratigraphic correlation but meaningless in terms of economic potential. In this report, the term oil shale refers to marlstone or clay shale that has an estimated or assayed oil yield of no less than 3 gallons per ton. The amount of organic material in rocks termed oil shale in the study area varies from about 1 to 18 percent.

The basal contact of the Parachute Creek Member on the Garden Gulch Member is placed at or near the base of the R–2 oil-shale zone and marks the first significant change upward from the early freshwater stage of Eocene Lake Uinta, in which dark clay shale was deposited, to the increasingly alkaline and saline late stage of the lake, in which carbonate-rich rocks were deposited. Carbonate deposition was intermittent, however, and temporary returns to freshwater conditions are reflected by interbedded clay shale and carbonate-rich rocks above the lowermost carbonate rocks of the Parachute Creek.

In the eastern part of the study area, the lowermost rocks of the Parachute Creek, constituting about the lower one-fifth of the member, are gray-weathering dolomitic shale interbedded with brown-weathering clay shale. In a northwesterly direction along the outcrop, dolomitic beds of the lower part become increasingly silty and, in the vicinity of Yellow Creek, include thin-bedded to shaly, brown-weathering calcareous or dolomitic siltstone that locally forms resistant ledges and is also interbedded with brown, gray-weathering, slightly calcareous or dolomitic shale that locally contains carbonized plant fragments and fish scales. In the vicinity of Yellow Creek, these rocks constitute approximately the lower one-fourth of the Parachute Creek where the member is about 1,300 ft thick (fig. 8).

Rocks in the upper three-fourths of the Parachute Creek Member in the southeastern part of the study area are dominantly marlstone, and most of the marlstones are oil shale. Marlstones of the Parachute Creek are mostly dense, hard, resistant rocks and generally form steep cliffs and strong ledges. In this area, as elsewhere throughout the Piceance Creek basin, they form the high, commonly precipitous cliffs that rim much of the basin. The oil-shale marlstones are medium to dark brown on fresh surfaces, and most weather light gray. Rich oil shale, exceeding 30 gallons per ton, weathers to a distinctive bluish-gray color. Barren marlstone is gray to light grayish brown and also weathers light gray. An X-ray mineralogy study of the Parachute Creek Member in a measured section near the eastern boundary of the study area on lower Piceance Creek shows that most of the mineral fraction of the Parachute Creek consists of mixtures of dolomite, calcite, quartz, feldspar, analcime, albite, and pyrite (Brobst and Tucker, 1973, p. 12–19, 24–28, 30–32, 36–37, 38). The saline minerals nahcolite and dawsonite are locally abundant. This same study (table 5) shows that in the lower Piceance Creek area marlstones of that part of the Parachute Creek below the Mahogany ledge are chiefly dolomite; they contain little calcite but substantial amounts of analcime, quartz, feldspar, and minor illite. Within the Mahogany ledge, the amount of calcite increases considerably, although dolomite is still dominant. The amount of calcite continues to increases in rocks above the Mahogany ledge until the amounts of calcite and dolomite are approximately equal. In the upper three-fourths to four-fifths of the Parachute Creek, rock types other than marlstone are minor. The marlstones are variably silty, and thin marly siltstone beds become more numerous to the northwest along the outcrop. From near Yellow Creek westward, the Parachute Creek contains several thin sandstone beds. Numerous very thin and several thick analcimic tuff beds are present in the Parachute Creek, and several of these tuff beds have been correlated widely throughout the Piceance Creek basin (Donnell, 1961, p. 865).

The upper boundary of the Parachute Creek Member is placed at the base of the lowest overlying tongue of the Uinta Formation. The Green River and Uinta Formations are complexly intertongued. Tongues of the Green River are marlstones, most of which merge laterally into rocks of the Parachute Creek Member, but owing to constraints of stratigraphic nomenclature, the marlstone tongues are designated tongues of the Green River Formation rather than tongues of the Parachute Creek Member. The intertonguing Green River and Uinta units are described elsewhere.

The Parachute Creek Member is correlative eastward with the Parachute Creek Member as mapped by Pipiringos and Johnson (1976) in the adjoining White River City quadrangle, except that rocks above the lowest mapped tongue of the Uinta are termed tongues of Green River rather than including them in the Parachute Creek and the basal contact is lower than the contact as mapped to the east. The member continues westward and then southward along the west rim of the Piceance Creek basin.

The Parachute Creek Member varies widely in thickness within the study area. On the outcrop, it is about 900 ft (270 m) thick at the eastern boundary of the area near Piceance Creek. It thickens northwestward to about 1,300 ft (400 m) in the vicinity of Yellow Creek and then thins northwestward to about 920 ft (280 m) at the western boundary of the study area. Measured surface sections by Brobst and Tucker (1973, p. 12–19) and Pipiringos and Johnson (1976) indicate a thickness greater than 900 ft (270 m) at the eastern edge of the study area, but the upper part of the Parachute Creek as defined by them includes marlstones herein designated as tongues of the Green River Formation. The greatest change in thickness for the Parachute Creek is in the subsurface toward the structural axis of the Red Wash syncline, which in the study area coincides with the depositional center for strata of the Garden Gulch and Parachute Creek Members. In the U.S. Bureau of Mines AEC–1 drill hole in the SE¼ sec. 13, T. 1 N., R. 98 W., the Parachute Creek is about 1,650 ft (500 m) thick. In the General Petroleum Yellow Creek 64–8 drill hole in the NE¼ sec. 8, T. 1 N., R. 98 W., it may be more than 2,100 ft (640 m) thick, but this figure includes several hundred feet of strata above the Mahogany zone that may contain tongues of the Uinta Formation.

Uinta Formation and Tongues of the Green River Formation

The Uinta Formation of Eocene age is a heterogeneous mass of clastic sedimentary rocks, mostly sandstone, siltstone, mudstone, and variably silty to sandy marlstone. These rocks comprise the complex, generally southward prograding, fluvial-deltaic sequence that ultimately filled Eocene Lake Uinta. Deposition was localized, shifting, and intermittent and was interrupted by episodes of open-water lacustrine deposition during which marlstones of the Green River Formation were

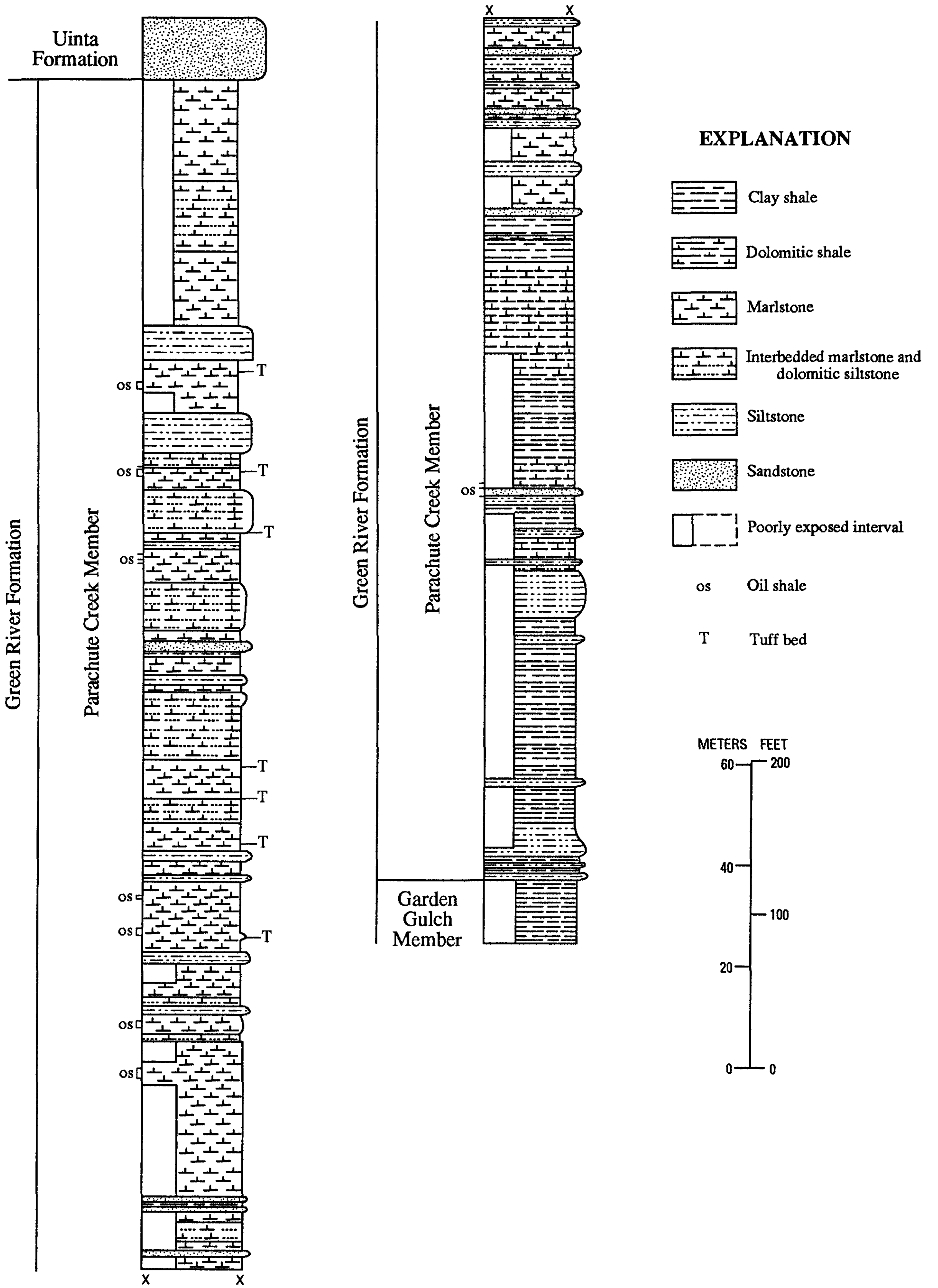


Figure 8. Measured section of Parachute Creek Member of Green River Formation. West side of Yellow Creek in SW¼ sec. 9, T. 2 N., R. 98 W. Township-range map shown in figure 12.

deposited. This depositional pattern resulted in complex intertonguing between the Uinta and Green River Formations. The southward-prograding deltaic nature of the Uinta Formation has been described by Johnson (1981b, p. 56–58). In general, successively younger tongues of the Uinta extend farther south beyond the pinchout point of older tongues, such that in north to south cross section the sequence consists of southward-thinning tongues of Uinta between northward-thinning tongues of Green River. This pattern of intertonguing has been shown by Trudell and others (1970, fig. 4), based on subsurface studies, and in subsequent studies by Duncan and others (1974, fig. 4), O'Sullivan (1975, fig. 2), Hail (1977, fig. 2), and Johnson (1981b, fig. 1), based on detailed surface mapping and subsurface correlations. Many of the detailed mapping and subsurface studies throughout the Piceance Creek basin show that most of the marlstone tongues of the Green River Formation merge laterally, generally southward, with other Green River tongues or with the main body of the Parachute Creek Member. Intertonguing of the Uinta and Green River units occurs throughout the entire sequence. Not all marlstone tongues of the Green River have been mapped in the study area or elsewhere in the Piceance Creek basin; only certain widespread, or conspicuous, or otherwise selected units were mapped. Those marlstone units not mapped separately are included in the Uinta Formation. Within the intertonguing sequence, the Uinta Formation dominates and the marlstone tongues of the Green River are relatively thin. Figure 9 is a generalized diagram showing the correlation of mapped Uinta and Green River tongues, from west to east, in the southern part of the lower Yellow Creek area including the Barcus Creek and Barcus Creek SE quadrangles (Hail, 1984, 1988), the adjoining Calamity Ridge quadrangle (Donnell and Hail, 1984), and the adjoining White River City quadrangle (Pipiringos and Johnson, 1976). Table 3 shows correlations of Uinta and Green River map units for the Rough Gulch and Barcus Creek quadrangles (Hail, 1974a, 1984) and for the Smizer Gulch and Barcus Creek SE quadrangles (Hail, 1973, 1988). Figure 10 shows a representative composite section of the Uinta and Green River intertonguing sequence in the northwestern part of the Barcus Creek SE quadrangle.

