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PALEONTOLOGY AND STRATIGRAPHY OF MIDDLE EOCENE ROCK UNITS IN THE SOUTHERN GREEN RIVER AND UINTA BASINS, WYOMING AND UTAH

Paul C. Murphey, K.E. Beth Townsend, Anthony R. Friscia, James Westgate, Emmett Evanoff, and Gregg F. Gunnell

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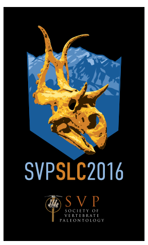

Cover

View of the Bridger D and E on "Old Hat Mountain," a prominent butte on the southeast flank of Hickey Mountain, in the Bridger basin sector of the Green River Basin, Uinta County, Wyoming. Photo taken looking southwest.

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Paleontology and Stratigraphy of Middle Eocene Rock Units in the Southern Green River and Uinta Basins, Wyoming and Utah*

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"A large part of the collection in this region was of the remains of small animals. The fossils were generally found in the buttes, and on account of their minuteness, their discovery was attended with much difficulty. Instead of riding along on the sure-footed mule and looking for a gigantic tell-tale vertebra or ribs, it was necessary to literally crawl over the country on hands and knees…Often a quarter of a mile of the most inviting country would be carefully gone over with no result, and then again someone would chance upon a butte which seemed almost made of fossils."

A description of fossil collecting in the Bridger Formation written by an unnamed member of the 1871 Yale College Expedition, led by paleontologist O.C. Marsh.

ABSTRACT

The Bridger Formation is restricted to the Green River Basin in southwest Wyoming, and the Uinta and Duchesne River Formations are located in the Uinta Basin in Utah. These three rock units and their diverse fossil assemblages are of great scientific importance and historic interest to vertebrate paleontologists. Notably, they are also the stratotypes from oldest to youngest for the three middle Eocene North American Land Mammal Ages—the Bridgerian, Uintan, and Duchesnean. The fossils and sediments of these formations provide a critically important record of biotic, environmental, and climatic history spanning approximately 10 million years (49 to 39 Ma). This article provides a detailed field excursion through portions of the Green River and Uinta Basins that focuses on locations of geologic, paleontologic, and historical interest. In support of the field excursion, we also provide a review of current knowledge of these formations with emphasis on lithostratigraphy, biochronology, depositional, and paleoenvironmental history, and the history of scientific exploration.

*This field guide is an updated version from Murphey and others (2011). We thank the Geological Society of America for its kind use.
Murphey, P.C., Townsend, K.E.B., Friscia, A.R., and Evanoff, E., 2011, Paleontology and stratigraphy of middle Eocene rock units in the Bridger and Uinta Basins, Wyoming and Utah, *in* Lee, J., and Evans, J.P., editors, Geologic field trips to the Basin and Range, Rocky Mountains, Snake River plain, and terranes of the U.S. Cordillera: Geological Society of America Field Guide 21, p. 125–166.

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INTRODUCTION AND STRUCTURAL SETTING

Situated to the north and south of the Uinta Mountains in Wyoming and Utah, respectively, the Green River and Uinta Basins have great scientific importance and are of historic interest to vertebrate paleontologists. The rock units and fossils of the Bridger basin (an informal subarea of the southern Green River Basin) and the Uinta Basin have been the focus of paleontological investigations for the last 140 years. Perhaps the most familiar of the rock units within the Green River and Uinta Basins is the Green River Formation because of its economic importance and exquisitely preserved vertebrate, invertebrate, and plant fossils. However, despite the geological and paleontological importance of this world renowned lacustrine rock unit, this field excursion focuses on three closely related, stratigraphically adjacent and overlying fluvial rock units that are best known for their assemblages of middle Eocene vertebrate fossils. The Bridger, Uinta, and Duchesne River Formations are the stratotypes for the Bridgerian, Uintan, and Duchesnean North American Land Mammal Ages (NALMA) (Wood and others, 1941; Gunnell and others, 2009). The fossils and sediments of these formations provide a critically important record of biotic, environmental, and climatic history spanning approximately 10 million years (49 to 39 Ma).

The Greater Green River Basin occupies 32,187 km^2 (12,430 mi^2) of southwestern Wyoming and northwestern Colorado (Roehler, 1992a). Structurally, it is a large asymmetrical syncline with an approximately north-south axis and with mostly gently dipping flanks (3° to 5°) having steeper dips along the southern margin of the basin (Koenig, 1960; Roehler, 1992a). The Greater Green River Basin is divided into four smaller basins by three intrabasin arches (figure 1). The largest of these arches, the north-south trending Rock Springs uplift, divides the basin into roughly equal halves, with the Green River Basin to the west, and the Great Divide, Sand Wash, and Washakie Basins to the east. The term Bridger basin used and shown by Hayden (1871), Matthew (1909), Osborn (1929), and Bradley (1961) generally refers to the outcrop extent of the Bridger Formation in the western part of the Greater Green River Basin, which nearly coincides with the Green River Basin on figure 1.

The Uinta Basin occupies 10,943 km^2 (4225 mi^2) of northeastern Utah. Structurally, it is an asymmetrical, elongate, east-west trending synclinal basin bounded by the Uinta Mountains to the north, the Douglas Creek arch and Roan Plateau to the east, the Book Cliffs/Tavaputs Plateau to the south, and the Wasatch Range to the west (figure 2). It was formed in the latest Cretaceous and Paleocene during the Laramide uplift of the Uinta Mountains. The Uinta Basin is closely related structurally and sedimentologically to the Piceance Creek Basin in northwestern Colorado. The Uinta and Piceance Creek Basins are separated by the Douglas Creek arch, a broad north-south trending anticline that separated the two sedimentary basins until the early-middle Eocene, when the two basins coalesced across the top of the arch to form one large sedimentary basin (Moncure and Surdam, 1980; Johnson, 1985, 1989). Like the Uinta Basin, the Piceance Creek Basin is highly asymmetrical (Johnson, 1985). Early Cenozoic strata in the Uinta Basin dip gently from all directions to the northern margin of the basin, where the strata are sharply upturned and faulted along the southern flank of the Uinta Mountains uplift (Johnson, 1985).

The Greater Green River, Uinta, and Piceance Creek Basins began forming during the Laramide orogeny, a period of tectonism in western North America that was initiated during the Late Cretaceous and continued for approximately 30 million years until the latest Eocene. In addition to the uplifting of surrounding mountain ranges, Laramide tectonism resulted in rapid subsidence in basin depositional centers, and lacustrine and fluvial deposition in these intermontane basins was mostly continuous. Lacustrine deposition was characterized by a complex history of expansions and contractions in response to basin subsidence, climatic conditions, and volcanic activity (Roehler, 1992b; Murphey, 2001; Murphey and Evanoff, 2007).

PART I. SOUTHERN GREEN RIVER BASIN FIELD TRIP

With its abundant and diverse vertebrate fossils and extensive exposures, the Bridger Formation provides

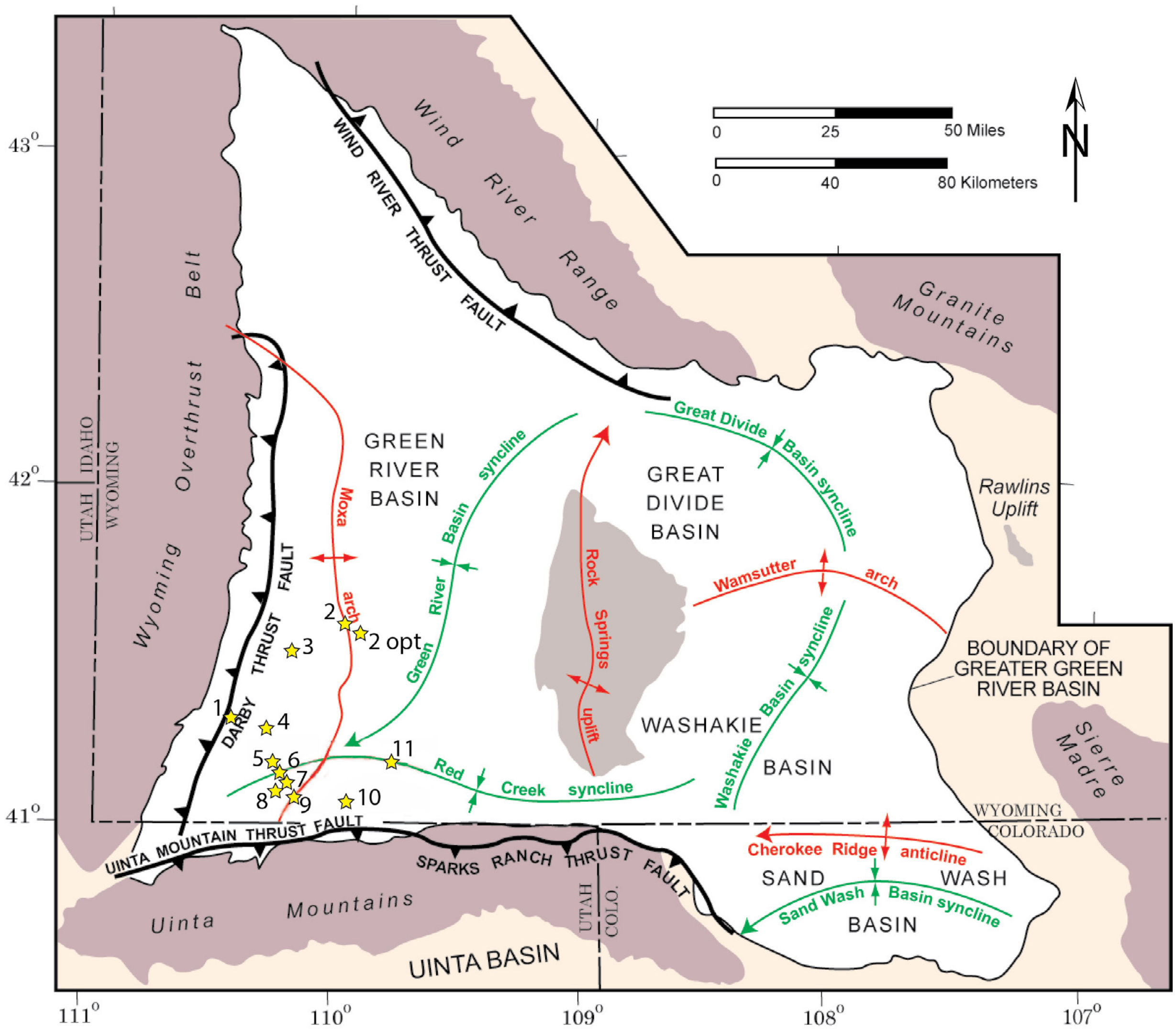


Figure 1. Index map of the Greater Green River Basin showing major structural features and surrounding uplifts. Numbered yellow stars are the approximate location of the field trip stops in the type area of the Bridger Formation (modified from Murphey and Evanoff, 2007).

an excellent opportunity to study middle Eocene continental environments of North America. The dramatic and picturesque Bridger badlands are an 842 m (2763 ft) thick sequence dominated by green-brown and red mudstone and claystone, with interbedded scattered ribbon and sheet sandstone, widespread beds of micritic, sparry, and silicified limestone, and thin but widespread beds of ash-fall tuff (Evanoff and others, 1998; Murphey and Evanoff, 2007).

This field trip offers participants the opportunity to examine paleontologically significant strata of the Bridger Formation in the southern Green River Basin. The following sections of the field trip guide provide a summary of the Cenozoic geologic history of the Green River Basin, as well as the history of investigations, stratigraphy, depositional and paleoenvironmental history, and fossils of the Bridger Formation. This is followed by a detailed road log.