The Uinta and Green River intertonguing sequence forms by far the largest area of exposed Tertiary rocks in the Piceance Creek basin and is the surface rock for most of the basin within the drainage area of Piceance and Yellow Creeks. (See geologic map of Donnell, 1961, pl. 48.) Mapping of the thin marlstone tongues of the Green River Formation throughout the basin has provided the basis for recognizing and subdividing the complex stratigraphy of the sequence and for deducing its depositional history.

Table 3. Correlation of map units of the Uinta and Green River Formations between the Rough Gulch and Barcus Creek quadrangles and between the Smizer Gulch and Barcus Creek SE quadrangles

[All units shown except Tgp (Parachute Creek Member of the Green River Formation) are tongues of the Uinta Formation (Tu) or tongues of the Green River Formation (Tg). References: Rough Gulch (Hail, 1974a); Barcus Creek (Hail, 1984); Smizer Gulch (Hail, 1973); Barcus Creek SE (Hail, 1988)]

Rough Gulch quadrangle GQ-1195	Barcus Creek quadrangle GQ-1578
	Tug
Tgt	Tgt
Tu	Tue Tgy Tud Tgm Tuc Tgtc Tub
Tgpt	Tgua
Tut	Tua
Tgp	Tgp
Smizer Gulch quadrangle GQ-1131	**Barcus Creek SE quadrangle GQ-1613**
	Tu2 and higher units (see fig. 9)
Tgpa	Tgl
Tgea*	Tul
Tgp	Tgp

*Part of Evacuation Creek Member of Green River Formation; now Uinta Formation

Evacuation Creek Member of the Green River Formation—Uinta Formation Nomenclature Change

Prior to 1974, rocks herein termed Uinta Formation were regarded as the uppermost member of the Green River Formation. Bradley (1931, p. 14–15, pl. 8) named the Evacuation Creek Member of the Green River Formation and designated its type as a section measured in sec. 27, T. 9 S., R. 25 E., Uintah County, Utah, where it consists mostly of oil shale and marlstone. He applied the name to a sequence of rocks above the Parachute Creek Member of the Green River Formation in the Piceance Creek basin that includes both barren marlstone and sandy beds. Cashion and Donnell (1974, figs. 2, 3) showed by correlations of oil-shale histograms of nearby drill holes that Bradley's type Evacuation Creek is stratigraphically equivalent to much of that part of his type Parachute Creek above the Mahogany bed and has essentially the same lithology. They (p. 3–9, fig. 3) also concluded that rocks designated by Bradley as Bridger Formation in the eastern Uinta basin are correlative with rocks designated by him as Evacuation Creek in the Piceance Creek basin. The rocks termed Bridger by Bradley are now regarded as Uinta Formation in the Uinta basin; these rocks, dominantly sandstones, had in the past commonly been designated as Evacuation Creek Member in the Piceance Creek basin. On the basis of these conclusions, Cashion and Donnell (p. 8, 9) made the following changes in nomenclature. They (1) abandoned the name Evacuation Creek, (2) placed the upper boundary of the Parachute Creek Member at the base of the Uinta Formation, (3) applied the name Uinta Formation in the Piceance Creek basin to those rocks previously assigned to the Evacuation Creek Member, and (4) abandoned the name Bridger Formation for the Piceance Creek basin.

Tongues of the Uinta Formation

The tongues of the Uinta Formation include a wide range of rock types. Brown-weathering sandstone and siltstone predominate, but variably silty gray-weathering marlstone, mudstone or claystone, conglomerate, and conglomeratic sandstone also are abundant. Thin beds of Green River–type light-gray marlstone are also included in some tongues. Altered tuffaceous material is abundant and forms the dominant mineral constituent in many beds. Thickness of the mapped tongues varies greatly. Several terminate laterally in or near the study area as a result of either pinchout or abrupt facies change. Basal contacts of the tongues of the Uinta range from gradational to sharply disconformable. They commonly are sharp and show no evident structural discordance, or they are gradational across a narrow interval from white marlstone of the underlying tongues of the Green River to brown-weathering siltstone or sandstone of the tongue of the Uinta. Locally, especially where medium- to coarse-grained sandstone forms the basal beds, contacts appear to be disconformable, and locally the underlying beds may be scoured. In many such places, the bases of broken sandstone masses are downwarped or slumped into the underlying marlstone beds. Slumping was penecontemporaneous and occurred after some degree of consolidation of the sandstones, which were deposited on underlying soft, nonresistant, or poorly indurated marly sediments. The underlying marlstones also commonly show considerable distortion including differential compaction, plastic flow, and minor local faulting.

Most of the Uinta sedimentary rocks are fine-grained, marly or argillaceous siltstone or very fine grained sandstone that grades to mudstone or silty marlstone. These rocks were probably deposited in a delta-front lacustrine environment, but almost all the tongues contain at least some alluvial-type channel sandstones. Many of the channel sandstones have sharply scoured basal contacts and are locally crossbedded and conglomeratic. Conglomerate beds generally contain locally derived soft-pebble clasts. Where firmly cemented, the siltstones and sandstones form cliffs, ledges, and benches, resulting in the typical ridge and valley topography of the basin interior.

For purpose of discussion, the tongues of the Uinta are divided into a lower group and an upper group; the boundary between the two groups is a tongue of the Green River, the marlstone at Mare Canyon and its equivalents.

Lower Group of Tongues of the Uinta Formation

The stratigraphically lowest mapped tongue of the Uinta Formation (map units Tua and Tul, fig. 9) lies within or just above the Mahogany ledge of the Parachute Creek Member of the Green River Formation. Its relationship to the Mahogany ledge is not clear because it crops out mostly in an area where the Mahogany is not well identified owing to very low oil-shale values. The maximum outcrop thickness of the tongue is about 300 ft (90 m) on lower Yellow Creek between Barcus and Greasewood Creeks. The tongue thins abruptly in both directions along the outcrop from this point and pinches out entirely about 4.5 mi (7 km) to the southeast. It was mapped as far west as the western boundary of the study area, where it is only a few feet thick, and it pinches out or phases out entirely in the extreme northeastern corner of the Calamity Ridge quadrangle (Donnell and Hail, 1984), adjacent to the western part of the study area. It apparently is absent to the southeast, but isolated unmapped pods and lenses along the North and Middle Forks of Greasewood Creek may represent outliers of the tongue. It apparently is present in the subsurface in U.S. Bureau of Mines drill holes AEC–1 and AEC–3 (secs. 13, 14, T. 1 N., R. 98 W.), where it is about 120–140 ft (37–43 m) thick, but pinches out southward inasmuch as it apparently is not present in the Humble Oil Co. 1 Yellow Creek drill hole 4 mi to the south in sec. 2, T. 1 S., R. 98 W. In the vicinity of Yellow Creek, its basal contact appears disconformable and locally lies on eroded beds of the underlying Parachute Creek Member of the Green River Formation. The stratigraphic extent of the disconformity is not known. The tongue consists of brown to gray, mostly brown weathering, fine- to medium-grained sandstone; lesser brown-weathering, locally marly siltstone; and some variably silty marlstone. The sandstone is mostly massive to even bedded and is locally concretionary. Channel deposits are relatively abundant and have sharp basal contacts and coarse soft-pebble basal conglomeratic beds. Limonite, biotite, and other rock and mineral fragments are abundant in the coarser grained sandstones. Near the mouth of Barcus Creek, the unit is mostly siltstone and is very firmly quartz cemented, hard, and resistant.

The next higher mapped tongue of the Uinta (map units Tub and Tu2, fig. 9) is present across the entire study area and basinward in the subsurface and underlies the marlstone at Trail Canyon (map unit Tgtc) or its lateral equivalents. Although the tongue was not mapped separately in the Rough Gulch quadrangle, it constitutes the basal part of the undifferentiated Uinta (map unit Tu, table 3) in that area. The tongue thins to the southeast and extends beyond the pinchout point of the lower tongue into the adjacent White River City quadrangle (Pipiringos and Johnson, 1976), where it is no thicker than 40 ft (12 m) and is included in the main body of the Parachute Creek Member of the Green River Formation. It is relatively thin in outcrops in the northwestern part of the Barcus Creek quadrangle, possibly as thin as 40 ft (12 m), but abruptly thickens southward to as much as 300 ft (90 m) along the Middle Fork of Greasewood Creek. It extends westward into the adjacent Calamity Ridge quadrangle (Donnell and Hail, 1984) and pinches out in the south-central part of that quadrangle. The tongue is tentatively identified in the subsurface and may be as thick as 270 ft (82 m) in the Sundance Oil and Gas Company Federal 8024 drill hole in sec. 2, T. 1 N., R. 98 W. Subsurface studies suggest that the lower part of the unit phases to the east and west into rocks of the Parachute Creek Member of the Green River Formation. The tongue consists mostly of brown-weathering sandstone, lesser amounts of variably marly siltstone, and minor marly siltstone or mudstone. Channel deposits are fairly abundant. The sandstone is mostly light to medium brown, very fine to medium grained, and locally coarse grained to sparsely conglomeratic in channel units. The bedding is massive or even to crossbedded, and some spherical concretionary masses are present. Paleoslump blocks are locally present at the base. The more resistant beds form cliffs along some valley walls. In an area in the lower part of the forks of Greasewood Creek in the northern part of the Barcus Creek quadrangle, the overlying marlstone at Trail Canyon of the Green River Formation is absent owing to the presence of a local deltaic lobe that results in a vertically continuous clastic sequence including both this and the overlying tongue of the Uinta (map units Tuc and Tu3, fig. 9). This sequence is designated map unit Tucb. (See fig. 9 and Barcus Creek geologic map, Hail, 1984.)

The next higher Uinta tongue of the lower group (map units Tuc and Tu3, fig. 9) is present only in the western part of the area and pinches out eastward in surface exposures about a mile east of Yellow Creek. It was not mapped separately in the Rough Gulch quadrangle but was included in the main body of the Uinta (map unit Tu, table 3). The unit is relatively thin in the northwestern part of the area, about 50 ft (15 m) thick in the drainage of Greasewood Creek, but thickens southward in the upper drainage of Barcus Creek to as much as 220 ft (67 m). The tongue consists of light-gray to brown, very fine to medium grained sandstone, siltstone, and considerable mudstone and variably siltymarlstone. It contains a few ostracodal limestone and sandstone beds in the northwestern part of the Barcus Creek quadrangle. The tongue also contains several channel deposits. The basal contact is locally sharp, scoured, and disconformable.

The highest tongue of the lower group of Uinta tongues (map unit Tu4, fig. 9) crops out only in the Barcus Creek SE quadrangle. It pinches out westward at Yellow Creek and thins eastward to about 30 ft (9 m) at Piceance Creek. Its maximum thickness is about 120 ft (37 m) on the divide between Piceance and Yellow Creeks. This tongue was tentatively identified in the subsurface in the U.S. Bureau of Mines AEC–1 drill hole in sec. 13, T. 1 N., R. 98 W., and in Sundance Oil Company Federal 8005 drill hole in sec. 29, T. 1 N., R. 97 W., where it is about 70–80 ft (21–24 m) thick. The tongue consists mostly of light- to medium-brown, fine- to coarse-grained sandstone and includes several conglomeratic channel deposits in the western two-thirds of its outcrop area. Eastward, near Piceance Creek, the tongue grades laterally into thin tuffaceous sandstone interbedded with marly siltstone and silty marlstone. It is not present as a mappable unit east of Piceance Creek.