Paleogene Geologic History of the Green River Basin, Wyoming

The greater Green River Basin was filled with Paleocene and Eocene fluvial and lacustrine sediments, and, during the Eocene, sedimentation appears to have been continuous in most of the basin. The oldest Ce-

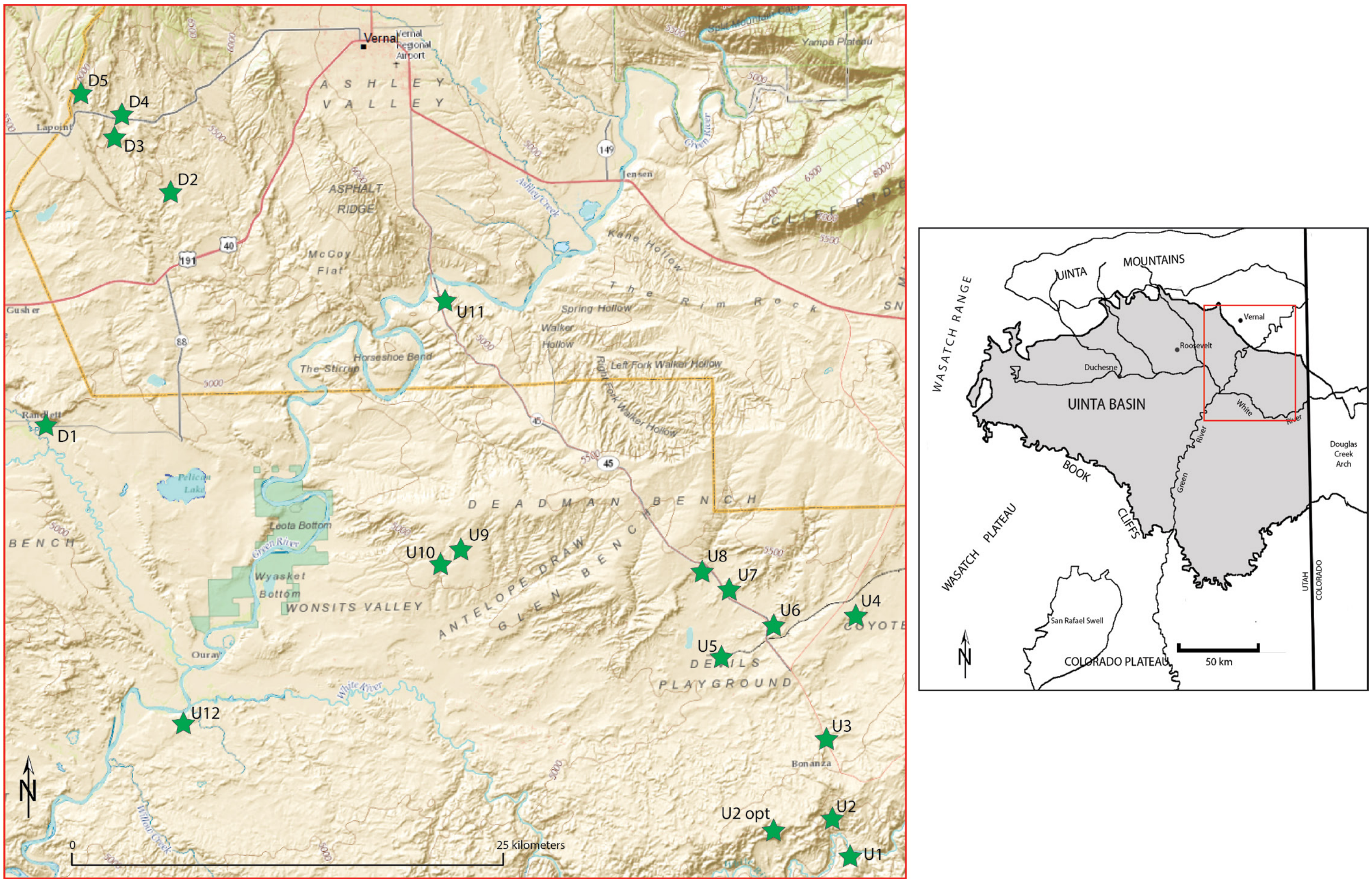


Figure 2. Index map on right showing adjacent structural and physiographic features. The gray region represents the areal extent of Tertiary deposits in both the Uinta Basin, Utah, and Piceance Creek Basin (not labeled), western Colorado. The Douglas Creek Arch separates the two basins. Map on left (location indicated by red box on map to the right) showing approximatel location of the field trip stops (numbered green stars); U-numbered stars are Uinta Formation stops and D-numbered stars are Duchesne River Formation stops.

nozoic rock units in the Greater Green River Basin, the Paleocene Fort Union Formation and the early Eocene Wasatch Formation, are exposed mostly along its eastern and western flanks. During the Paleocene and earliest Eocene, deposition in the Greater Green River Basin was predominantly fluvial, with epiclastic sediments accumulating in river drainages and on adjacent floodplains. The onset of lacustrine deposition associated with the Green River lake system may have commenced as early as the late Paleocene (Grande and Buchheim, 1994). Lake sediments accumulated on broad floodplains of low topographic relief, and the lake waters expanded and contracted numerous times over the next approximately 5 million years in response to climatic changes, tectonic influences, and episodic volcanic activity.

Occupying the center of the basin in the shape of a large, irregular lens (Bradley, 1964; Roehler, 1992b, 1993), the Green River Formation is the result of at least 5 million years of lacustrine deposition lasting from about 53.5 to 48.5 Ma (Smith, 2003), although lacustrine deposition may have persisted later in the southernmost part of the basin along the Uinta Mountain front (Murphey and Evanoff, 2007). The Green River Formation was deposited in a vast ancient lake system that existed from the late Paleocene to the middle Eocene in what is now Colorado, Utah, and Wyoming. The smallest and oldest of these lakes, Fossil Lake, was deposited in Fossil Basin, which is located in the Wyoming thrust belt just to the west of the Green River Basin in southwestern Wyoming. Lake Gosiute was deposited in the Greater Green River Basin, which includes the Green River and Washakie Basins in southwestern Wyoming, and the Sand Wash Basin in northwestern Colorado. Fossil Lake and Lake Gosiute may never have been physically connected (Surdam and Stanley, 1980). Lake Uinta was deposited in the Uinta Basin in northeastern Utah and the Piceance Creek Basin in northwestern Colorado. Lithologically, the Green River Formation in the greater Green River Basin is a complex sequence of limestone, shale, and sandstone beds with a maximum thickness of approximately 838 m (2750 ft) (Roehler, 1993). It was deposited lateral to and above the predominantly fluvial Wasatch Formation, and lateral to and below the fluvial and lacustrine Bridger and Washakie Formations. The Laney Member is the uppermost member of the Green River Formation in Wyoming and represents the final expansion of Lake Gosiute.

Most volcaniclastic sediments deposited in the Green River Basin during the middle Eocene were apparently transported from the Absaroka volcanic field in what is now northwestern Wyoming. These sediments were washed into the basin in rivers and streams. Some volcaniclastic sediments were transported into the basin via eolian processes and deposited as ash fall in lakes and on floodplains. A large influx of fluvially transported volcaniclastic sediment is believed to have led to the final middle Eocene filling of Lake Gosiute (Mauger, 1977; Surdam and Stanley, 1979; Murphey, 2001; Murphey and Evanoff, 2007). Mauger (1977) and Surdam and Stanley (1979) estimated that Lake Gosiute was ultimately extinguished by about 44 Ma.

The Bridger, Green River, and Washakie Formations are locally and unconformably overlain by the Oligocene Bishop Conglomerate and the middle-to-late–Miocene Browns Park Formation. Since the Eocene, the Greater Green River Basin has been modified by erosion, regional uplift, and normal faulting, but the basic structure of the basin remains the same as it was during deposition of the Wasatch, Green River, Washakie, and Bridger Formations.

Middle Eocene Paleoenvironments of the Green River Basin

Numerous studies based on paleontological and geological evidence have concluded that the Eocene-age rock units in the Greater Green River Basin were deposited in warm temperate, subtropical, and tropical climatic conditions (Roehler, 1993). Perhaps the most reliable information concerning paleoclimates comes from analysis of plant mega- and micro-fossils. According to Leopold and MacGinitie (1972), early Eocene floras (based on palynology of samples collected from the Niland Tongue of the Wasatch Formation and the Luman and Tipton Tongues of the Green River Formation) suggest a humid subtropical to warm temperate climate having summer rainfall and only mild frost and with a mean annual temperature of 55°F. Nichols (1987) concluded that the climate of the basin floor during deposition of the Niland Tongue was subtropical, without freezing temperatures.

The earliest middle Eocene climates pertaining to the Cathedral Bluffs Tongue of the Wasatch Formation and the Wilkins Peak Member of the Green River Formation were interpreted as generally hot and dry (Leopold and MacGinitie, 1972). Climatic conditions in the early-middle Eocene during deposition of the lower part of the Laney Member of the Green River Formation were characterized as warm and humid with tropical affinities. Floras of the upper part of the Laney Member indicate a change to cooler, subhumid conditions (Leopold and MacGinitie, 1972). Both pollen and leaf data from the Washakie Formation indicate a dry but temperate climate (Leopold and MacGinitie, 1972). Roehler (1993) reported in a written communication that MacGinitie reinterpreted temperature and precipitation ranges on the basis of palynology of samples collected from the Washakie Basin by Roehler (1992a). This reinterpretation estimated mean annual temperatures of 18°C (65°F) during the early Eocene, 17°C (63°F) during the earliest middle Eocene, and 16°C (62°F) during the middle Eocene. Average annual precipitation was estimated at more than 100 cm (40 in) during the early Eocene, 65 to 90 cm (25–35 in) during the earliest middle Eocene, and 38 to 50 cm (15–20 in) in the middle Eocene. Sedimentological evidence of a more arid climate during the middle Eocene (transitional Uintan NALMA) includes massive beds of gypsum capping the Turtle Bluff Member of the Bridger Formation (Murphey, 2001; Murphey and Evanoff, 2007). The shift from dominantly tropical forest environments to more open, savanna-like conditions in the Eocene intermontane basins during late Bridgerian (early-middle Eocene) and Uintan (middle Eocene) times has also been studied by using ecological diversity analysis applied to mammalian faunas (Townsend, 2004; Murphey and Townsend, 2005).

As indicated by fossil distribution and diversity, the Green River lakes and their forested margins provided highly favorable habitats and preservational environments for both aquatic and terrestrial organisms. Lake margin habitats, riparian corridors, and adjacent floodplains were apparently vegetated during much of the time of Green River Formation deposition, as indicated by a paleoflora that includes a variety of trees and bushes such as palm, cinnamon, oak, maple, lilac, and hazel, as well as cattails and rushes. Insects of many varieties lived in the lakes and forests and are locally well preserved in lake sediments. A variety of terrestrial and aquatic mollusks (clams and snails) are also known to have inhabited the Green River lakes (Hanley, 1974). Crayfish, prawn, and ostracods inhabited the warm lake waters, as did a diversity of fish species, including relatives of the herring, perch, paddlefish, bowfin, gar, catfish, and stingray (McGrew and Casilliano, 1975; Grande, 1984; Grande and Buchheim, 1994). Frogs, crocodiles, and turtles were common residents of shallower proximal shoreline waters. A diversity of reptile species, including tortoise, lizards, and snakes, inhabited the forests surrounding Eocene lakes and ponds. Flamingos, hawks, rails, stone curlews, and other bird species frequented the forests, wetlands, and lakes (Murphey and others, 2001). The forests teemed with the primitive ancestors of many modern mammalian groups, including rodents, insectivores, bats, primates, perissodactyls (horse, rhinoceros, and tapir), and carnivores, as well as more bizarre archaic forms such as creodonts, brontotheres, and massive six-horned uintatheres (McGrew and Casilliano, 1975; Gazin, 1976; Grande and Buchheim, 1994; Gunnell and Bartels, 1994; Murphey and others, 2001).