Upper Group of Tongues of the Uinta Formation

The stratigraphically lowest mapped tongue of the Uinta Formation (map unit Tud and Tu5, fig. 9) of the upper group of Uinta tongues underlies the widespread Yellow Creek Tongue of the Green River Formation. It is one of the most widespread and persistent of the Uinta tongues in the study area and has been mapped eastward as far as the eastern boundary of the White River City quadrangle (Pipiringos and Johnson, 1976), where it is the unnamed unit of the Uinta Formation lying above the Parachute Creek Member of the Green River Formation and below the base of the Yellow Creek Member. The tongue is present to the west in the southern part of the Calamity Ridge quadrangle (Donnell and Hail, 1984) and to the south in the Wolf Ridge quadrangle (map unit Tu3; Duncan, 1976a). It was not mapped separately in the Rough Gulch quadrangle but is included in map unit Tu of that quadrangle (table 3). The tongue varies greatly in thickness. It is generally no thicker than 100 ft (30 m) in the northwestern part of the Barcus Creek quadrangle. It is only about 80 ft (24 m) thick on lower Yellow Creek near the mouth of Barcus Creek (fig. 10) but thickens southeastward to about 450 ft (140 m) just west of Piceance Creek and southwestward to about 350 ft (110 m) in the uppermost drainage of Barcus Creek. It is about 400 ft (120 m) thick in several drill holes in the southern part of the Barcus Creek SE quadrangle. The

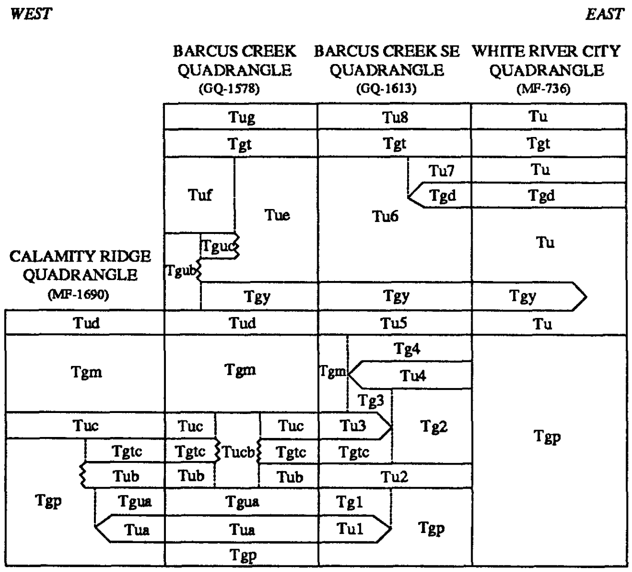
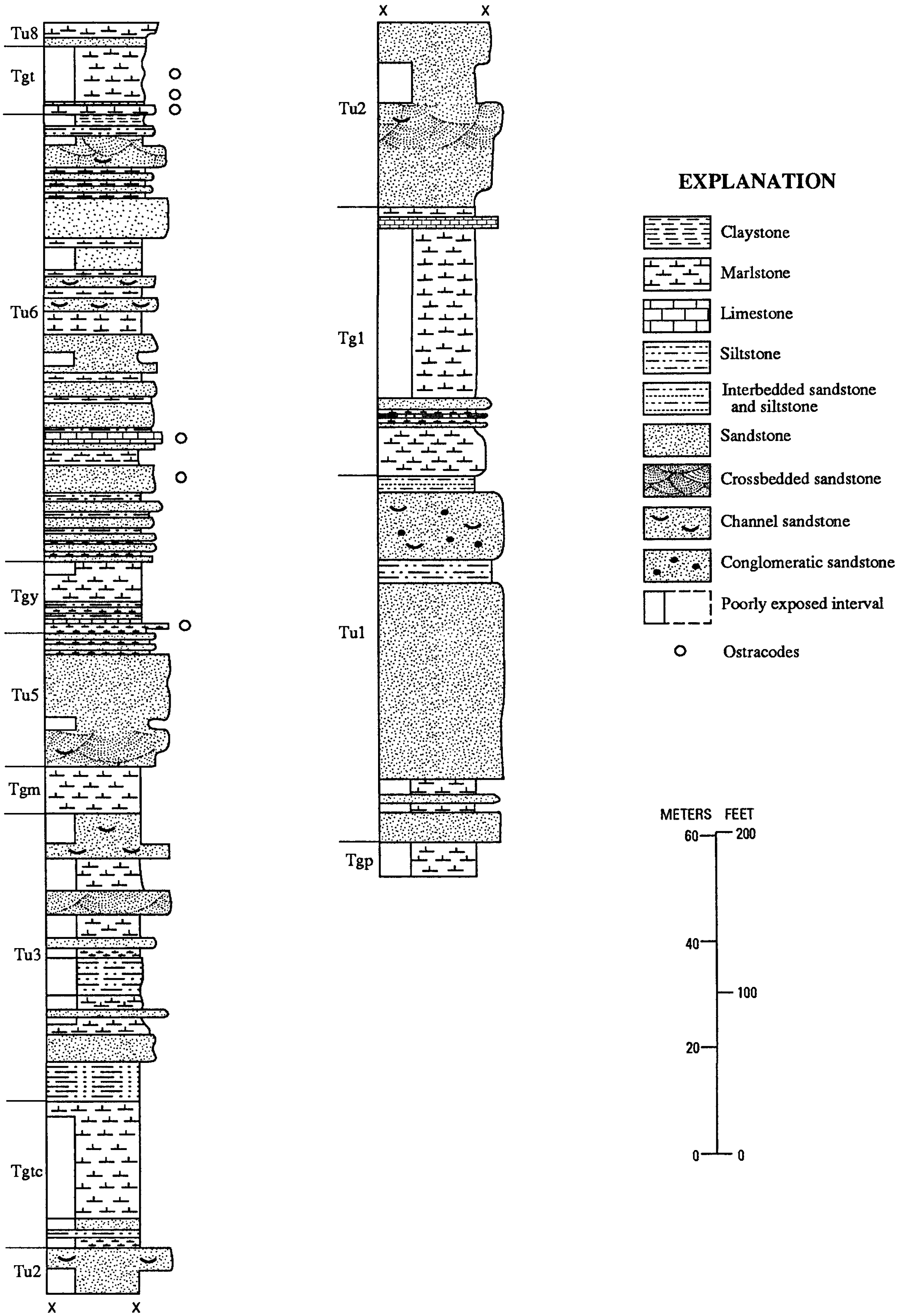


Figure 9. Correlation of outcropping mapped units of the intertonguing sequence of Uinta and Green River Formations in the Barcus Creek (Hail, 1984), Barcus Creek SE (Hail, 1988), Calamity Ridge (Donnell and Hail, 1984), and White River City (Pipiringos and Johnson, 1976) quadrangles. All units shown are tongues of the Green River (Tg) or Uinta (Tu) Formations except Tgp (Parachute Creek Member of the Green River Formation). Formally named tongues of the Green River Formation are Thirteenmile Creek Tongue (Tgt), Dry Fork Tongue (Tgd), and Yellow Creek Tongue (Tgy). Vertical dashed lines are lateral boundaries between map units.

Figure 10 (facing page). Composite measured section of intertonguing sequence of Uinta (Tu) and Green River (Tg) Formations. Measured between Barcus and Yellow Creeks in W½ sec. 26, NW¼ sec. 35, and E½ sec. 34, T. 2 N., R. 98 W., Barcus Creek SE quadrangle. Explanation of symbols: Tu8, unnamed tongue 8 of Uinta Formation; Tgt, Thirteenmile Creek Tongue of Green River Formation; Tu6, unnamed tongue 6 of Uinta Formation; Tgy, Yellow Creek Tongue of Green River Formation; Tu5, unnamed tongue 5 of Uinta Formation; Tgm, marlstone at Mare Canyon of Green River Formation; Tu3, unnamed tongue 3 of Uinta Formation; Tgtc, marlstone at Trail Canyon of Green River Formation; Tu2, unnamed tongue 2 of Uinta Formation; Tg1, unnamed tongue 1 of Green River Formation; Tu1, unnamed tongue 1 of Uinta Formation; Tgp, Parachute Creek Member of Green River Formation.

tongue is mostly brown and gray sandstone and siltstone, but considerable claystone, mudstone, and marlstone including several thin, widespread, beds of Green River-type marlstone are also present. The sandstone is fine to coarse grained, variably tuffaceous, limonitic, and locally concretionary. Channel deposits are commonly conglomeratic sandstones in sharp contact with underlying sandstone or siltstone beds. Clasts in the conglomeratic beds are soft-rock fragments. The basal contact of the tongue is locally sharp and disconformable on the underlying marlstone tongue of the Green River but elsewhere is gradational. The tongue forms conspicuous cliffs in much of its outcrop area. Among these are the brown cliff on lower Piceance Creek, which form a conspicuous contrast to the white-weathering marlstone of the underlying Parachute Creek Member of the Green River Formation.

The next higher tongue (map units Tuf, Tue and Tu6, fig. 9) in the upper group of Uinta tongues is underlain by the Yellow Creek Tongue of the Green River Formation or its lateral equivalents and overlain by the Dry Fork Tongue or by the Thirteenmile Creek Tongue of the Green River Formation beyond the pinch-out of the Dry Fork Tongue. The unit is widespread and persistent and forms the surface rock of much of the southern part of the study area. It was mapped west of the area in the Calamity Ridge quadrangle (Donnell and Hail, 1984), to the east in the White River City quadrangle (Pipiringos and Johnson, 1976), where it is an unnamed tongue of the Uinta between the Thirteenmile Creek and Dry Fork Tongues of the Green River Formation, and to the south in the Wolf Ridge quadrangle (Duncan, 1976a), where it is designated Tu4, and in the Square S Ranch quadrangle (Hail and Duncan, 1984), where it is map unit Tu3. It was not mapped separately in the Rough Gulch quadrangle but is included in map unit Tu (table 3). In those areas where the tongue is directly underlain by the Yellow Creek Tongue of the Green River Formation and directly overlain by the Thirteenmile Creek Tongue, it is 250–350 ft (76–106 m) thick and thickens from northwest to southeast. An even greater southeastward thickening for the sequence between the Yellow Creek and Thirteenmile Creek Tongues would be indicated if the laterally equivalent tongue (map unit Tu7, fig. 9) were included. In the southwestern part of the study area, lower beds of the tongue interfinger with and grade laterally into marlstones of the Green River (map units Tgub and Tguc, fig. 9); this gradation results in a thinning of the tongue in that area. Rocks of the tongue are mostly brown weathering sandstone and siltstone and silty marlstone. The unit also contains considerable mudstone, claystone, and sparse limestone, and as many as three thin, but laterally persistent Green River-type marlstone beds are present in the southern part of the area. The sandstone is light to medium brown or gray, fine to medium grained and locally coarse grained, massive to even bedded, and locally crossbedded. Channel deposits are numerous, especially in the southeastern part of the area. Many of these contain soft-pebble clasts in the


Tu8
Tgt
Tu6
Tgy
Tu5
Tgm
Tu3
Tgtc
Tu2
X
X
X
X
Tu2
Tgl
Tul
Tgp
EXPLANATION
Claystone
Marlstone
Limestone
Siltstone
Interbedded sandstone and siltstone
Sandstone
Crossbedded sandstone
Channel sandstone
Conglomeratic sandstone
Poorly exposed interval
Ostracodes
METERS
FEET
60
200
40
100
20
0
0

conglomeratic basal beds. In the adjacent White River City quadrangle, Pipiringos and Johnson (1976) noted fossil wood just below the top of the unit where it is overlain by the Dry Fork Tongue of the Green River Formation. The siltstone, most of which weathers brown, is tuffaceous and marly and locally argillaceous and grade to mudstones. A distinctive grayish-green claystone or mudstone is present at or near the top of the tongue, where it is overlain by the Thirteenmile Creek Tongue of the Green River. The unit contains an increasingly large proportion of silty marlstone in the southern part of the study area, especially west of the divide between Yellow and Piceance Creeks, and becomes more sandy and silty eastward and less silty westward. The basal contact of the tongue generally is disconformable, sharp, and scoured but is locally gradational. Penecontemporaneous slump blocks are common at the basal contact. The more firmly cemented sandstone beds locally form cliffs, benches, and ledges.

Wherever the Dry Fork Tongue of the Green River Formation is present, overlying rocks of the Uinta Formation below the Thirteenmile Creek Tongue of the Green River are designated as a separate tongue (map unit Tu7, fig. 9) although they are equivalent to the upper part of map unit Tu6 into which they merge. The tongue of the Uinta is present in the southeastern part of the area and was mapped east of the area, in the White River City quadrangle (Pipiringos and Johnson, 1976), as the unnamed tongue of the Uinta between the Dry Fork and Thirteenmile Creek Members and south of the area, in the Square S Ranch quadrangle (Hail and Duncan, 1984), as unit Tu4. The tongue is about 80–140 ft (24–43 m) thick. It is mostly variably marly sandstone, siltstone, and claystone or mudstone and includes sparse marlstone and minor limestone. The sandstone is light to medium brown and fine to medium grained. Most sandstone beds are poorly cemented and nonresistant but locally form ledges wherever firmly calcite cemented. The tongue includes several channel deposits that locally contain sparse clay-pebble clasts. The siltstone is medium brown to greenish brown and mostly argillaceous grading to mudstone. The sandstone and siltstone are increasingly marly in the southern part of the area. Claystone in the upper part of the tongue commonly is greenish brown to grayish green and grade into mudstones with an increase in silt and sand content. Green claystone commonly is present near the top of the tongue.

The uppermost tongue of the Uinta (map units Tug and Tu8, fig. 9) is the highest stratigraphic unit in the study area. It overlies the Thirteenmile Creek Tongue of the Green River Formation. Only a few small isolated patches of this tongue are present in the study area, and their maximum thickness does not exceed 30 ft (9 m). Higher beds have been removed by erosion. The unit is unique among the Uinta tongues in that it contains chert-pebble conglomeratic beds. South of the area, in the Wolf Ridge (Duncan, 1976a) and Square S Ranch (Duncan, 1976b; Hail and Duncan, 1984) quadrangles, a thick tongue of the Uinta was mapped above the Thirteenmile Creek Member as map unit Tu5. The tongue locally contains chert-pebble conglomerate beds. The outcrop of the tongue in the study area east of Yellow Creek consists of gray to greenish-gray and brown calcareous sandstone and lenses of chert-bearing conglomerate and conglomeratic sandstone. The chert fragments range from grit size to about 0.5-in. (1 cm) diameter pebbles. In the outcrop outliers west of Yellow Creek, the unit includes some marlstone and limestone, as well as conglomeratic sandstone. The conglomeratic sandstone contains mostly clasts of soft rocks—siltstone and claystone—as long as 1.25 in. and considerable chert and quartzite pebbles as long as 0.75 in.; enclosing sandstone is moderately clean, quartzitic, and calcareous. The conglomeratic sandstone beds locally are overlain by thin beds of hard granular limestone and marlstone more typical of the underlying Thirteenmile Creek Tongue. The conglomeratic sandstone beds are soft and nonresistant in contrast to the hard, bench-forming marlstones at the top of the underlying Thirteenmile Creek Tongue of the Green River Formation.

Tongues of the Green River Formation

Intertonguing beds of the Green River and Uinta Formations were first shown on a preliminary map of the Barcus Creek SE quadrangle (Hail, 1972). In the lower part of the intertonguing sequence, two tongues of Green River (map units Tgpa and Tgpb) were mapped. In higher strata, only the top of a marlstone unit designated Yellow Creek marker bed and the base of a unit designated Barcus Creek marker bed were shown on the map; these were included with the Uinta Formation (then Evacuation Creek Member of the Green River Formation). The Yellow Creek marker bed later was formally named the Yellow Creek Tongue of the Green River Formation and the Barcus Creek marker bed was included in the Thirteenmile Creek Tongue of the Green River Formation (Duncan and others, 1974, p. 4, 9). As a result of detailed quadrangle mapping in the northern part of the Piceance Creek basin, both the nature and lateral extent of the marlstone units were recognized, and Duncan and others (1974) formally named four tongues of the Green River. These are (in ascending order) the Yellow Creek, Dry Fork, Thirteenmile Creek, and Black Sulphur Tongues. Subsequent published maps show these formally named tongues as well as certain other unnamed tongues. Other marlstone units not mapped separately were included with the Uinta Formation. In revising the preliminary maps of the Barcus Creek and Barcus Creek SE quadrangles for publication as USGS

Geologic Quadrangle maps, the formally named Green River tongues (Yellow Creek, Dry Fork, and Thirteenmile Creek) and several other informally designated tongues were shown. These tongues are shown diagrammatically on figure 9 and table 3.

The tongues of the Green River are chiefly marlstone; they also include a fairly large proportion of limestone and numerous sandstone beds. Much of the marlstone is silty, ranging to marly siltstone. Significant oil-shale beds generally are absent in the Green River tongues, but a few thin, low-grade oil-shale beds are present locally. Brobst and Tucker (1974, p. 28, table 5) noted the dominance of calcite over dolomite in those marlstones of the Parachute Creek Member above the Mahogany ledge in the lower Piceance Creek area, a dominance consistent with the abundant limestone of the Green River tongues that merge with the upper part of the Parachute Creek Member. The tongues are mostly very light gray or very light brownish gray. Sandstone in the tongues is light gray to light grayish brown. The light gray of the marlstone tongues is in conspicuous contrast to the pervasive brown of the enclosing Uinta tongues. For purposes of discussion, the Green River tongues are divided into a lower group and an upper group, the boundary between the two being the tongue of the Uinta identified as map unit Tud and Tu5 (fig. 9).

Lower Group of Tongues of the Green River Formation

The lowermost tongue of the Green River Formation (map units Tgpt, Tgua, and Tgl; fig. 9, table 3) merges with the Parachute Creek Member of the Green River Formation in sec. 32, T. 2 N., R. 97 W., and just west of the study area in the northeastern part of the Calamity Ridge quadrangle (Donnell and Hail, 1984). In the subsurface of the study area, it merges southward with the Parachute Creek Member between the U.S. Bureau of Mines AEC–1 drill hole in sec. 13, T. 1 N., R. 98 W., and the Humble Oil Co. 1 Yellow Creek drill hole about 4 mi to the south in sec. 2, T. 1 S., R. 98 W. The tongue is about 40–200 ft (12–60 m) thick. It was mapped as a separate unit in all four quadrangles of the study area. It consists mostly of light-gray dolomitic marlstone and considerable calcareous marlstone and several beds of limestone. The dolomitic marlstone is variably silty and grades to marly siltstone. It is mostly thin and flat bedded and locally weathers to hard platy slabs. The unit also contains numerous very thin, clean, quartzose beds of light-gray sandstone and siltstone. West of Yellow Creek, it includes a thin (3 ft (1 m) thick) bed of resistant granular limestone near the top of the tongue.

The next higher tongue of the Green River is an informally named unit, the marlstone at Trail Canyon (Hail, 1984), shown as map unit Tgtc on the Barcus Creek quadrangle. It merges eastward in surface exposures with another tongue of the Green River, map unit Tg2 (fig. 9) about a mile (1.5 km) east of Yellow Creek. West of the study area, in the southern part of the Calamity Ridge quadrangle, it merges with the Parachute Creek Member of the Green River (Donnell and Hail, 1984). It is locally absent in the northern part of the Barcus Creek quadrangle owing to the presence of an apparent lobe of Uinta Formation clastic rocks. It is present but was not separately mapped in the Rough Gulch quadrangle (Hail, 1974a) where it is included with the Uinta Formation (map unit Tu, table 3). It is evidently present throughout most of the subsurface of the study area. It ranges in thickness from about 60 to 250 ft (18–76 m). It consists mostly of light-gray to light-brown, variably silty marlstone, most of which is flat bedded and locally weathers to platy slabs or chips. The unit also contains some marly siltstone and minor thin beds of very fine grained, light-gray to light-brown sandstone. In the northwestern part of the Barcus Creek quadrangle, the unit contains some thin beds of ostracodal limestone and sandstone. In the extreme southwestern part of the study area, the tongue contains two thin ledges of very low grade oil shale (4 gallons per ton or less).

The next higher tongue of the Green River River in the area west of Yellow Creek is the informally named marlstone at Mare Canyon shown as map unit Tgm (fig. 9, table 3). It is a generally thin, but widespread unit. It splits eastward at Yellow Creek to form two tongues (map units Tg3 and Tg4, fig. 9) separated by a tongue of the Uinta (map unit Tu4). It is present but not mapped separately in the Rough Gulch quadrangle, where it is included with the Uinta Formation (map unit Tu, table 3). It is present west of the study area in the southern part of the Calamity Ridge quadrangle (Donnell and Hail, 1984). The tongue consists of light-gray to light-grayish-brown, variably silty marlstone and some marly siltstone. In the north-central part of the Barcus Creek quadrangle it contains some greenish-gray marly claystone. In the southwestern part of the Barcus Creek quadrangle it contains a very thin bed of papery, rich oil shale (20–25 gallons per ton). The tongue is about about 5–60 ft (1.5–18 m) thick.

In the area east of Yellow Creek, the marlstone at Trail Canyon and the lower part of the marlstone at Mare Canyon (map unit Tg3) merge laterally eastward into one tongue of the Green River (map unit Tg2). This tongue is similar in lithology to the marlstone at Trail Canyon; it consists of light-gray to light-brown, variably silty, locally platy weathering marlstone. It contains a few thin, light-gray sandstone beds, and near Piceance Creek it contains several beds of very low grade oil shale and several very thin tuff beds. It ranges in thickness from about 150 to 350 ft (46–107 m). The tongue designated map unit Tg3 occupies only a small outcrop area east of Piceance Creek between the pinchout of the two enclosing Uinta tongues. The tongue consists of light-gray silty marlstone and several beds of light-brown sandstone including a few channel deposits. It ranges in thickness from about 60 to 90 ft (18–27 m). The tongue designated Tg4 is chiefly the eastward lateral equivalent of the marlstone at Mare Canyon and is similar in lithology. It is mostly light brown to light gray, locally platy weathering, variably silty marlstone. It contains a few thin, very low grade oil-shale beds in the eastern part of its outcrop area and a few very thin tuff beds. It ranges in thickness from about 45 to 90 ft.

Upper Group of Tongues of the Green River Formation

The upper group of tongues of the Green River Formation comprises mostly three formally named tongues (in ascending order), the Yellow Creek, Dry Fork, and Thirteenmile Creek, and, in the extreme southwestern part of the area, two unnamed tongues (map units Tgub and Tguc, fig. 9).

The Yellow Creek Tongue of the Green River Formation is widespread through the north-central part of the Piceance Creek basin. It crops out in the Barcus Creek, Barcus Creek SE, and Rough Gulch quadrangles. It was not shown separately on the map of the Rough Gulch quadrangle but was included in the Uinta Formation (map unit Tu, table 3). In the southwestern part of the Barcus Creek quadrangle, it merges with a higher marlstone tongue (map unit Tguc, fig. 9) and the merged unit is designated Tgub. The Yellow Creek Tongue was mapped eastward into the White River City quadrangle (Pipiringos and Johnson, 1976). In the study area, it is 10–70 ft (3–21 m) thick. Local thinning is due to scouring and channel filling by the overlying tongue of the Uinta Formation. The Yellow Creek Tongue consists of light-gray to light-brownish-gray, variably silty marlstone; lesser light-gray siltstone, much of which is marly; and several beds of light-gray to light-brown siltstone and very fine grained sandstone. The marlstone beds are flat and even bedded and weather to thin chips or platy slabs. In the western part of the study area, the marlstone is more resistant and forms ledges and benches. It also is more limy, and in this area the unit contains one or more granular ostracodal limestone beds, which also are resistant and form benches. In the upper drainages of Barcus Creek and Greasewood Creek, these rocks cap buttes on interstream divides. Near the mouth of Barcus Creek, the tongue contains a thin bed of very low grade oil shale.

The tongue of the Green River designated map unit Tguc (fig. 9) occupies only a small area in the southwestern part of the Barcus Creek quadrangle. Its eastern boundary is an arbitrarily designated line that marks a relatively abrupt facies change westward from the dominantly sandy tongue of the Uinta to the east. The tongue consists mostly of light-gray, variably silty and sandy marlstone and several sandstone beds. Where it merges with the Yellow Creek Tongue it is mostly marlstone. Its maximum thickness is about 90 ft (27 m).