Bridger Formation

History of Paleontological Investigations in the Bridger Formation

John Colter, who traveled to the headwaters of the Green River in 1807, was probably among the first non-Native Americans to visit the Green River Basin (Chadey, 1973). Hundreds of subsequent trappers and explorers traversed the basin during the first half of the nineteenth century, and a number of records of these early explorations make reference to fossils and coal (Roehler, 1992a). The earliest scientific observations on the geology of the Green River Basin were made by Army Lt. John C. Fremont. After entering the basin through South Pass at the southern end of the Wind River Mountain, Fremont (1845) described varicolored rocks (now known as Eocene-age Wasatch Formation) along the Big Sandy and New Fork Rivers. Femont also collected fossil shells from near Cumberland Gap (Veatch, 1907). The earliest vertebrate fossils reported from the Green River Basin were fishes discovered in the Green River Formation. In 1856, Dr. John Evans collected a specimen of a fossil fish from an unknown Green River Formation locality west of Green River City. Evans sent this specimen to paleontologist Joseph Leidy in Philadelphia for study, and Leidy named it *Clupea humilis* (later renamed *Knightia humilis*) (West, 1990). Hayden (1871) described the discovery of a locality he referred to as the "Petrified Fish Cut" along the main line of the Union Pacific Railroad about 3.2 km (2 mi) west of Green River. Employees of the railroad had initially discovered the locality and later turned many specimens over to Hayden. Paleontologist Edward Drinker Cope described the fish fossils from the "Petrified Fish Cut" in Hayden's (1871) expedition report.

The initial discovery of mammalian fossils in the Green River Basin was probably made by a long-time local resident, trapper Jack Robinson (also called Robertson) who found what he described as a "petrified grizzly bear" sometime in the late 1860s. The specimen came from what is now called the Bridger Formation but had initially been named the "Bridger Group" by Hayden (1869). This story was related to Joseph Leidy by Judge William Carter of Fort Bridger as an explanation for the name "Grizzly Buttes," an area 16 to 24 km (10–15 mi) southeast of Fort Bridger where fossils were particularly common (the name Grizzly Buttes has since disappeared from the local geographic vocabulary).

Several government geological and topographical surveys with specific but overlapping territories were operating in the southern Green River Basin between 1867 and 1879. Hayden and his party collected along the Henrys Fork valley and farther north in the vicinity of Church Buttes in 1870 as part of the 1867 to 1878 U.S. Geological and Geographical Survey of the Territories (Hayden, 1873). Fossils collected by Hayden's group were sent to Leidy for study and were described in a monograph on fossil vertebrates (Leidy, 1873). Later paleontological studies for the Hayden Survey were carried out by Cope. Under the direction of John Wesley Powell, the U.S. Geological and Geographical Survey of the Territories, Second Division (1875–1876), worked along the Henrys Fork River in 1869, and in a corridor 16 to 32 km (10–20 mi) wide on either side of the Green River in 1871 (Powell, 1876). The U.S. Geological Survey of the Fortieth Parallel (1867–1872), directed by Clarence King, worked in the Green River Basin in 1871 and 1872. The fossils collected by the King Survey were sent to Othniel Charles Marsh for description. Most of the fossils collected during these surveys were discovered in the Bridger Formation.

Many of the early scientific expeditions to the Green River Basin were based out of Fort Bridger, a trading post originally set up in 1843 by trapper and guide Jim Bridger and his partner Louis Vasquez. The fort became an army post after the 1857 Mormon War. Judge Carter and Dr. J. Van A. Carter, later residents of Fort Bridger, maintained an active correspondence Leidy during the late 1860s and early 1870s. This correspondence included mailing fossils to Leidy, which were described in subsequent publications (Leidy, 1869, 1871, 1872a, 1872b, 1873). Leidy, who is often regarded as the father of North American vertebrate paleontology (Lanham, 1973), named the first Bridger Formation fossil to be formally described, the omomyid primate *Omomys carteri*, after Dr. Carter (Leidy, 1869). *Omomys carteri* was also the first described fossil primate from North America.

Early reports of fossils from the Green River Basin did not go unnoticed by rival paleontologists Marsh and Cope. The incidents that set the stage for the long and bitter conflict between these two men began in the Green River Basin while they were prospecting in the Bridger Formation in 1872. Sometimes referred to as the "bone wars," the dispute between Marsh and Cope lasted for more than 30 years and included efforts by each man to destroy the scientific reputation and integrity of the other (Lanham, 1973). This conflict soured Leidy's interest in paleontology and led to his eventual abandonment of the discipline after 1872.

Professor Marsh was the first professional paleontologist to collect fossils from the Bridger Formation and for four consecutive summers from 1870 to 1873 brought crews with him from Yale College. Leidy's only excursion to the West took place in 1872, when he visited the Bridger badlands guided by the Carter brothers of Fort Bridger. Cope's only visit to the Bridger badlands occurred in 1872, while Cope was attached to the Hayden Survey as the paleontologist. This visit infuriated Marsh, who, at the time, considered the Green River Basin and Bridger Formation his exclusive fossil-collecting territory. By the late 1870s, Cope and Marsh had left the Green River Basin for good, although both men independently and at different times retained the services of paid fossil collector Sam Smith (West, 1990).

Other early fossil collectors who visited the Green River Basin in 1877 and 1878 included Henry Fairfield Osborn, William Berryman Scott, and Francis Speir for Princeton University. Scott returned to the area with Speir in 1886. Jacob Wortman and James W. Gidley collected for the American Museum of Natural History (AMNH) in 1893. The early fossil-collecting expeditions to the Green River Basin resulted in large collections of fossils primarily from the Bridger Formation at the Philadelphia Academy of Natural Sciences (Leidy), Yale University (Marsh), the AMNH (which purchased Cope's collection just before the turn of the century), and Princeton University (Osborn, Scott, and Speir). Unfortunately, these early collectors paid little attention to the stratigraphic provenance of the fossils they collected. Their collections do, nevertheless, contain the holotypes of most presently recognized Bridgerian mammal taxa.

In 1902, H.F. Osborn, who was then the U.S. Geological Survey (USGS) paleontologist, initiated the first program of stratigraphic fossil collection to take place in the Green River Basin and one of the first in North America. Osborn charged Walter Granger and William Diller Matthew of the AMNH with the task of carrying out the study. Matthew was also directed to find a uintathere to display at the AMNH. The AMNH party, led by Granger, worked in the Bridger Basin from 1902 to 1906 (Matthew, 1909). The second halves of the 1903 and 1905 field seasons were devoted to mapping and describing the stratigraphy of the Bridger Formation, while the remainder of the time was spent searching the badlands for fossils. The efforts of the AMNH parties over these four years resulted in an excellent fossil collection that was, for its time, very well documented stratigraphically.

These AMNH expeditions also resulted in the first paper to be published on the geology of the Bridger Formation by William J. Sinclair (1906), who had joined the AMNH field party for the summer of 1905. The geology of the Bridger Formation was described briefly, and a system of stratigraphic subdivisions for the formation was introduced in Matthew's classic 1909 monograph, *The Carnivora and Insectivora of the Bridger Basin, Middle Eocene*. Matthew's subdivisions, Bridger A–E, were based on areally extensive limestone beds, which he called "white layers."

Following the early fossil-collecting expeditions of the nineteenth century and initial scientific field studies conducted by AMNH crews in the early twentieth century, the Bridger Formation in the Green River Basin has remained the focus of almost continuous paleontologic inquiry because of its abundant and diverse vertebrate fossils, although Matthew's (1909) original stratigraphy was only recently refined by Murphey and Evanoff (2007). West (1990) wrote an excellent historical summary of vertebrate paleontological work in the Green River Basin from 1840 to 1910.

Osborn devoted considerable discussion to the Bridger Formation and its fossils in a monograph, *The Titanotheres of Ancient Wyoming, Dakota, and Nebraska* (Osborn, 1929). Horace Elmer Wood (1934) divided the Bridger Formation into two members. The Blacks Fork Member corresponds to Matthew's Bridger A and B, and the Twin Buttes Member corresponds to Matthew's Bridger C and D, with the Sage Creek White Layer marking their boundary. Contrary to rules of stratigraphic nomenclature, these members were defined on perceived faunal differences rather than lithologic differences. The informal usage of the terms "Blacksforkian" and "Twinbuttean" as land mammal subages derives from the names of the two Bridger members. Under the direction of J.W. Gidley, followed by C. Lewis Gazin, the Smithsonian Institution began an active collecting program in the Bridger Formation beginning in 1930. Gazin was active in the Green River Basin from 1941 to 1968. This period of activity resulted in a relatively large and well-documented collection that was the subject of numerous publications by Gazin (e.g., 1934, 1946, 1949, 1957, 1958, 1965, 1968, and 1976) focused primarily on the systematic paleontology of Bridgerian mammal fossils.

Paul O. McGrew and Raymond Sullivan worked on the stratigraphy and paleontology of the Bridger A in the late 1960s and published the results of their work in 1970. Robert M. West began an active collecting program for the Milwaukee Public Museum in 1970 and worked in the basin until the late 1970s. West's work, which also resulted in a large number of paleontological publications, included the use of screenwashing techniques to collect microvertebrates, a portion of the fauna that had not been previously well sampled. Like Wood (1934) and Koenig (1960), West (1976) noted difficulties with the correlation of Matthew's white layers across the basin and suggested that a bipartite division of the Bridger into upper (Twin Buttes) and lower (Blacks Fork) members was most appropriate. West and Hutchison (1981) named Matthew's Bridger E the Cedar Mountain Member, adding a third member to the Bridger Formation. Paleontological and geological studies of Tabernacle Butte, an isolated remnant of the Bridger Formation of late Bridgerian age with an important fossil fauna, were published by McGrew (1959), McKenna and others (1962), and West and Atkins (1970).

Evanoff and others (1998), Murphey (2001), and Murphey and Evanoff (2007) significantly refined Matthew's (1909) Bridger Formation stratigraphic scheme. Their work included the addition of newly described marker units; the establishment of new stratigraphic subdivisions and correlation of marker units across the southern part of the basin where the most complete stratigraphic sequence is exposed; descriptions of detailed stratigraphic sections measured through the Bridger B, C, D, and E; renaming of the Cedar Mountain Member to the Turtle Bluff Member in order to conform with the rules of stratigraphic nomenclature; stratigraphic positioning of more than 500 fossil localities; isotopic dating of four ash-fall tuffs; and geologic mapping of more than 1600 km^2 (600 mi^2) of the southern Green River Basin at the scale of 1:24,000. Geologic maps and publications relating to the Bridger Formation are available at http://www.rockymountainpaleontology.com/bridger.

Stratigraphy and Depositional Environments of the Bridger Formation

The Bridger Formation was named the "Bridger group" by Hayden (1869). The first stratigraphic framework for the Bridger Formation was established by W.D. Matthew (1909) of the AMNH in the southern Green River Basin where the formation is thickest and best exposed. Matthew's (1909) stratigraphic subdivisions of the Bridger Formation were based primarily on five areally extensive limestone beds. These he named the Cottonwood, Sage Creek, Burnt Fork, Lonetree, and upper white layers, and some were used to subdivide the formation into five units, from lowest to highest: Bridger A, B, C, D, and E. Matthew's intent was to make it possible to stratigraphically locate the numerous known fossil localities in the formation. Because they are the most fossiliferous, the Bridger B, C, and D were further divided into five subunits corresponding to basal, lower, middle, upper, and top levels (e.g., B1, B2, B3, B4, B5). Because Matthew (1909) did not define the upper and lower boundaries of these subunits with stratigraphic markers or measured sections, correlations between them and the later subdivisions proposed by Evanoff and others (1998), Murphey (2001), and Murphey and Evanoff (2007) are uncertain. The history of stratigraphic nomenclature for the Bridger Formation is provided in figure 3.