The tongue of the Green River designated map unit Tgub represents the merged Yellow Creek Tongue and overlying tongue and occupies only a small area in the southwestern part of the Barcus Creek quadrangle. It is mostly very light gray, variably silty and sandy marlstone and includes minor light-brown siltstone and sandstone. Its maximum thickness is about 80 ft (24 m). This unit was mapped to the south in the Wolf Ridge quadrangle (Duncan, 1976a), where it was designated map unit Tgu.

The Dry Fork Tongue of the Green River Formation crops out in the southeastern part of the study area between Yellow and Piceance Creeks. In the study area, the Dry Fork Tongue wedges out into the Uinta Formation approximately along the axis of the Red Wash syncline. The tongue was mapped to the east in the White River City quadrangle (Pipiringos and Johnson, 1976), to the southeast in the Greasewood Gulch quadrangle (Duncan, 1976c), and to the south in the Square S Ranch quadrangle (Hail and Duncan, 1984). The Dry Fork Tongue is light-gray to light-brown, variably silty marlstone to marly siltstone; it also includes one or two sandstone beds and locally some argillaceous marlstone in the upper part. The marlstone beds are mostly soft and nonresistant but in the southern part of the area locally are resistant enough to form benches on interstream divides. The Dry Fork Tongue thins to the northwest, becoming more silty and sandy, and finally ceases to be a mappable unit. In the Square S Ranch quadrangle to the south, it thins to the west and apparently approaches its western wedge edge near the mouth of Duck Creek. The Dry Fork Tongue reaches its maximum thickness of about 60 ft near the southern boundary of the study area.

The Thirteenmile Creek Tongue of the Green River Formation is the stratigraphically highest tongue of the Green River in the study area. It crops out as outliers mostly along the trough and southern flank of the Red Wash syncline. It is one of the most widespread of the formally named Green River tongues in the northern part of the Piceance Creek basin and crops out almost as far south as upper Piceance Creek in T. 2 S., Rs. 94, 95, and 96 W. (O'Sullivan, 1974a; Duncan, 1976d). It was mapped in adjacent quadrangles to the east, south, and southwest. It merges westward with other Green River tongues about a mile (1.5 km) south of the southwest corner of the study area, in the Wolf Ridge quadrangle (Duncan, 1976a). The thickness of the tongue in the study area is not well known inasmuch as most of the outcrops are stripped of overlying beds. The maximum remaining thickness is about 50–80 ft (15–24 m). The Thirteenmile Creek Tongue in the study area comprises mostly light gray carbonate rocks including dolomitic, limy, and argillaceous marlstone and limestone. Thin beds of light-brown siltstone and very fine grained sandstone and grayish-green claystone commonly are present but are less abundant or sparse. The marlstone beds in the lower part of the unit are hard and resistant and generally form stripped bench surfaces that cap interstream divides. These marlstones commonly are even bedded and weather to platy slabs or chips. Some marlstones higher in the unit, sparsely preserved from erosion, are argillaceous, soft, nonresistant and form slopes. The relatively abundant limestone beds generally are dense to coarsely crystalline; some are granular. Most are variably ostracodal or oolitic, and algal structures are common. These limestones probably reflect shallow open-water lacustrine deposition. The Thirteenmile Creek Tongue contains a larger proportion of ostracodal and algal limestone beds than any other tongue of the Green River. Oil-shale beds are absent, but several miles to the south, in the southern part of the Square S Ranch quadrangle (Duncan, 1976b), the Thirteenmile Creek Tongue contains three very thin, low-grade oil-shale beds. These beds are correlative in part with the so-called Big Three oil-shale beds (Duncan and others, 1974, p. 8; O'Sullivan, 1974b), widely recognized in oil-shale assay logs throughout much of the central and southern part of the Piceance Creek basin (Cashion and Donnell, 1972). In the Sagebrush Hill quadrangle to the southwest of the study area, Donnell (1982) reported oil-shale beds, including the Big Three beds, in a marlstone tongue (marlstone at Duck Creek) that is correlative in part with the Thirteenmile Creek Tongue.

Quaternary Deposits

Surficial deposits of Holocene and Pleistocene age include terrace gravels, alluvium, and landslides. Stream-gravel terrace deposits are present along the White River and several of its tributaries. These deposits are 40–400 ft (12–120 m) above the river and represent former positions of the valley floor. All of these deposits along the White River have similar lithologies. The constituent material ranges from sand size to as much as 1 ft (30 cm) in longest dimension. The larger clasts are mostly silicified sandstone, siltstone, and quartzite but also include abundant basalt or similar volcanic flow rocks and sparse granitic or other crystalline or metamorphic rocks. The larger clasts are well rounded. Many of the terrace gravels along the White River are covered or mostly obscured by hillwash or other alluvial material. A few patches of terrace gravel along the White River are firmly calcite cemented and form resistant conglomerates. The few small patches of terrace gravel along Piceance Creek are about 60–140 ft (18–43 m) above the present valley floor and consist mostly of silicified sandstone and siltstone and minor limestone. Basaltic and granitic rocks are absent. Scattered patches of stream gravel also occur along other tributaries of the White River including Colorow Gulch, Deep Channel Creek, Crooked Wash, Coal Creek, and Wolf Creek. These patches of gravel are 20–180 ft (6–55 m) above the valley bottoms. The rock constituents of these gravels include quartzitic to nonquartzitic sandstone and siltstone, locally limestone, and chert. Clasts of basaltic and granitic or other crystalline rocks are absent. The maximum thickness of the stream-gravel terrace deposits is about 20 ft (6 m).

The term alluvium is applied to all mapped alluvial and colluvial deposits in the area except the terrace gravels, and it includes the valley-bottom alluvium of the White River and its tributary streams, alluvial fans at the junctions of branch streams with the White River and Piceance Creek, fans at the base of cliffs along the White River, and some hillwash and colluvial cover. These units are designated on the original four 7.5-minute maps of the area as map units Qal (alluvium), Qaw (alluvium in the valley of the White River), and Qac (alluvial and colluvial deposits undifferentiated). The alluvium is a mixture of rounded gravel derived from distant sources to the east and locally derived mud, silt, sand, and gravel. It also includes fans at the mouths of intermittent branch streams where they join trunk streams. Such fans build periodically following heavy rainstorms. Torrential fans spread out from the bases of steep cliffs onto the lower ground flanking the cliffs and cover appreciable areas of terrace gravel deposits along the White River.

Landslide deposits are relatively sparse in the area. Most consist of coherent to chaotic rocks masses or slumped ground and originate in or on nonresistant clay or shale of the Mancos Shale, Wasatch Formation, and Garden Gulch Member of the Green River Formation. The largest landslide mass lies in sec. 27, T. 1 N., R. 97 W., on the northeast side of the conspicuous butte just north of the White River. It is composed of jumbled masses mostly of sandstones of the Anvil Points Member of the Green River Formation and some units of the underlying Wasatch. A small area of landslide in sec. 11, T. 1 N., R. 97 W., near the east boundary of the area, involves burned or clinkered beds probably of the Mahogany ledge oil-shale zone. There are no major areas of active landsliding. Minor slumping occurs as a result of heavy rainstorms in gullied areas of the Wasatch Formation.

STRUCTURE

The lower Yellow Creek area is in the northwestern part of the Piceance Creek basin, the deepest structural basin in Colorado (MacLachlan and Kleinkopf, 1969, pl. 1) A segment of the structural trough line of the Piceance Creek basin trends northwestward through the lower Yellow Creek area, where it is designated the Red Wash syncline (fig. 11). The deepest part of the basin, about 18,000 ft (5,500 m) below sea level to Precambrian basement, is a few miles southeast of the study area, but the deepest occurrence of Tertiary rocks is within the study area in Tps. 1 and 2 N., R. 98 W. The maximum structural relief on the Precambrian surface within the lower Yellow Creek area is about 15,000 ft (4,600 m).

Structural trends in the study area generally are characteristic of those throughout the entire Piceance Creek basin. Fold axes and faults generally trend northwesterly. The area contains several low-ampitude folds and some faults having relatively small stratigraphic displacement.

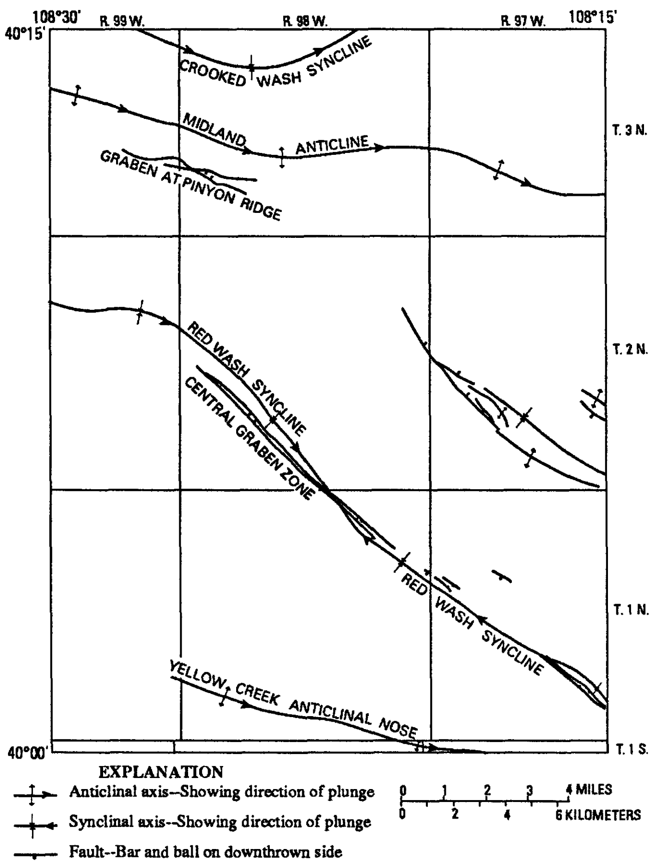


Figure 11. Faults and fold axes in the lower Yellow Creek area. Some small faults are not shown.

Midland Anticline, Graben at Pinyon Ridge, and Crooked Wash Syncline

Both the Midland anticline and the Crooked Wash syncline generally trend east-west and extend eastward from off the Skull Creek anticline, a major uplift a few miles west of the study area. Axial traces of these folds as shown on figure 11 are based on structure contours drawn on Cretaceous horizons at or below the top of the Mancos Shale.

The Midland anticline is a major structural element that extends across the northern part of the study area. The anticline controls the outcrop pattern of formations in the northern part of the area and marks the abrupt change in strike demonstrated by the south-striking rocks that form Pinyon Ridge and the east-striking rocks that form Coal Ridge. The anticline forms the structural boundary of the northwestern Piceance Creek basin, west of the Gray Hills segment of the basin. It plunges eastward and has steep dips on its south flank and gentle dips on its north flank. In the Stadtman Mesa area (Rough Gulch quadrangle), dips on the south flank are as much as 3,500–4,000 ft/mi (660–760 m/km); farther to the east, dips generally are less than 2,500 ft/mi (470 m/km). Dips on the north flank generally are 500–1,000 ft/mi (95–190 m/km). Nine oil and gas test holes were drilled along or near the anticlinal axis. All were dry except Mobil Oil Federal 15–29 and 1–30, which yielded gas and minor oil.

A graben about 2 mi (3.2 km) long is present in the northwestern part of the study area (Rough Gulch quadrangle). Exposed rocks in the faulted area include the upper part of the Cretaceous Mancos Shale and the lower part of the Williams Fork Formation. The faults are vertical to steeply dipping normal faults. Some of the apparent sinuosity of the fault traces is due to topography. The graben is about 250–2,000 ft (76–610 km) wide. The maximum stratigraphic displacement is about 350 ft (106 m) on its northern fault and about 200 ft (60 m) on its southern fault. The fault zone is just south of the axis of the Midland anticline at the position of maximum change in outcrop trend direction that marks the geographic boundary between the generally south trending Pinyon Ridge and the east-trending Coal Ridge. This position coincides with the marked structural steepening of the south flank of the asymmetrical Midland anticline.