In 1909 monograph, Matthew (1909:296) gave a brief description of five proposed members and white layers. "Horizon A" was 60 m (200 ft) thick, composed primarily of calcareous shales alternating with tuffs, and with rare fossils. "Horizon B" was 140 m (450 ft) thick, consisting of two benches separated by the Cottonwood white layer and containing abundant and varied fossils. Matthew went on to note that the largest number of complete skeletons from the entire formation was found in the lower part of Horizon B (B2). "Horizon C" was 90 m (300 ft) thick, "defined inferiorly" by the Sage Creek white layer, with the Burntfork white layer occurring at about its middle, and with abundant and varied fossils. Matthew also noted that the Sage Creek white layer was the "heavy and persistent calcareous stratum" at Sage Creek Spring, thus designating a type locality where this unit had been previously described and illustrated, but not named, by Sinclair (1906). "Horizon D" was 107 m (350 ft) thick, composed of harder gray and greenish-gray sandy and clayey tuffs, "defined inferiorly" by the Lonetree white layer, containing the upper white layer about 23 m (75 ft) from the top, and with abundant and varied fossils. "Horizon E" was 150 m (500 ft) thick, composed of soft banded tuffs having heavy volcanic ash layers, with a high gypsum content and nearly barren of fossils. The total thickness of the Bridger reported by Matthew was 550 m (1800 ft). Despite the lithologic descriptions of the five horizons made by Matthew (1909), subsequent workers have not been able to subdivide the Bridger Formation on the basis of lithologic differences (Bradley, 1964; Roehler, 1992a; Evanoff and others, 1998; Murphey, 2001; Murphey and Evanoff, 2007). Furthermore, with the exception of the Bridger B–C and D–E boundaries, Matthew's subdivisions do not correspond to major faunal changes (Simpson, 1933; Wood, 1934; Murphey, 2001; Murphey and Evanoff, 2007).

The Bridger Formation has been subdivided into three members. The Blacks Fork Member, or lower Bridger, is equivalent to Matthew's Bridger A and B; the Twin Buttes Member, or upper Bridger, is equivalent to Matthew's C and D; and the Turtle Bluff Member, also considered part of the upper Bridger, is equivalent to Matthew's Bridger E. A detailed history of geologic and paleontologic investigations focusing on the Bridger Formation, and the history of stratigraphic nomenclature for this unit, are provided by Murphey and Evanoff (2007).

Evanoff and others (1998), Murphey (2001), and Murphey and Evanoff (2007) published the first major stratigraphic revision of the Bridger Formation since Matthew (1909). The most recent stratigraphic subdivisions are based on widespread limestone beds, tuffs, and tuffaceous sheet sandstone which are used as marker units. Fifteen such units were described, and seven of these were considered major markers. These were used to subdivide the Bridger C and D (Twin Buttes Member) into lower, middle, and upper informal subdivisions (figures 3 and 4). Two additional markers were used to redefine the base and define the top of the Bridger E (Turtle Bluff Member). Four of Matthew's original "white layers" were included in the stratigraphy of the Bridger C and D, and these were mapped and redescribed in detail. In conjunction with the latest stratigraphic revision, geologic mapping of ten 7.5-minute quadrangles which cover the area encompassed by the upper Bridger Formation was completed, and these maps are available from the Wyoming State Geological Survey. Because many marker units are not continuously exposed or traceable across the entire basin (from Hickey Mountain, Sage Creek Mountain, and Cedar Mountain east to Twin Buttes and Black Mountain), a distance of approximately 64 km (40 mi), accurate correlation was made possible by using the mineralogically diagnostic Henrys Fork Tuff as a datum.

Rock accumulation rates, isotopic ages of ash-fall tuffs (Murphey and others, 1999), and fossils indicate that the 842-m-thick (2763 ft) Bridger Formation was

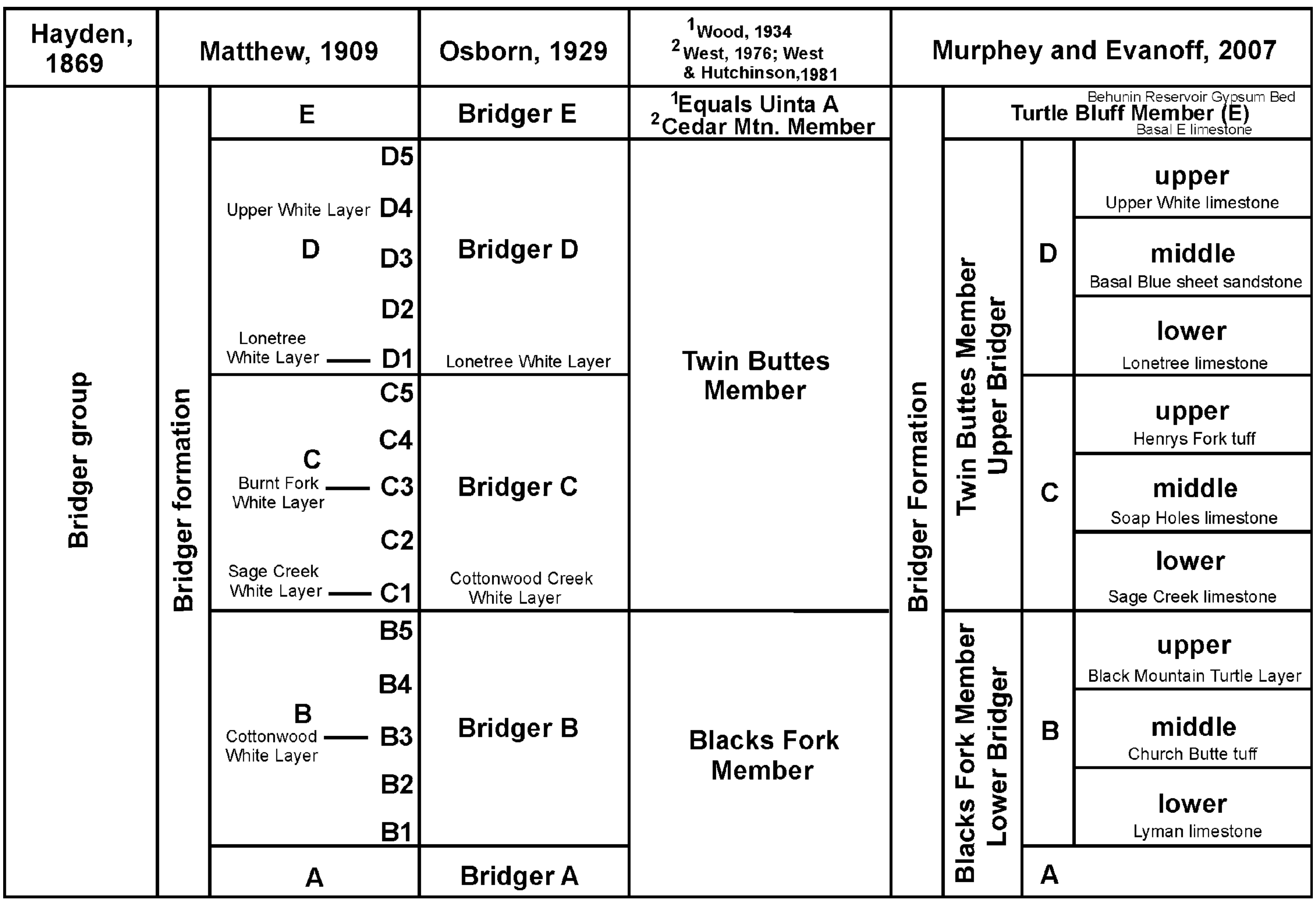


Figure 3. History of Bridger Formation stratigraphic nomenclature from 1869 until present. The correlation between Mathew's (1909) subdivisions (1–5) and the lower, middle, and upper subdivisions of Murphey and Evanoff (2007) are uncertain.

deposited over an approximately 3.5-million-year interval from about 49.09 to 45.57 Ma, and that the faunal transition from the Bridgerian to the Uintan Land Mammal Age was underway by about 46 Ma as indicated by fossils collected from the Turtle Bluff Member (Evanoff and others, 1994; Murphey, 2001; Robinson and others 2004; Murphey and Evanoff, 2007; Gunnell and others, 2009). Recognized depositional environments of the Bridger Formation include fluvial, lacustrine, playa lacustrine, paludal, marginal mudflat, basin margin, and volcanic. Murphey and Evanoff (2007) concluded that an influx of fluvially transported volcaniclastic sedi-

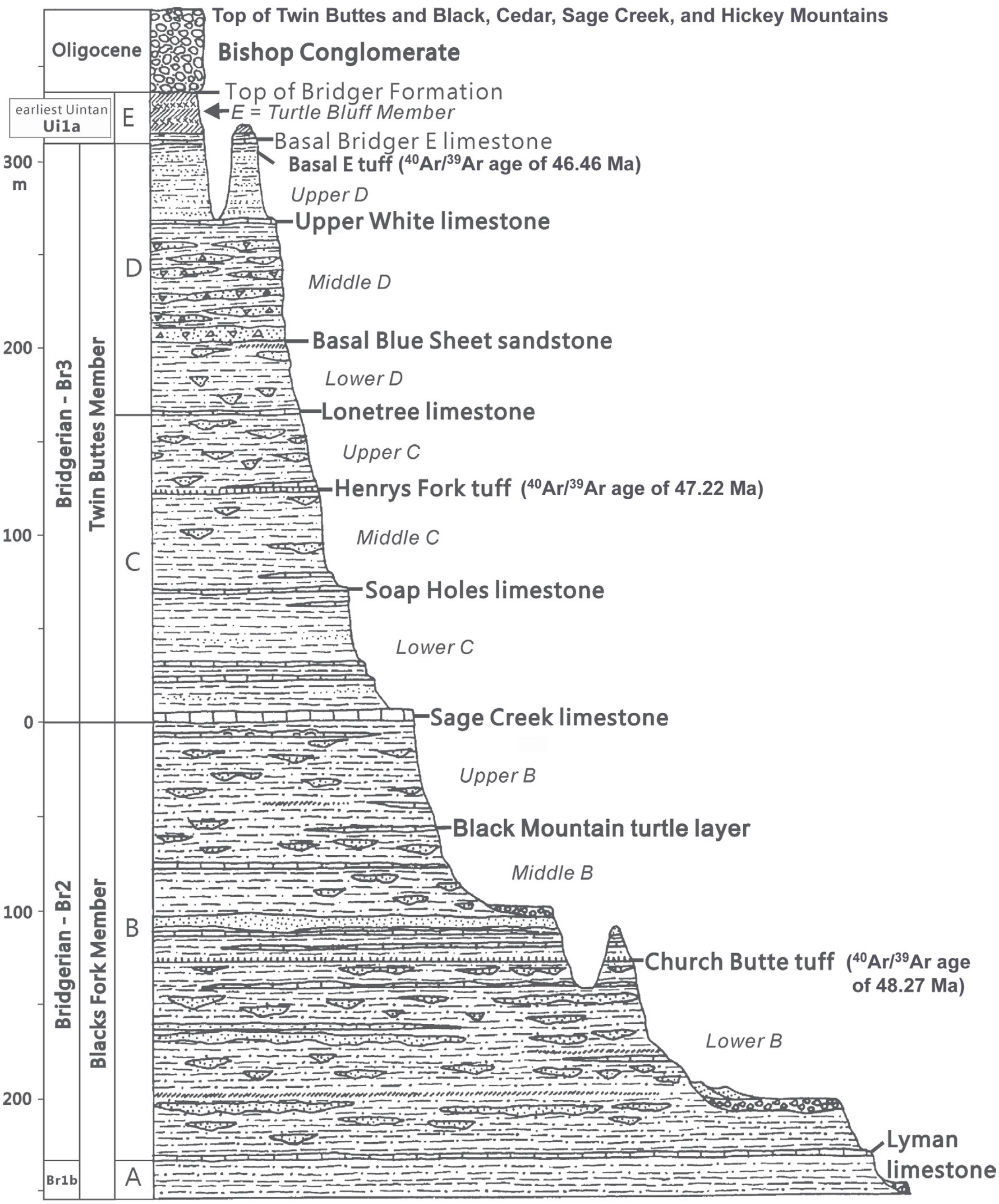


Figure 4. Generalized stratigraphic section of the Bridger Formation in the southern Green River Basin, southwestern Wyoming. Isotopic ages reported by Murphey and others (1999) have been recalculated using the 28.201 Ma sanidine standard for the Fish Canyon Tuff (Renne and others, 1998).

ment to the Green River Basin during middle Eocene time led to the filling of Lake Gosiute and the development of muddy floodplains of low topographic relief, which persisted for up to 85% of the time during which the upper Bridger was deposited. Occasional lapses in the flow of sediment to the basin permitted the development of shallow, mostly groundwater-fed lakes and ponds, which accumulated up to four times as slowly as floodplain deposits. These lapses decreased in frequency throughout deposition of the upper Bridger Formation. As indicated by fossil distribution and diversity, lakes and their margins provided favorable habitats for both aquatic and terrestrial organisms during deposition of the Bridger Formation.

Fossils and Biochronology of the Bridger Formation

One of the world's most abundant and diverse middle Eocene vertebrate faunas is preserved in the Bridger Formation. Preserved in a variety of sedimentary environments, preservational states, associations, and in locally varying abundances, these fossils include primarily vertebrates and mollusks, with less common plants and ichnofossils. Plant fossils include leaves, seeds, and wood, which is sometimes algal covered (see Murphey and others, 2001). Ichnofossils include solitary bee cases, earthworm pellets, caddis fly larvae, and fish pellets. Vertebrate fossils include fish, amphibians, reptiles (lizards, snakes, turtles, and crocodilians), a diversity of birds (see Murphey and others, 2001), and mammals. Mammalian fossils include apatotheres, artiodactyls, chiropterans, carnivores, condylarths, dermopterans, dinoceratans (uintatheres), edentates, insectivores, leptictids, marsupials, pantolestids, perissodactyls, primates, rodents, taeniodonts, and tillodonts (Gazin, 1976; Gunnell and others, 2009; Woodburne and others, 2009a, 2009b; unpublished paleontological data, University of Colorado Museum, compiled in 2002). Combined for all biochrons in the Bridger Formation more than 125 species representing 77 genera, 35 families, and 18 orders of fossil mammals are recognized (Gazin, 1976; Gunnell and others, 2009). Leidy's 1869 description of *Omomys carteri* was the first scientific description of a fossil from the Bridger Formation. Subsequently, Bridger fossils have been the subject of numerous publications, including many classic papers by pioneers of American vertebrate paleontology (Leidy, 1869, 1871, 1872a; Marsh, 1871, 1886; Cope 1872, 1873; Granger, 1908; Matthew, 1909; Osborn, 1929). Like many other highly fossiliferous formations, the Bridger contains an abundance and diversity of fossils that make it well suited for paleontological research, most of which has focused on the phylogenetics, systematic paleontology, and biostratigraphy of the vertebrate fauna (Gazin, 1957, 1958, 1965, 1968, 1976; McGrew and Sullivan, 1970; West and Hutchison, 1981; Krishtalka and others, 1987; Evanoff and others, 1994; Covert and others, 1998; Robinson and others, 2004; Gunnell and others, 2009). Despite the relative ease with which diverse and statistically significant fossil samples can be collected, and the large historical collections of Bridger vertebrates available in many museums, taphonomic and paleoecologic studies of Bridger vertebrate faunas are relatively few (Gunnell and Bartels, 1994; Gunnell, 1997; Murphey and others, 1999; Brand and others, 2000; Alexander and Burger, 2001; Townsend, 2004; Murphey and Townsend, 2005; Townsend and others, 2010).

Over the last twenty years, stratigraphically documented fossil collections made by workers from the University of Colorado Museum, Denver Museum of Nature and Science, University of Michigan Museum of Paleontology, and more recently by the San Diego Natural History Museum, have added significantly to existing biostratigraphic knowledge of the Bridger Formation. These collections, together with precise provenance data, have made it possible to define formal biochronologic units for the Bridgerian NALMA, most of which are based upon stratotype sections that are located in the Bridger Formation. Gunnell and others (2009) divided the Bridgerian into four "biochrons." Formerly referred to as Gardnerbuttean land mammal sub-age, or Br0, biochron Br1a is the only Bridgerian biochron not found in the Bridger Formation. Its stratotype section is the *Eotitanops borealis* interval zone of the Davis Ranch section of the Wind River Formation. Biochron Br1b is equivalent to the lower Blacksforkian, and its stratotype spans the Bridger A (lower part of the Blacks Fork Member). Biochron Br2 is equivalent to the upper Blacksforkian, and its stratotype section spans the

Bridger B (upper part of the Blacks Fork Member). Biochron Br3 is equivalent to the Twinbuttean, and its stratotype section spans the entire Bridger C and D (Twin Buttes Member). The uppermost member of the Bridger Formation, the Turtle Bluff Member or Bridger E, is the stratotype section for the earliest Uintan biochron, Ui1a (Walsh and Murphey, 2007; Gunnell and others, 2009; Kelly and Murphey, in press; Murphey and Kelly, in review; Murphey and others, in preparation). In summary, the mammalian fauna of the Bridger Formation has been used to formally define biochrons Br1b, Br2, Br3, and Ui1a. Appendix A in Murphey and others (2011; modified from Gunnel and others, 2009) is a biochronologic range chart for Bridgerian, Uintan, and Duchesnean mammalian taxa based on the most up to date information at that time. It is important to note that the Ui1a fauna listed in appendix A is inaccurate because it lacks faunal revisions and additions that have recently been made (Kelly and Murphey, in press; Murphey and Kelly, in review; Murphey and others, in preparation).

The fossil assemblages of the Bridger Formation and other Eocene rock units in the greater Green River Basin provide an unprecedented opportunity to study ancient communities and environments. Studies of these fossils and the rocks in which they are preserved are the source of much of our knowledge of the Eocene Epoch of North America. The vertebrate faunas are of particular scientific importance because they represent an exceptional record of early Tertiary mammalian evolution and diversification spanning the Wasatchian, Bridgerian, and earliest Uintan NALMA.

Bridger Formation Field Trip Stops

The field trip route travels through the southern Green River Basin (Bridger basin sector) making 11 stops in an approximately stratigraphic manner (figure 1). After leaving historic Fort Bridger, the staging area for many of the early fossil collecting expeditions to the Bridger Formation, the route travels east along Interstate 80 (I-80) crossing through badland outcrops of the Bridger B that are stratigraphically close to the Bridger A-B boundary (Blacks Fork Member). We travel west along I-80 to Lyman and then head south along Wyoming Highway 414 to the historic Grizzly Buttes badlands in the Bridger B (Br2). We continue south along Wyoming 414, climbing stratigraphically through the Bridger C and D (Twin Buttes Member, Br3), and examine exposures of this interval in the vicinity of Sage Creek and Hickey Mountains, and at the "Lonetree Divide" (base of Bridger D). Weather permitting, we will then make our way to the southwest rim of Cedar Mountain and visit exposures of the Bridger E (Turtle Bluff Member). Finally, we will head east along Wyoming Highway 414 along the south side of Cedar Mountain with excellent vistas of the Bridger C, D, and E that are overlain by the Oligocene Bishop Conglomerate. The field trip concludes after visiting exposures of the Bridger C at the base of Black Mountain.

Note that all field trip distances are provided in statute (miles), whereas stratigraphic thicknesses are provided in both metric and statute. All distances were measured using a handheld GPS device calibrated to the NAD27 datum.

Stop 1. Fort Bridger State Historic Site parking lot (0.0 km/miles, cumulative 0.0 km/miles): Fort Bridger was originally established as a trading post in 1843 by trapper Jim Bridger and his guide Louis Vasquez. The U.S. Army acquired the trading post in 1857 during the Mormon War. It was located along the emigrant trail to Oregon, California, and Utah, and more than twenty years after the establishment of the trading post, the route of the newly constructed Union Pacific Railroad passed not far to the north. As discussed in greater detail above, many of the early scientific expeditions to the Bridger Formation were based out of Fort Bridger. Yale University paleontologist O.C. Marsh and his field classes stayed at Fort Bridger before heading out to the Bridger badlands in 1870, 1871, and 1873. Rival paleontologist E.D. Cope stayed at the fort in 1872 during his only fossil collecting expedition to the Bridger. Joseph Leidy, often regarded as the father of North American vertebrate paleontology and the first paleontologist to formally describe a Bridger Formation fossil, made his only fossil collecting trip to the west in 1872, and also stayed at Fort Bridger. Today, Fort Bridger is a state historical site and has been partially reconstructed.

The low butte just to the west of Fort Bridger is Bridger Butte, and is composed of Bridger B strata and capped with Quaternary gravels.

Turn west out of the fort parking lot along the I-80 business loop and then turn east onto I-80 (towards Green River). Drive for approximately 32 miles and take the Granger Junction exit (Exit 66) heading north along U.S. Highway 30. Follow U.S. Highway 30 for 1.8 miles after exiting the interstate. Then turn east and cross the cattle guard onto a dirt road for 0.2 miles at which point you will arrive at the route of old U.S. Highway 30 (unmarked gravel road that is still paved in places). Park immediately after turning right (southeast) onto old U.S. Highway 30. Outcrops of the Lyman Limestone are located just to the east.

Stop 2. The Lyman Limestone at Granger Junction (58.4 km [36.3 mi] from Stop 1, cumulative 58.4 [36.3 mi]): This stop provides a close up look at the Lyman limestone, which marks the boundary between the Bridger A and the lower Bridger B within the Blacks Fork Member (figures 3 and 4). Here, the Lyman is a gray limestone with locally abundant shells of the gastropod *Goniobasis*. The presence of this high-spired snail is a useful diagnostic indicator for this marker unit at many localities in the Bridger basin. The Lyman limestone is widespread in its distribution. It is exposed to the west where it forms the bench that is visible to the south of I-80 upon which its namesake the town of Lyman is situated, almost as far east as the Rock Springs uplift, at least 24 km (15 mi) north of Granger, and almost as far south as the town of Manila, Utah.

Stratigraphically below the Lyman limestone are strata of the Bridger A. This interval has been problematic for paleontologists because it is sparsely fossiliferous. P.O. McGrew and R. Sullivan worked on the stratigraphy and paleontology of the Bridger A in the late 1960s and published the results of their work in 1970 (McGrew and Sullvian, 1970). More recently, parties from the University of Michigan, Museum of Paleontology have greatly expanded the known diversity of the Bridger A (Gunnell, 1998; Gunnell and Bartels, 2001). This has made possible the recent formalization of new biochronologic units (Gunnell and others, 2009). As discussed above in "Fossils and Biochrononlogy," the Bridger A contains a mammalian fauna (biochron Br1b) that is biostratigraphically distinct from the fauna of the Bridger B (Br2).

Optional Stop: Approximately 18 m (59 ft) stratigraphically above the Lyman limestone 2.7 km (1.7 mi) to the southeast along old U.S. Highway 30 is an unusual type of deposit for the Bridger Formation. Approximately one third of the way up the hill, look for abundant dark brown rock fragments littering the slopes underlain by a thick green mudstone interval. The thin dark brown bed contains abundant fossil caddis-fly larval cases and other more enigmatic fossils preserved in what appear to be algal covered logs (SDSNH Loc. 5783). The taphonomy and paleoecology of this unit has yet to be adequately studied. The fossil-bearing bed is overlain by a 2.8 m (9 ft) thick sequence of green to tan, well-indurated, platy, fine-grained, silty sandstone. It is underlain by a 1.5 m (5 ft) thick, platy, grayish-brown, non-fossiliferous, mudstone with a distinct top contact. Insect and plant fossils are sparse in the Bridger Formation, and this bed contains the most abundant insect trace fossils known from the formation.

Return to I-80 and head west (note that throughout this field trip guide the mileages given refer to the prior stop unless specified otherwise). Heading west along I-80, the first prominent butte you come to south of the interstate is Jagged Butte, which is capped by the Jagged Butte limestone. The second prominent butte you come to (approximate highway milepost 56.5) is Wildcat Butte, which is capped by the Sage Creek limestone (Sage Creek white layer of Matthew, 1909), and which forms the base of the Twin Buttes Member. Exit I-80 at the Church Butte exit (Exit 53) and turn north onto Church Butte Road (no sign). At 30 km (19.2 mi) from Stop 2, with Church Butte just to the east of your location, turn left (southwest) onto Granger Road, Uinta County Road (CR) 233. At kilometer 33.8 (mile 21.0), turn southeast off of County Road (CR) 233 onto a two track road heading towards the westernmost point of Jackson Ridge. Park where the two track road crosses the pipeline right-of-way at 34 km (21.2 mi) from Stop 2.