A small segment of the Crooked Wash syncline is present in the extreme northern part of the study area. The fold is somewhat asymmetric. Dips on the north flank are about 1,500 ft/mi (280 m/km), whereas dips on the south flank are about 750 ft/mi (140 m/km). The syncline plunges eastward throughout its extent, both within and north of the study area.

Folds and Faults in the Vicinity of the White River

Several northwest-striking folds and normal faults are present along or just south of the White River in the east-central part of the area (fig. 11).

Fold axes were determined on the basis of dips of mapped formation contacts in the area; control points are sparse and the placement of the fold axes is not well established. The existence of the syncline drawn along the alluvium of the White River (Barcus Creek SE quadrangle) is chiefly speculative but accounts for dip reversals of the Wasatch–Green River contact on the north and south sides of the river. The axis of this syncline apparently extends only a short distance east of the study area. The anticlinal axis, about 0.5 mi (0.75 km) southwest of the syncline, extends to the east boundary of the study area where it aligns with a major southeast-trending fault (Pipiringos and Johnson, 1976). Analysis of drill-hole logs in sec. 1, T. 2 N., R. 97 W., does not confirm the presence of faulting, and it is assumed that the fault merges to the northwest into the anticlinal fold. A separate short anticlinal segment is also present just north of the larger anticline.

Extending northwesterly beyond the fold axes are three faults that locally offset contacts of the Wasatch Formation and the Anvil Points and Garden Gulch Members of the Green River Formation. The offsets are relatively small, from 10 to 50 ft (3–15 m), but at the northwest corner of sec. 29, T. 2 N., R. 97 W. (Barcus Creek SE quadrangle), the displacement is as much as 100 ft (30 m). The two larger faults are downthrown on the northeast, whereas the shortest of the three faults is downthrown on the southwest, forming a small graben. The largest fault is aligned roughly with, and extends northwest from, the larger anticline. This alignment suggests differing structural adjustments to a common structural trend.

Two very short structural segments are shown on figure 11 at the eastern boundary of the study area in T. 2 N., R. 97 W. The anticlinal axis is the northwest end of the so-called White River dome, a structural feature present mostly east of the study area. The normal fault, downthrown to the southwest, is the northwest end of a major fault that extends southeastward more than 6 mi (10 km) (Pipiringos and Johnson, 1976).

Red Wash Syncline and Central Graben Zone

The Red Wash syncline is the dominant fold in the area. The axial trace of the syncline as shown on figure 11 is based on structure contours drawn on the top of the Mahogany oil-shale zone in the Parachute Creek Member of the Green River Formation. A structure contour map by Johnson (1983) drawn on the top of the Cretaceous Iles Formation and a structure contour map by Dyni (1969, pl. 1) drawn on the orange marker in the upper part of the Garden Gulch Member of the Green River Formation both show a similar axial trend for the syncline in the older rocks. The northwestward extension of the Red Wash syncline forms the structural boundary between the Rangely anticline and the Skull Creek anticline to the west of the area. The syncline extends southeastward for about 11 mi (18 km), with two reversals in plunge direction, and dies out before reaching the eastern margin of the Piceance Creek basin (Dyni, 1969, pl. 1; Pitman and Johnson, 1978, sheet 2). Within the study area the syncline is doubly plunging (fig. 11) toward the structural low just southeast of Barcus Creek near the township boundary between Tps. 1 and 2 N. (see Barcus Creek and Barcus Creek SE geologic maps). The maximum structural closure within the study area is about 400 ft (120 m).

The Red Wash syncline is asymmetric; it has a steep north flank and a gentle south flank. North flank dips are about 1,000 ft/mi (190 m/km) and south flank dips are about 200 ft/mi (38 m/km). Maps by Pitman and Johnson (1978), Pitman (1979), and Pitman and others (1989) show that isopach trends of the R–5, R–6, and Mahogany oil-shale zones roughly coincide with the structural configuration along the Red Wash syncline in the study area. These oil-shale zones are thickest in the structural low, and structural deepening probably occurred during deposition of the upper part of the Parachute Creek Member of the Green River Formation. Lower oil-shale zones in the Parachute Creek Member show no such deepening.

The central graben zone (fig. 11) is closely parallel with the axis of the Red Wash syncline for much of its extent in the study area. The fault zone extends southeasterly from sec. 19, T. 2 N., R. 98 W., in the Rough Gulch quadrangle, for an overall distance of about 13 mi (21 km), to sec. 35, T. 1 N., R. 97 W., in the Barcus Creek SE quadrangle. Faulting is continuous, however, only along the northwestern 6.5 mi (10.5 km) of the zone. A few intermittent faults mark the zone to the southeast and displacements are small. Stratigraphic displacements are greatest generally along the southwestern fault; maximum displacement is about 100 ft (30 m), but most displacements do not exceed 50–60 ft (15–18 m). Along the northeastern fault, the maximum displacement is about 80 ft (24 m), but most displacements do not exceed 10–20 ft (3–6 m). The faults are locally and very sparsely mineralized by calcite. Zones of fault breccia are sparse but locally present. The nature of the faults at depth is unknown owing to the lack of subsurface information, but the system is presumed to be deep seated. Surface exposures indicate that the faults are essentially vertical.

The proximity and parallel trend of the fault zone and the axis of the Red Wash syncline suggest a genetic relationship. The alignment of normal faults along well-defined fold axes, both synclinal and anticlinal, is common in the study area and elsewhere in the northern Piceance Creek basin. In addition to the fault zones described in the study area, all of which are clearly associated with fold axes, at least two others are noteworthy. The Dudley Bluffs graben, about 8 mi (13 km) south and southeast of the study area, generally is south of and parallel with the axial trace of the Piceance Creek dome throughout much of its length of about 12 mi (19 km) (see maps by Dyni, 1969, pl. 1; Duncan, 1976b, c, d; Pitman and Johnson, 1978, sheet 2). The epicenter of possibly the largest earthquake in Colorado in historic time, November 7, 1882, may have been the Dudley Bluffs graben (McGuire and others, 1982). If so, the Dudley Bluffs graben is likely a deep-seated fault system. The Sulphur Creek anticlinal nose (Dyni, 1969, pl. 1), about 10 mi (16 km) south and southwest of the study area, is marked by numerous normal faults throughout most of its length of about 12 mi (19 km) (see maps by Duncan, 1976a, e, f; Donnell, 1982; Pitman and Johnson, 1978, sheet 2). The faults are probably deep seated and developed along the trends of the Laramide-age folds.

Yellow Creek Anticlinal Nose

The Yellow Creek anticlinal nose is present near the southern boundary of the study area (fig. 1). The axial trace of the fold is based on structure contours drawn on the top of the Mahogany oil-shale zone in the Parachute Creek Member of the Green River Formation. The fold represents structural steepening of the Rangely anticline to the west of the area and was designated Rangely anticline on structure contour maps by Dyni (1969, pl. 1) and Hail (1974). Redrawing of structure contour lines for the revised Barcus Creek quadrangle geologic map (Hail, 1984) did not demonstrate, however, a definitive fold axis for the Rangely anticline near the western boundary, and the use of the name Rangely anticline is not regarded as appropriate for the eastward extension of the clearly evident structure now termed the Yellow Creek anticlinal nose. The structure extends from the boundary between Rs. 98 and 99 W., where obvious nosing begins, southeastward about 8 mi (13 km) to the southern boundary of the study area, and terminates about 3 mi (5 km) farther southeast in a structural saddle near Piceance Creek. It is relatively symmetrical and plunges southeastward about 40–110 ft/mi (8–21 m/km). There is no structural closure.

ECONOMIC GEOLOGY

Oil Shale and Associated Minerals

Rich oil-shale deposits underlie the southern part of the study area, mostly in the Barcus Creek and Barcus Creek SE quadrangles. Oil shale is present in the Parachute Creek and Garden Gulch Members of the Green River Formation, and all the named oil-shale zones are exposed. The Garden Gulch Member includes rich oil-shale zone R–1 and lean zone L–1, as well as some oil shale below zone R–1. The Parachute Creek Member includes all oil-shale zones above zone L–1. Fischer assay logs showing oil yield and oil-shale zones for six core holes in and near the study area are shown on the geologic maps of the Barcus Creek and Barcus Creek SE quadrangles (Hail, 1984, 1988).

Tables 4 and 5 show oil-shale resources for the Barcus Creek and Barcus Creek SE quadrangles, respectively. The information in these tables is derived from published resource maps by Pitman (1979), Pitman and Johnson (1978), and Pitman and others (1989). Oil shale is present in the Rough Gulch quadrangle, but subsurface information is sparse and outcrops of the oil-shale-bearing part of the Green River Formation in the quadrangle are mostly barren of significant oil shale. Trends of oil-shale values depicted in the published resource maps suggest that none of the oil-shale zones in the Rough Gulch quadrangle contains significant resources. Within the Barcus Creek and Barcus Creek SE quadrangles, oil-shale values and thicknesses for all the zones generally decrease northward from the southern parts of the quadrangles. Oil-shale resources for oil-shale beds above the Mahogany zone and below the R–1 zone are not included in the resource tables. Oil-shale resources above the Mahogany zone are probably insignificant in the area. These oil-shale beds generally are of low grade and lie within the Uinta and Green River intertonguing sequence. Pitman and Donnell (1973) showed, however, that large resources of oil shale are present above the Mahogany farther south in the Piceance Creek basin. The total oil-shale resources in the study area, as shown in tables 4 and 5, are about 111 billion barrels of oil.

Potentially valuable deposits of the sodium minerals nahcolite and dawsonite are closely associated with the oil shale. These minerals presumably would be produced commercially only as byproducts of oil-shale production. Nahcolite ($NaHCO_3$) is a potential source of industrial soda ash and a gas-scrubbing agent. Dawsonite

Table 4. Oil-shale resources in the Barcus Creek quadrangle

[No subsurface resource information is available for area north of township line between T. 1 N. and T. 2 N., and, although oil shale is present in the area, no resources are estimated. No resources are estimated for individual oil-shale zones below the following barrels-per-acre isovalue lines: R-1, 200,000; L-1, 10,000; R-2, 50,000; L-2, 20,000; R-3, 50,000; L-3, 20,000; R-4, 100,000; L-4, 50,000; R-5, 100,000; L-5, 25,000; R-6, 50,000; Mahogany, 50,000]

Zone	Thickness (approx. range in feet)	Gallons per ton (approx. range)	Barrels per acre (approx. range)	Approx. total resource (billions of barrels)
Mahogany	170-240	<10-24	50,000-340,000	7.2
R-6	<200-250	<5-23	<50,000->350,000	8.2
L-5	<140-180	<5-12	<25,000-145,000	2.6
R-5	<200-320	<15-30	<100,000-500,000	9.7
L-4	100->160	<10-22	<50,000-245,000	4.1
R-4	<120-150	<25-37	<100,000-355,000	7.2
L-3	<40-65	<10-20	<20,000-60,000	1.2
R-3	<60-120	<20-32	<50,000-240,000	4.4
L-2	30-43	<10-23	<20,000-75,000	1.1
R-2	<60-70	<25-37	<50,000-55,000	3.4
L-1	<30-30	<10-13	<10,000-25,000	0.3
R-1	130-220	<20-21	<200,000-320,000	5.0

Table 5. Oil-shale resources in the Barcus Creek SE quadrangle

Zone	Thickness (approx. range in feet)	Gallons per ton (approx. range)	Barrels per acre (approx. range)	Approx. total resource (billions of barrels)
Mahogany	180-240	10-26	50,000-400,000	8.6
R-6	<200->260	<5-23	<50,000->350,000	8.1
L-5	<100-195	<5-15	<25,000-165,000	3.1
R-5	140-310	<15-28	<100,000-535,000	10.0
L-4	<80-160	<10-22	<50,000-240,000	4.2
R-4	60-150	<20-37	<100,000-365,000	6.6
L-3	25-40	<10-20	<20,000-70,000	1.3
R-3	<40-115	<20-32	<50,000-225,000	4.0
L-2	20-55	10-21	<20,000-75,000	1.4
R-2	45-70	15-37	<50,000-150,000	3.4
L-1	20-40	5-14	5,000-35,000	0.6
R-1*	135-220	15-26	<200,000-315,000	5.3

*Figures shown are for southern half of quadrangle only because of lack of subsurface information in northern half of quadrangle.