Stop 3. Church Butte and Jackson Ridge (34.1km [21.2 mi] from Stop 2, cumulative 92.5 km [57.5 mi]): Church Butte is a large linear badland knob formed by the erosion of rocks of the middle Bridger Formation (lower Bridger B beds, figures 4, 5, 6, and 7a). The butte was a landmark along the old Oregon-California-Mormon Trail, now Uinta CR 233. Just to the west of the butte is a north-south trending rim separating Porter Hollow on the east with the valley of the Blacks Fork River on the west. The trail dropped off the rim just to the southwest of Church Butte, and the outcrops of Bridger Formation below the rim were easily accessed by early geologists and paleontologists who travelled along the trail.

Church Butte and the rim exposures are all within the middle part of the Blacks Fork Member of the Bridger Formation of Wood (1934), or the lower Bridger B of Matthew (1909). The rocks in the area are primarily interbedded brown to green mudstone sheets and brown to gray sandstone ribbons and sheets. The sequence includes two sandstone-dominated intervals and three mudstone-dominated intervals (figure 5). Four thin but regionally widespread marker units occur in the sequence that is 120 m (394 ft) thick. The following descriptions are of the Bridger exposures along the west side of the rim, over an area approximately 8 km^2 (3 mi^2) south of where the county road crosses the rim.

The two sandstone-dominated intervals are characterized by a series of thick ribbons to broadly lenticular sheet sandstone beds within a sequence of stacked, thin, muddy sandstone and mudstone sheets. Sandstones can comprise 100% of the total thickness within the sandstone-dominated interval, but the lower interval averages 58% sandstone and the upper interval averages 84% sandstone within a minor amount of mudstone. The thick sandstone beds within these sandstone-dominated sequences are highly connected both laterally and vertically. The thick beds have a reticulate pattern, with some beds oriented toward the south-southeast (vector mean of 173°) and others oriented toward the east-southeast (vector mean 118°). The sinuosities of the individual sandstone beds are low (mean 1.02). These sandstone-dominated intervals represent a river system with numerous splays and local avulsions. The two intervals outcrop as cliffs in the badland exposures.

The mudstone-dominated intervals are characterized by thick ribbon sandstone beds that are typically separated from adjacent sandstones by extensive mudstone beds. Mudstone-dominated intervals have sandstone contents that range from 10% to 35% of total interval thickness. The sandstone ribbons represent large channels carrying mostly medium sand within a mud-dominated system. The paleocurrent indicators in these ribbons (mostly medium to thick trough cross-bed sets) and bed orientations indicate an original flow toward the east-southeast (vector mean of 120°). The sinuosities of the sandstone beds are low (mean 1.03) and their geometry is in a "broken stick" pattern with long straight reaches and short sharp bends. Sandstone bed widths and thicknesses are relatively small in straight reaches, but at bends the sandstone beds are thicker and wider and contain well-developed lateral accretion sets. Fossil bones typically accumulate near the bases of these bends. Thin sandstone sheets representing overbank splay deposits are rare and are limited to near their source channels. The mudstone-dominated intervals outcrop as benches and slopes in the badland exposures.

The Eocene streams which deposited the lower Bridger B channel sandstones in this area were perennial and flooded every year. This is indicated by the abundance of freshwater turtles, gar-pike scales, fish bones, and a large freshwater snail fauna in the overbank deposits. The channel-belt deposits also contain the shells of numerous freshwater mussels (unionid clams), which indicate perennial, well-oxygenated waters in streams and rivers. Fossil plants of this time (MacGinitie and Leopold, 1972) indicate subtropical temperatures and mesic moisture with seasonal precipitation.

There are four regionally widespread marker beds in the Bridger exposures in this area. Two widespread thin limestone sheets occur at the base and top of the section in the Church Butte area. The lower limestone is the Lyman limestone at the base of the Bridger B (along the Blacks Fork), and in this area it is a brown to gray ostracodal limestone with scattered catfish bones. The upper limestone occurs on the flat-surface on top of the rim, just south of the county road. This upper limestone is a brown micrite with brown to black banded chert masses and scattered large planorbid snail shells (*Biomphalaria* sp.). Both limestone beds can be mapped over much of the Bridger basin in lower Bridger B exposures. The predominantly fluvial sequence preserved in the Church Butte area was bracketed by these wide-

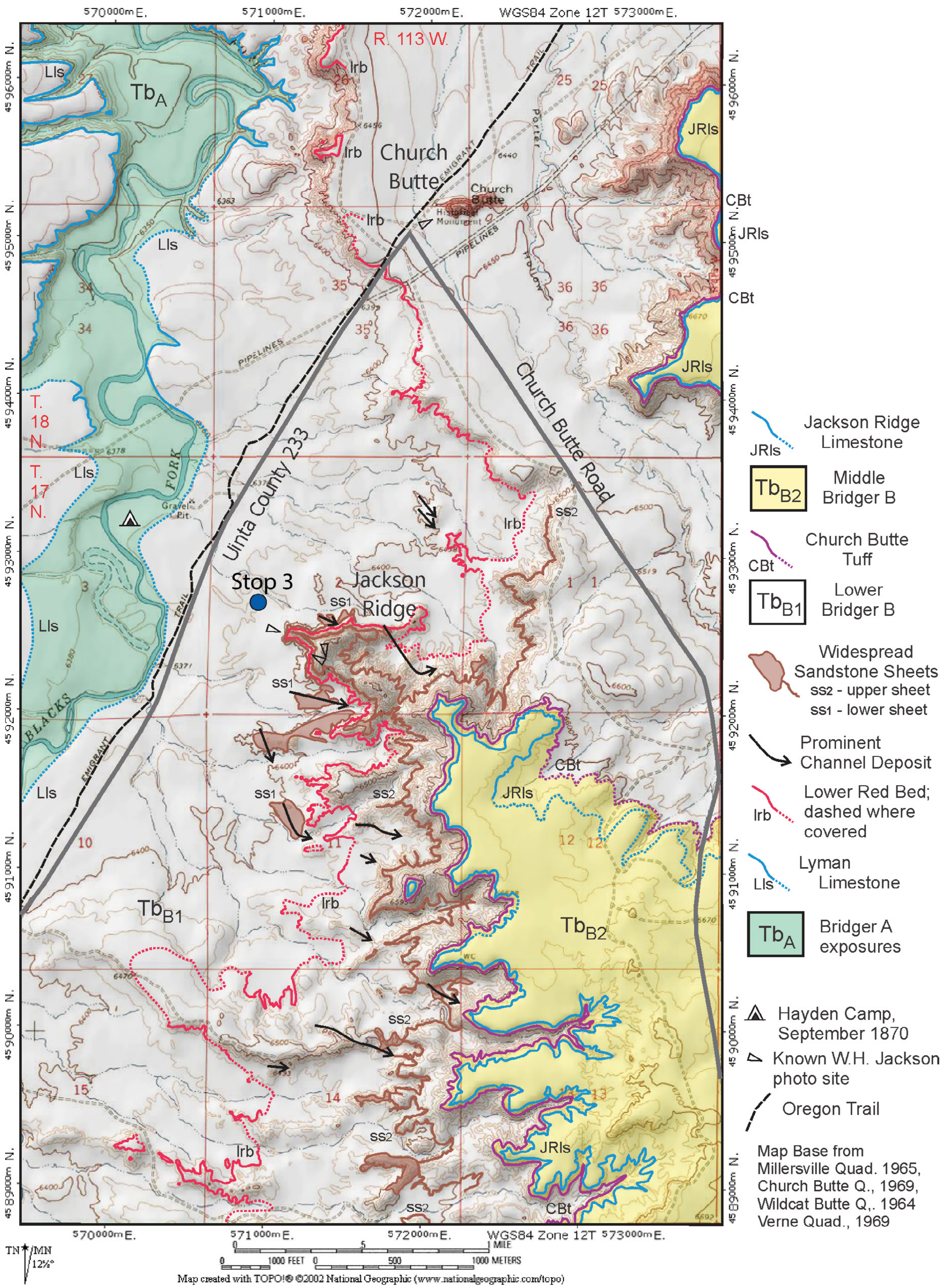


Figure 5. Geologic map of the Church Butte – Jackson Ridge area showing major marker beds in the lower Bridger B interval, laterally extensive sandstone sheet intervals, and trends of major sandstone channel-belt deposits. Also shown are important sites of the Hayden 1870 expedition, including known sites where W.H. Jackson took photos. See the text for details.

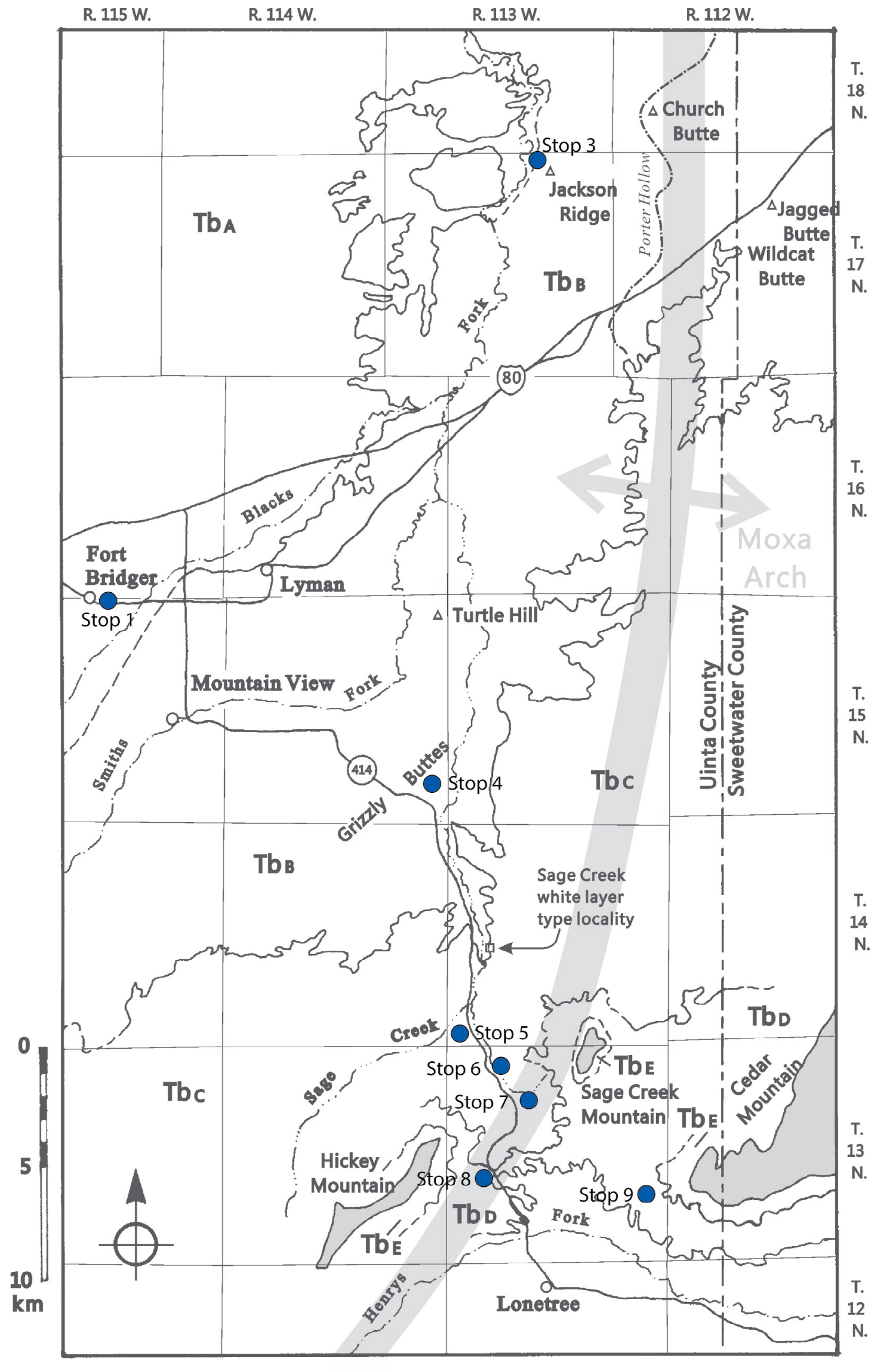


Figure 6. Index map of the western Bridger Basin, Uinta and Sweetwater Counties, Wyoming.

spread lacustrine deposits.

Two lithified volcanic ash beds (tuffs) occur in the section. The lower tuff is represented by a red clayey mudstone that ranges from 0.2 to 0.6 m (0.6–2 ft) thick, 33 m (108 ft) above the Lyman limestone. The bed does not contain euhedral biotite crystals in this area, but in other parts of the Bridger basin this bed thickens and is white with euhedral biotite crystals. This bed has not been radiometrically dated. This red tuff has been mapped over much of the western Bridger basin. A second tuff bed occurs between 10.1 and 11.7 m (33 and 39 ft) below the upper limestone and ranges in thickness from 0.5 to 0.7 m (1.6–2.3 ft) thick. It is a tan to olive clayey mudstone bed that weathers gray and contains abundant euhedral crystals of biotite and hornblende. Sanidine in this tuff has produced a $^{40}Ar/^{39}Ar$ age of 49.05 ± 0.16 Ma (Smith and others, 2008). This upper tuff is called the Church Butte tuff, with the type locality located at the north side of the point on the east end of the long ridge called Jackson Ridge (UTM coordinates of Zone 12T, 572123mE, 4592105mN, WGS 84). The Church Butte tuff occurs throughout the Bridger basin wherever lower Bridger B rocks are exposed.

Many of the first fossils collected from the Bridger Formation came from the Church Butte area. The first geologist known to have collected fossils from the area was F.V. Hayden. In 1868 Hayden collected fragments of a fossil turtle that were later described as *Trionyx guttatus* by Leidy (1869). Hayden returned to the area as part of the Geological and Geographical Survey of the Territories of 1870. The survey camped just to the west of the area along the Blacks Fork River and collected fossils in the Church Butte area on September 10 and 11 of 1870 (figure 7; Hayden, 1872, p. 41). The 1870 survey

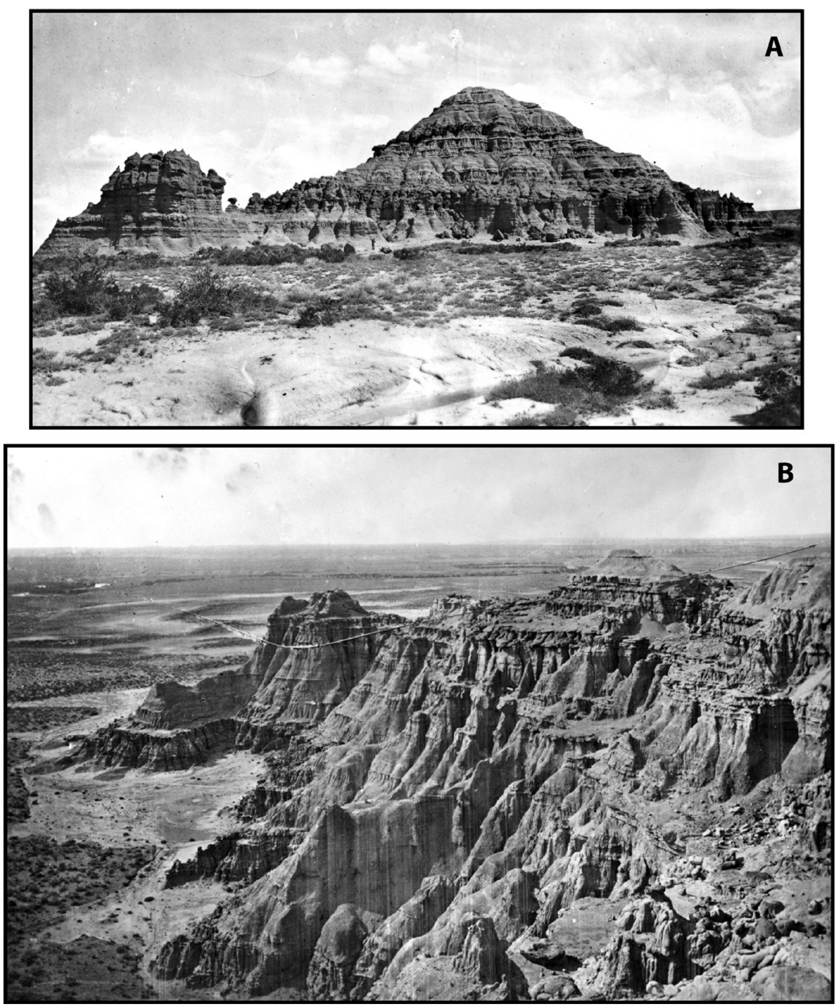


Figure 7. (A) William H. Jackson photo of Church Butte taken on September 10 or 11, 1870. The view is to the east northeast. The UTM location of the photo site is Zone 12T, 571955mE, 4595101mN, WGS84 datum (USGS photo jwh00462). (B) William H. Jackson photo of the west end of Jackson Ridge, taken mid-day either on September 10 or 11, 1870. The view is toward the northwest. The Hayden Survey campsite was along the Blacks Fork River near here but is not in view of this photo. Notice the crack that was in the original glass-plate negative. The UTM location of the photo site is Zone 12T, 571318mE, 4592360mN, WGS84 datum (USGS photo jwh00309).

was the first time the pioneer photographer W.H. Jackson accompanied Hayden. Years later, Jackson recalled these two days:

> "Twelve miles farther on we came to Church Buttes, a remarkable formation in the Bad Lands and a famous landmark along the old trail. While Gifford [*an artist of the 1870 expedition who assisted Jackson*] and I were making pictures of the interesting scenes, the geologists under the lead of Dr. Hayden were digging for fossils. They collected a wagon load of ancient turtles, shell fish, and other creatures... For my part, I made seventeen negatives during the day, something of a record for wet plate work, considering the many changes of location I had to make in getting the different views."
> (Jackson and Driggs, 1929, p. 89, 91)

The best known of Jackson's photos from the area (figure 7b) was taken near the end of a long badlands ridge that is herein named Jackson Ridge in honor of the photographer. The upper limestone bed marker in the area is named the Jackson Ridge limestone.

Jackson's photos of the area document the type area of such fossil mammals as *Notharctus tenebrosus*, *Palaeosyops paludosus*, *Hyrachyus agrestis*, and *Microsus cuspidatus*, all described by Leidy (1870, 1872b) and illustrated in 1873 (Leidy, 1873). The mollusk type specimens collected at Church Butte by the Hayden Survey include *Physa bridgerensis*, "*Viviparus*" *wyomingensis* (a land snail that is similar in form to the aquatic *Viviparus*), and "*Unio*" *leanus* described by Meek (1870, 1871, 1872). Seven other species of fossil mammals have their type area in or near the Church Butte area, and these were collected by such paleontologists as E.D. Cope, O.C. Marsh, and J. Wortman. Type species of fossil mammals collected from the Church Butte area are listed in table 1.

Drive back onto CR 233, and turn left (southwest) towards Lyman. Turn left at mile 5.5 onto CR 247 which then crosses the Blacks Fork River, winding south to I-80. Turn westbound (towards Evanston) onto I-80 at kilometer 12 (mile 7.4). Pass the Lyman exit and drive to the Mountain View-Fort Bridger (Exit 39, 25 km [15.5 mi] from Stop 3). Turn south onto Wyoming

Table 1. Type species of fossils from the Church Butte – Blacks Fork area.

MAMMALS		
	Marsupialia	
		Peratherium innominatus (Simpson) 1928
	Pantolesta	
		Pantolestes longicaudus Cope 1872
	Primates	
		Notharctus tenebrosus Leidy 1870
	Tillodontia	
		Tillodon fodiens (Marsh) 1875
	Rodentia	
		Microparamys minutus (R.W. Wilson) 1937
		Sciuravus bridgeri R.W. Wilson 1937
	Carnivora	
		Miacis parvivorus Cope 1872
	Hyaenodontida	
		Sinopa major Wortman, 1902
	Condylarthra	
		Hyopsodus paulus Leidy 1872
	Perissodactyla	
		Orohippus major Marsh 1874
		Palaeosyops paludosus Leidy 1870
	Cetartiodactyla	
		Microsus cuspidatus Leidy 1870
TURTLE		
	Trionychidae	
		"*Aspideretes*" *guttatus* Leidy 1869
MOLLUSKS		
	Bivalvia, Unionidae	
		"*Unio*" *leanus* Meek 1870
	Gastropoda, Pulmonata	
		Physa bridgerensis Meek 1872
		"*Viviparus*" *wyominensis* Meek 1871

Data compiled from Leidy, 1872a; Meek, 1872; Henderson, 1935; and Gazin, 1976.

Highway (SH) 414, crossing the Blacks Fork River and climbing up onto the Lyman limestone at the top of the hill. Continue through Urie and Mountain View, where the highway will bend to the east near the center of town. Refer to figure 8 for a map that shows the major geographic features of the remainder of the field trip route. As you drive east from the center of Mountain View along Wyoming Highway 414, the badlands to the south that are visible beginning at Wyominh Highway 414 milepost 105 were known to the early residents and explorers as "Grizzly Buttes" (lower and middle Bridger B). The north end of the badlands to the northeast constitute the type area of the Blacks Fork Member. Continue southeast on Wyoming Highway 414 and the

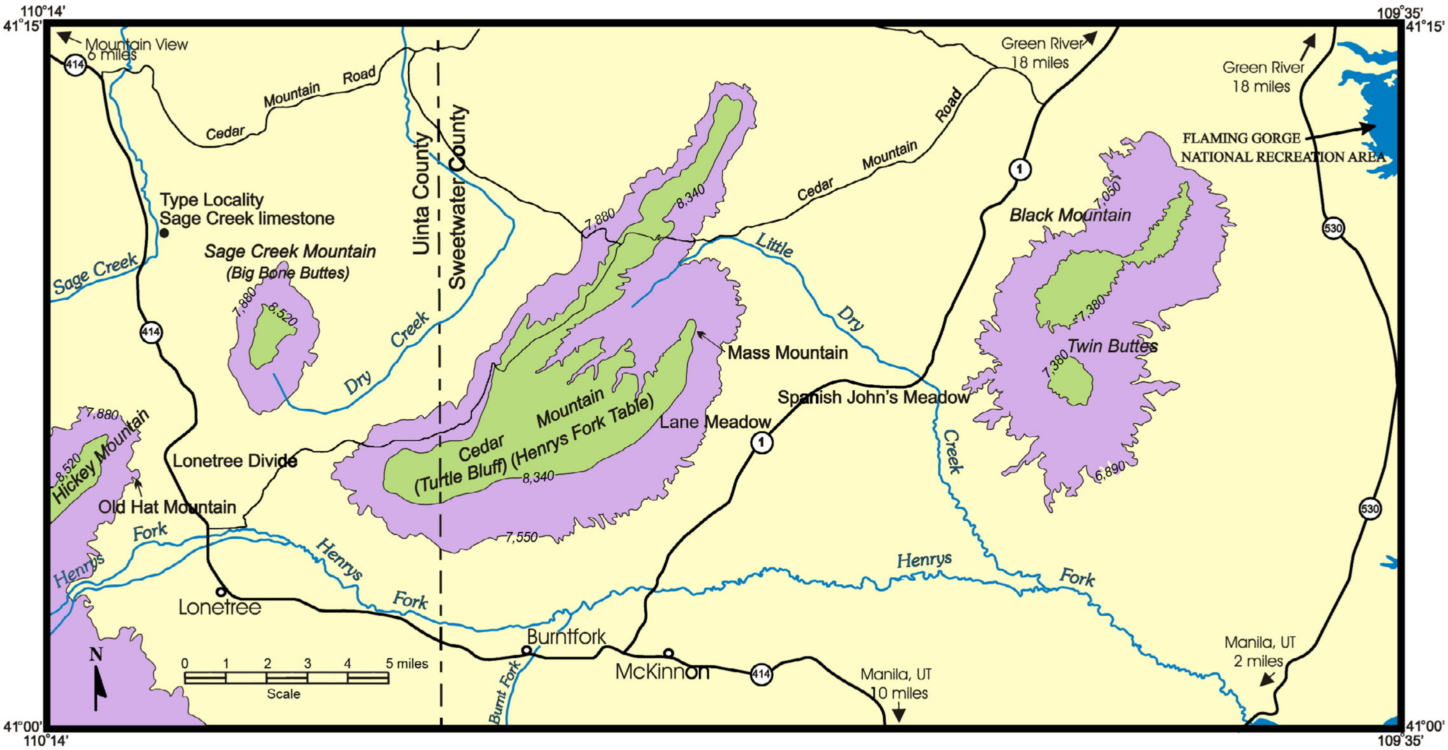


Figure 8. Map of a part of the southern Green River Basin encompassing most of the area of outcrop of the upper Bridger Formation. Map shows both modern and historic geographic terminology (from Murphey and Evanoff, 2007).

highway rises onto the Cottonwood Bench. Immediately after reaching the top of this bench, at 47.8 km (29.7 mi) from Stop 3, turn east and then immediately north. At 0.3 km (0.2 mi) from the turn off, do *not* turn east on Cedar Mountain Road (BLM 4315) and instead continue traveling north. At 50 km (30.4 mi) from Stop 3, turn west onto the two track road and follow it for 1 km (0.6 mi) to the Grizzly Buttes overlook.