($NaAl(OH)CO_3$) is a potential source of aluminum. Both minerals occur in the saline facies of the Parachute Creek Member of the Green River Formation (Hite and Dyni, 1967; Beard and others, 1974; Dyni, 1974). The saline facies occupies the deeper parts of the northern Piceance Creek basin. Most of the Parachute Creek Member in the southern part of the study area is within the saline facies. Stratigraphically, the nahcolite and most of the dawsonite are below the base of a widespread leached zone (approximately the L–5 or R–5 oil-shale zone level) from which the readily soluble nahcolite has been dissolved and removed and above approximately the L–2 or R–2 oil-shale zone (Trudell and others, 1970; Beard and others, 1974; Dyni, 1974). Published resource data for the study area are sparse, and definitive estimates are not possible, but some information is available. Resource maps by Beard and others (1974) show that nahcolite resources range from about 300 million tons per square mile at the southern boundary of the area to zero in the central part; dawsonite resources range from about 120 million tons per square mile at the southern boundary to zero in the central part. Based on these maps, with some modifications suggested by J.R. Dyni (written commun., 1985), the total nahcolite resources of the study area are estimated to be about 8.9 billion tons and the total alumina resources in dawsonite are estimated to be about 6.1 billion tons.

Coal

Coal-bearing rocks of the Cretaceous Iles and Williams Fork Formations occupy the southeastern part of the Lower White River Coal Field, as defined by Gale

(1910, p. 179, pl. 18). They are present in the northwestern part of the study area in the Rough Gulch and Smizer Gulch quadrangles.

Coal beds are present in the upper, middle, and lower parts of the Williams Fork Formation and near the top and base of the Iles Formation. A few very thin coal beds of no economic value are present in the upper member of the Fort Union Formation. The coal beds occur in carbonaceous shale zones, some of which persist for several miles along the outcrop, but most of the individual coal beds are lenticular and nonpersistent. On the geologic maps of the Rough Gulch and Smizer Gulch quadrangles, measured sections of 160 coal-bearing localities are shown. Coal beds less than 1.2 ft (37 cm) thick generally were not measured. The maximum coal-bed thickness is 7.2 ft (2.2 m) in the Rough Gulch quadrangle and 6.7 ft (2.0 m) in the Smizer Gulch quadrangle. Most of the beds are less than 4 ft (1.2 m) thick. Most of the available information on coal in the study area is based on examination of surface exposures. No coal has been produced in the area except for local use by ranches from a few small, long-abandoned mines.

Analyses are not available for coals in the area. The U.S. Bureau of Mines (Aresco and others, 1966, p. 6) reported analyses of three samples from the Staley-Gordon mine about 11 mi (17.5 km) west of the area, from probably correlative strata. Heat values range from 10,830 to 11,210 Btu/lb (moist basis), and sulfur content from 0.4 to 0.5 percent. The coal is ranked as high-volatile C bituminous.

Iles Formation

A persistent coal-bearing carbonaceous shale zone overlies the basal sandstone of the Iles Formation north of the White River, but coal beds in the zone are discontinuous. The zone is covered by alluvium of the White River in R. 99 W., except at the west edge of the area where coal beds are apparently absent. Ten coal sections were measured in this zone and are numbered 64 through 73 on the Rough Gulch geologic map. The thickest measured bed in the lower Iles coal zone is 3.4 ft (1 m) thick. Coal is mostly absent in higher beds of the Iles except for a single bed south of the White River (coal section 85 on the Rough Gulch geologic map), which is 2.4 ft (73 cm) thick and lies about 80 ft (24 m) below the top of the formation.

Williams Fork Formation

Most of the coal in the study area is in the Williams Fork Formation, and the two principal coal-bearing zones of the area are near the base and in the upper part of the formation. The lower zone, present only in the Rough Gulch quadrangle, actually comprises as many as three closely spaced coal-bearing carbonaceous zones, the lowest of which is the most persistent. All generally are within about 300 ft (92 m) above the base of the formation. Sixty-three coal sections (numbers 11–63 and 74–83 on the Rough Gulch geologic map) were measured in the lower zone. About one-third of the sections contain more than one coal bed. The thickest measured coal bed in the lower zone is 7.2 ft (2.2 m) thick. Coal-bearing rocks are widespread in this stratigraphic interval throughout the Piceance Creek basin. They are equivalent to the main coal zone of the Mesaverde Group in the Rangely area to the west (Barnum and Garrigues, 1980; Garrigues and Barnum, 1980), to the Fairfield coal group in the Meeker area (Hancock and Eby, 1930, p. 24), and to the Cameo-Fairfield coal zone in the southern part of the Piceance Creek basin (Johnson, 1983).

The upper Williams Fork coal zone comprises several closely spaced coal-bearing carbonaceous zones, all within about 950 ft (290 m) below the top of the formation. The upper coal zone is limited mostly to the Smizer Gulch quadrangle and is absent from most of the Rough Gulch quadrangle owing to truncation on the Cretaceous-Tertiary unconformity. Seventy-six coal sections (numbers 1–75 on the Smizer Gulch geologic map; number 1 on the Rough Gulch geologic map) were measured in the upper zone. About one-third of these sections contain more than one coal bed. The thickest measured coal bed in the upper zone is 6.7 ft (2.0 m) thick.

Coal beds between the upper and lower coal zones are mostly thin and discontinuous and do not occur in persistent carbonaceous zones. Ten coal sections of these beds were measured (numbers 1–10 on the Rough Gulch geologic map), and the thickest coal bed is 3.4 ft (1 m) thick.

Resources

U.S. Geological Survey reports on coal resources for the Rough Gulch and Smizer Gulch quadrangles (AAA Engineering and Drafting, 1979a, b) contain no resource estimates except for isolated localities, owing to the absence of laterally persistent beds more than 5 ft (1.5 m) thick. The economic potential of coal in the area is limited by the small lateral extent of the individual coal beds, the apparent absence of thick individual coal beds, and relatively steep structural dips, which preclude possible strip mining.

Oil and Gas

Table 6 lists oil and gas drill holes in the study area for which records are available. The area includes the

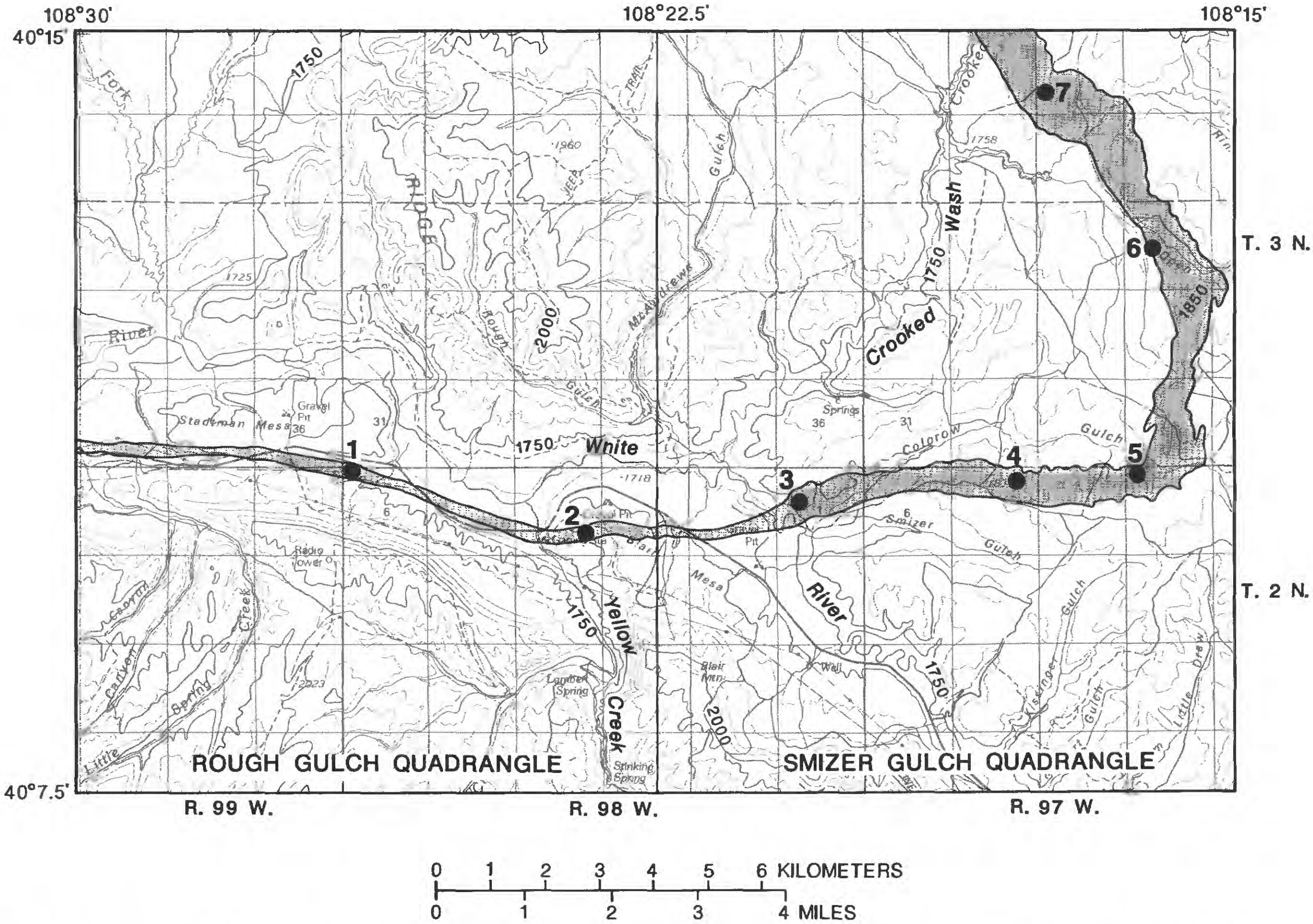


Figure 12. Area of outcrop (shaded) of upper member of Fort Union Formation, lower Yellow Creek area. Numbered circles show locations of uranium-enriched rocks (table 7).

western part of the White River Gas Field from which gas is currently being produced.

Sixteen of the drill holes tested pre-Tertiary rocks for oil and gas, but only one, the Mobil Oil Co. Federal 1–30 in the NE¼ sec. 30, T. 3 N., R. 97 W., yielded commercial amounts of oil and gas. This well produces gas and a small amount of oil from the Shinarump Member of the Chinle Formation of Triassic age. The well was drilled on the crest of the Midland anticline in an area where the fold is an anticlinal nose having no structural closure. In the Rangely area, west of the study area, oil is produced mostly from the Pennsylvanian Weber Sandstone; a smaller amount is produced from fractured shale of the Upper Cretaceous Mancos Shale. Oil fields along the crest of the Axial Basin uplift at the northeastern margin of the Piceance Creek basin, have yielded substantial amounts of oil from the Jurassic Entrada Sandstone and Morrison Formation, the Lower Cretaceous Dakota Sandstone, and fractured shale in the Mancos Shale (Dunn, 1974, p. 218–220). In the Elk Springs Oil Field northwest of the study area, oil is produced from the Weber Sandstone.

White River Gas Field

Gas was first discovered in 1890 in the White River Gas Field (Dunn, 1974, p. 221), but most of the production from the field has been in recent years because of the construction of pipeline facilities. Total Tertiary production has been relatively small, about 7.5 million cubic feet as of January 1987, and about two-thirds of this production has been from wells in the study area (Colorado Oil and Gas Commission, 1987, sec. V, p. 325). The eastern part of the field lies east of the study area, in the White River City and Indian Valley quadrangles. In that area, most of the gas, as well as some oil, is produced from Upper Cretaceous nonmarine rocks. Within the study area, however, all gas production is from Tertiary rocks. The reservoirs are lenticular sandstone beds at various stratigraphic levels in the Wasatch and Fort Union Formations. The entrapment apparently is stratigraphic rather than structural, and there is no evident relationship to the so-called White River dome to the east. The total cumulative Tertiary gas production in the study area to January 1, 1987, is

Table 6. Oil and gas drill holes, lower Yellow Creek area
[Cumulative production (cum. prod.) as of January 1987]

Name	Location	Total depth (in feet)	Formation at surface	Formation at total depth	Year drilled	Comments	Status
General Petroleum Yellow Creek 64-8	NE1/4 sec. 8, T. 1 N., R. 98 W.	3,859	Tongue of Uinta	Wasatch	1952		Abandoned
Teton Energy Colorado Wildlife 24-1	NE1/4 sec. 24, T. 1 N., R. 98 W.	9,102	Tongue of Uinta	Iles(?)	1980		Abandoned
General Petroleum Government 46-27	SW1/4 sec. 27, T. 1 N., R. 98 W.	3,223	Tongue of Green River	Wasatch	1952		Abandoned
Pacific Transmission Federal 22-12	NW1/4 sec. 12, T. 1 N., R. 99 W.	15,686	Tongue of Green River	Morrison	1979		Abandoned
General Petroleum Yellow Creek 26-25	SW1/4 sec. 25, T. 1 N., R. 99 W.	7,624	Tongue of Uinta	Williams Fork	1955		Abandoned
General Petroleum Yellow Creek 88-26	SE1/4 sec. 26, T. 1 N., R. 99 W.	1,691	Tongue of Uinta	Green River	1955	Completed as water well	Abandoned
Union Oil Colorow Government 1	SW1/4 sec. 16, T. 2 N., R. 97 W.	3,348	Wasatch	Fort Union	1952		Abandoned
American Resources Government 17-2	NE1/4 sec. 17, T. 2 N., R. 97 W.	2,183	Wasatch	Fort Union	1977	Gas in Wasatch	Shut-in
American Resources Government 17-1	NW1/4 sec. 17, T. 2 N., R. 97 W.	2,179	Wasatch	Fort Union	1977	Gas in Wasatch	Shut-in
Shell Oil Government 22X-17	NW1/4 sec. 17, T. 2 N., R. 97 W.	15,857	Wasatch	Morgan(?)	1967		Abandoned
Frontier Refining Colorow 2	SW1/4 sec. 17, T. 2 N., R. 97 W.	11,513	Wasatch	Mancos	1959		Abandoned
Frontier Refining-Shell Oil Colorow 1	SE1/4 sec. 17, T. 2 N., R. 97 W.	14,617	Wasatch	Weber	1958		Abandoned
American Resources Government 17-3	SE1/4 sec. 17, T. 2 N., R. 97 W.	2,150	Wasatch	Fort Union	1977	Gas in Wasatch	Shut-in
American Resources Government 18-1-5	SW1/4 sec. 18, T. 2 N., R. 97 W.	2,144	Green River	Fort Union	1977		Abandoned
American Resources Government 20-2	NE1/4 sec. 20, T. 2 N., R. 97 W.	2,644	Wasatch	Fort Union	1979		Abandoned
Trend Exploration Parker 1	SW1/4 sec. 20, T. 2 N., R. 97 W.	250	Wasatch	Wasatch	1973		Abandoned
American Resources Caldwell 1-20	SE1/4 sec. 20, T. 2 N., R. 97 W.	3,081	Wasatch	Fort Union	1972	Gas in Wasatch; cum. prod. 1,041,373 MCF	Gas well
Trend Exploration Parker 1A-20	SE1/4 sec. 20, T. 2 N., R. 97 W.	15,118	Wasatch	Morgan(?)	1974		Abandoned
American Resources Oldland 2-28	NW1/4 sec. 28, T. 2 N., R. 97 W.	2,939	Wasatch	Fort Union	1972	Gas in Wasatch; cum. prod. 777,287 MCF	Gas well
American Resources Oldland-Fritzlan 1	SE1/4 sec. 28, T. 2 N., R. 97 W.	3,100	Wasatch	Fort Union	1970	Gas in Wasatch; cum. prod. 44,982 MCF	Shut-in
American Resources Ivory-Fritzlan 1	NE1/4 sec. 34, T. 2 N., R. 97 W.	3,040	Wasatch	Fort Union	1970	Gas in Fort Union; cum. prod. 84,291 MCF	Abandoned
American Resources Government 1	NW1/4 sec. 34, T. 2 N., R. 97 W.	1,273	Wasatch	Wasatch	1970	Gas in Wasatch; cum. prod. 191,441 MCF	Gas well
American Resources Government 2-34	SW1/4 sec. 34, T. 2 N., R. 97 W.	3,001	Wasatch	Fort Union	1972	Gas in Wasatch; cum. prod. 1,197,178 MCF	Gas well
American Resources Ivory 1	SE1/4 sec. 34, T. 2 N., R. 97 W.	3,701	Wasatch	Williams Fork	1957	Gas in Wasatch; cum. prod. 1,709,184	Gas well

Table 6. Continued

Name	Location	Total depth (in feet)	Formation at surface	Formation at total depth	Year drilled	Comments	Status
Shell Oil Government 31-10	NE1/4 sec. 10, T. 2 N., R. 98 W.	15,430	Wasatch	Morgan	1968		Abandoned
Trident Coyote 1-A	SE1/4 sec. 27, T. 3 N., R. 97 W.	6,751	Wasatch	Mancos	1956		Abandoned
Trident Coyote 2	SE1/4 sec. 29, T. 3 N., R. 97 W.	7,105	Fort Union	Mancos	1957		Abandoned
Mobil Oil Federal 15-29	SE1/4 sec. 29, T. 3 N., R. 97 W.	12,042	Fort Union	Weber	1978	Small oil and gas prod. from Frontier Member of Mancos Shale	Shut-in
California Oil Federal 1	NE1/4 sec. 30, T. 3 N., R. 97 W.	3,830	Williams Fork	Mancos	1965		Abandoned
Mobil Oil Federal 1-30	NE1/4 sec. 30, T. 3 N., R. 97 W.	11,710	Fort Union	Weber	1977	Gas and small amount of oil from Shinarump Mbr. of Chinle Fm.	Gas well
Houston Oil Federal 24X-21	SW1/4 sec. 21, T. 3 N., R. 98 W.	9,610	Williams Fork	Weber	1978		Abandoned
Trident Coyote 3	NE1/4 sec. 25, T. 3 N., R. 98 W.	8,152	Williams Fork	Mancos	1959		Abandoned
Trident Stockmar Government 1	NE1/4 sec. 27, T. 3 N., R. 98 W.	2,056	Williams Fork	Mancos	1963		Abandoned
Seaboard Oil Massadona Government 3	SW1/4 sec. 15, T. 3 N., R. 99 W.	4,943	Mancos	Chinle	1956		Abandoned
Mobil Oil-G C Corp Federal Wolf Creek 1-23	NE1/4 sec. 23, T. 3 N., R. 99 W.	4,260	Mancos	Morrison	1980		Abandoned

Table 7. Description of samples from known uranium-enriched localities, lower Yellow Creek area
[Localities shown in figure 12]

Locality	Sample number	Radiometric count (times background)	Uranium (in ppm)	Lithology	Thickness of sampled bed (in feet)	Approximate stratigraphic position
1	MDW219	4	340	Carbonaceous shale	1.1	50
	MDW218	3	251	Carbonaceous shale	1.2	115
	MDW217	3	216	Carbonaceous shale	0.3	126
	MDW216	2	154	Coal	0.5-2.5	260
2	MDW206	3	23	Coaly carbonaceous shale	2.5	184
	MDW205	3	169	Coaly carbonaceous shale	1.0	187
	MDW204	2	25	Coaly carbonaceous shale	2.5	190
	MDW202	2	48	Coaly carbonaceous shale	0.5-1.0	206
	MDW203	3	76	Coal	0.5-1.0	206
	MDW278	3.5	109	Shaly coal	0.5-1.0	206
3	MDW211	3	152	Carbonaceous shale	2.0-2.5	138
	MDW210	3	110	Carbonaceous shale	1.2	428
	MDW209	2	19	Carbonaceous claystone	6.0	444
	MDW208	3	73	Carbonaceous claystone	0.5-1.0	462
	MDW207	2	66	Carbonaceous claystone	0.5-1.0	464
4	MDW270	5	215	Carbonaceous shale	0.8-1.2	245
	MDW271	5	248	Carbonaceous shale	0.8-1.2	245
	MDW272	5	110	Carbonaceous shale	0.8-1.2	245
	MDW273	3	78	Carbonaceous shale	0.8-1.2	245
	MDW279	2.5	125	Carbonaceous shale	0.8-1.2	245
	MDW280	3.5	168	Carbonaceous shale	0.8-1.2	245
5	MDW274	2.5	114	Shaly coal	1.0-2.5	316
	MDW275	2.5	89	Coaly carbonaceous shale	1.0-2.5	316
6	MDW214	3	84	Carbonaceous shale	1.2-2.5	402
	MDW215	3	153	Carbonaceous shale	1.2-2.5	402
7	MDW283	2	100	Coaly carbonaceous shale	1.2	187
	MDW282	3	257	Coaly carbonaceous shale	0.4	188
	MDW281	3	84	Carbonaceous claystone	0.8	189

5,045,736 thousand cubic feet (Colorado Oil and Gas Commission, 1987, sec. V, p. 325).

Uranium

Uranium occurs at several localities in thin carbonaceous beds of the upper member of the Fort Union Formation. Evaluation of drill-hole gamma-ray logs indicates that uranium-bearing beds are also present in the subsurface. Although the deposits are of too low a grade to be of potential economic value at the present time, the tonnages of uranium-bearing rock are large. No other uranium deposits are known in the study area. The deposits were described in the National Uranium Resource Evaluation (NURE) of the Vernal 1°×2° quadrangle (Craig and others, 1982), in which areas favorable for uranium deposits are defined as those containing at least 100 tons of U_3O_8 and having an average grade of 0.01 percent U_3O_8 at depths of less than 5,000 ft (1,525 m). A more detailed report on the Fort Union occurrences is included in a report by Hail (1981).

Figure 12 shows the area of outcrop of the upper member of the Fort Union Formation in the study area and the seven localities from which samples of radioactive carbonaceous shale or claystone were collected. Table 7 shows uranium values of samples from these localities. Uranium localities 1–3 (fig. 12) are in generally well exposed ground, and radiometric examination of these exposures is therefore believed to have revealed most, if not all, of the anomalously radioactive beds. Localities 4–7, however, are in poorly exposed ground, and radiometric examination may have missed radioactive beds at these localities.

The seven known uranium localities span a distance along the outcrop of about 13 mi (21 km). Uranium-bearing beds are also present north of the study area in the Elk Springs quadrangle (Hail, 1981, pl. 2). Reconnaissance along the Fort Union outcrop west of locality 1 (fig. 12) indicates no evident anomalous radioactivity. All the uranium localities are clearly stratiform, although they occur at various stratigraphic positions within the upper member. Most of the uranium-bearing or radioactive beds are very thin; those beds containing at least 100 ppm U are a few inches to about 5 ft (1.5) thick, but most are less than 2 ft (60 cm) thick. Anomalous concentrations of uranium and anomalous radioactivity are limited to the more carbonaceous beds including coal, carbonaceous shale, and carbonaceous claystone. Commonly, anomalous radioactivity persists within a relatively thin bed along its strike for a considerable distance. Known distances range from a few feet to 1,100 ft (336 m), and these distances generally are limited to the dimensions of the surface exposures. Uranium minerals are unknown, and it is assumed that the uranium is in organic compounds.

Table 7 is a summary of information on samples collected from the seven numbered localities shown on figure 12. Several of the samples contain less than 0.01 percent U_3O_8 (83.6 ppm U), and these would not be used to calculate resources.

Gravel

Gravel is readily available from terrace deposits along the White River and lower Wolf Creek (map unit Qg; Barcus Creek SE, Smizer Gulch, and Rough Gulch quadrangles). Several pits have yielded gravel for use in local road construction and maintenance. Terrace gravel probably underlies part of the alluvial and colluvial deposits (map unit Qac; Smizer Gulch and Rough Gulch quadrangles).

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