Stop 4. Grizzly Buttes (49.9 km [31.0 mi] from Stop 3, cumulative 142.4 km [88.5 mi]): Heading southeast from Mountain View, Wyoming Highway 414 rises through a panel of badland exposures and climbs onto a high flat called the Cottonwood Bench. The bench is capped by gravels derived from the Bishop Conglomerate and transported to the area by Cottonwood and Sage Creeks. Below the gravel-flat is a series of badlands cut by Leavitt Creek, Little Dry Creek, and their tributaries. The badland hills directly west of the overlook comprise the traditional "Grizzly Buttes" of the early explorers, but the name is not known to the modern population of the Smith's Fork valley (see History of Paleontological Investigations in the Bridger Formation). Matthew (1909, p. 297) stated about the buttes:

> "This is the richest collecting ground in the basin; thousands of specimens have been taken from it, and many skulls and skeletons more or less complete."

Type species of fossil mammals collected from the Grizzly Buttes area are listed in table 2.

The lower half of the Bridger B is exposed in the Grizzly Buttes and along the Cottonwood Bench escarpment. Not far below the Quaternary gravels at this overlook is a widespread limestone that was named by Matthew (1909), the Cottonwood white layer (now known as the Cottonwood limestone). It is a white micritic limestone that is very widespread but is locally absent in the Church Butte area. The Cottonwood limestone is typically 5 m (16 ft) above the Church Butte tuff, but in this area it is 10.4 m (34 ft) above the tuff. The thickness of intervals between the widespread

Table 2. Type species of fossil mammals from Grizzly Buttes.

Lipotyphla	
Entomolestes grangeri Matthew 1909	
Nyctitherium serotinum (Marsh) 1872	
Nyctitherium dasypelix (Matthew) 1909	
Plesiadapiformes	
	Mycrosyops elegans (Marsh) 1871
Primates	
	Smilodectes gracilis (Marsh) 1871
Tillodontia	
	Trogosus castoridens Leidy 1871
Pholidota	
	Metacheiromys marshi Wortman 1903
	Metacheiromys tatusia Osborn 1904
	Metacheiromys dasypus Osborn 1904
Rodentia	
	Thisbemys plicatus A.E. Wood 1962
	Leptotomus parvus A.E. Wood 1959
	Reithroparamys delicatissimus (Leidy) 1871
	Pseudotomus robustus (Marsh) 1872
	Ischyrotomus horribilis A.E. Wood 1962
	Mysops minimus Leidy 1871
	Mysops parvus (Marsh) 1872
	Sciuravus nitidus Marsh 1871
	Tillomys? parvidens (Marsh) 1872
Hyaenodontida	
	Sinopa rapax Leidy 1871
	Sinopa minor Wortman 1902
	Tritemnodon agilis (Marsh) 1872
	Limnocyon verus Marsh 1872
Carnivora	
	Thinocyon velox Marsh 1872
	Viverravus gracilis Marsh 1872
	Oödectes proximus Matthew 1909
	Vulpavus profectus Matthew 1909
Perissodactyla	
	Palaeosyops major Leidy 1871
	Limnohyops priscus Osborn 1908
	Helaletes nanus (Marsh) 1871
Cetartiodactyla	
	Helohyus plicodon Marsh 1872

Compiled from Gazin, 1976.

marker beds increases from the Church Butte area toward the southwest. The Jackson Ridge Limestone has been eroded by Cottonwood Creek on the bench, but in this area it is typically 6 m (20 ft) above the Cottonwood white layer. The Church Butte tuff is a prominent gray band about half way down the escarpment. Notice that channel sandstone beds are not as abundant in the lower Bridger B rocks below you as they are in the Church Butte area.

To the east is a prominent escarpment rising far above the Cottonwood Bench. This escarpment is capped by the Sage Creek white layer, the boundary between the Blacks Fork and Twin Buttes Members of the Bridger Formation (the boundary between Matthew's Bridger B and C). Almost all the upper half of the Bridger B is exposed in the west face of the escarpment.

Return to Wyoming Highway 414 and travel south for 9.2 km (5.7 mi). Then turn east and drive for 0.3 km (0.2 mi) and park on the north side of the road. A short walk to the northeast will lead you to Sage Creek limestone and the type locality of the Sage Creek white layer.

Stop 5. Sage Creek white layer type locality (9.5 km [5.9 mi] from Stop 4, cumulative 151.9 km [94.4 mi]): This outcrop of the Sage Creek white layer is located next to the site of the old Sage Creek stage station and Sage Creek Spring along the old Lonetree stage road. It was first described and photographed by Sinclair in 1906 (figure 9), and then named and mapped by Matthew (1909). The Sage Creek white layer is the base of Matthew's Bridger C, the base of the Twin Buttes Member, and the base of the upper Bridger Formation as presently defined. Since Matthew's (1909) work, this unit has been renamed the Sage Creek limestone, and is the base of the lower Bridger C of Evanoff and others (1998), Murphey (2001), and Murphey and Evanoff (2007). The general stratigraphy of the upper Bridger Formation in the Sage Creek Mountain area is illustrated in figure 10.

At its type locality, the Sage Creek limestone is 4.1 m (13.5 ft) thick. It consists of a lower massive tan micritic limestone, a middle shaly limestone with dark gray to black chert bands, and an upper platy to shaly limestone. Elsewhere, it includes massive to blocky marly and micritic limestone, ledgy marlstone, and platy calcareous shale, and is locally interbedded with green to brown mudstone and claystone and thin carbonaceous shale. Fossils of this unit consist of scattered gastropods, bone fragments (mostly fish), and turtle shell fragments; the limestone within it is locally stromatolitic. The Sage Creek limestone supports a very widespread bench, and it is the thickest and most widespread lacustrine deposit

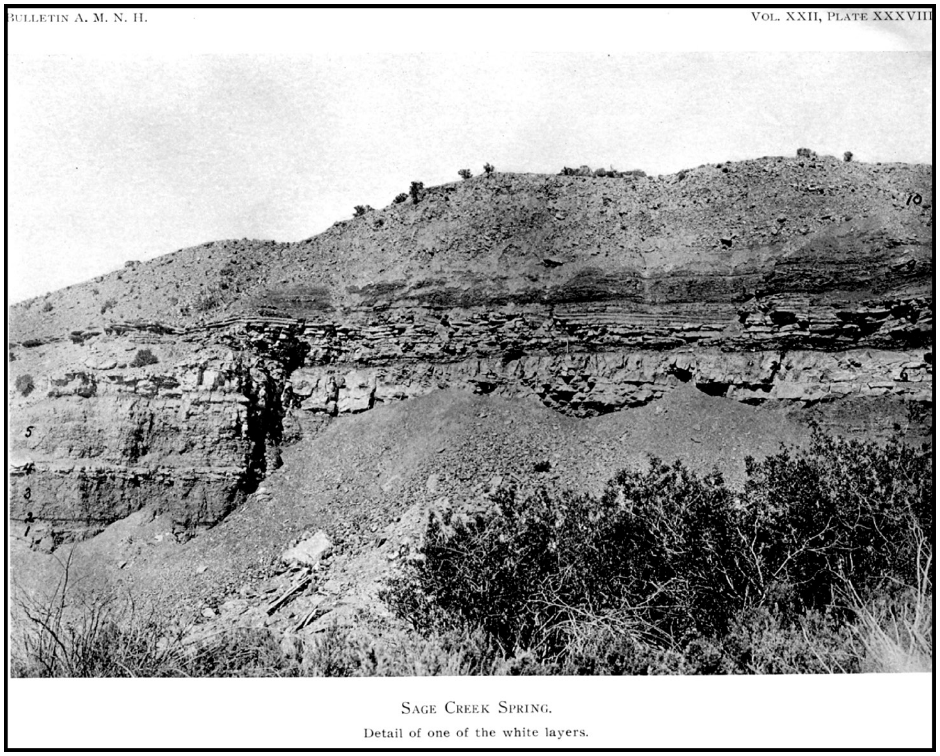


Figure 9. Photograph of the Sage Creek white layer taken by W.H. Sinclair in 1906 (Sinclair, 1906, plate 38). Note the unit numbers penned in near the left edge of the photo.

in the upper Bridger Formation.

Stratigraphically overlying the Sage Creek limestone within the lower Bridger C are two other limestone beds that are much thinner but are also widespread—the Whisky Reservoir and the Butcher Knife limestones (see figure 10). The lower Bridger C is the least fossiliferous subunit of the upper Bridger Formation (Twin Buttes and Turtle Bluff Members), despite the fact that it is by far the most geographically widespread.

Continue south along Wyoming Highway 414 for 5.1 km (3.2 mi). Travelling south, the highway route travels up section through the lower Bridger C and into the middle Bridger C. Sage Creek Mountain is the highest point on the west side of the highway and Hickey Mountain is the highest point on the east side of the highway. Both of these mountains are capped by the Oligocene Bishop Conglomerate. At 5.1 km (3.2 mi) from Stop 5, pull into the Henry #1 gas well pad on the east side of the road.

Stop 6. Soap Holes and Hickey Mountain limestones (5.1 km [3.2 mi] from Stop 5, cumulative 157 km [97.6 mi]): The Soap Holes limestone, the lower of the two thin, rusty brown limestone beds visible at this cliffy exposure, is a widespread marker unit that forms the base of the middle Bridger C (Evanoff and others, 1998; Murphey, 2001; Murphey and Evanoff, 2007). We believe that Matthew (1909) considered this bed to be equivalent to the Burnt Fork limestone, which is a lithologically similar unit that is exposed to the southeast in the Henrys Fork Valley but is actually not present in the section in this part of the basin. In the Henrys Fork Valley, however, it is in fact is 33 m (108 ft) higher than the Soap Holes limestone. The Soap Holes limestone contains few fossils, but it is noteworthy that it is stratigraphically closely associated with fossil logs at several localities. Fossils of the Soap Holes limestone include isolated, disarticulated and poorly preserved bones of fish, reptiles (especially turtles), and mammals within and on top of the unit. In the Black Mountain area, it is locally underlain by thin carbonaceous shale beds which preserve plant fragments. The Sage Creek and Soap Holes limestones have in fact yielded the fewest vertebrate fossils of any upper Bridger lacustrine deposits.

Situated within the middle Bridger C at 10.5 m (34 ft) above the base of the Soap Holes limestone (in the upper Bridger Formation reference section, Murphey and Evanoff, 2007), the Hickey Mountain limestone is a well studied and very important unit paleontologically.

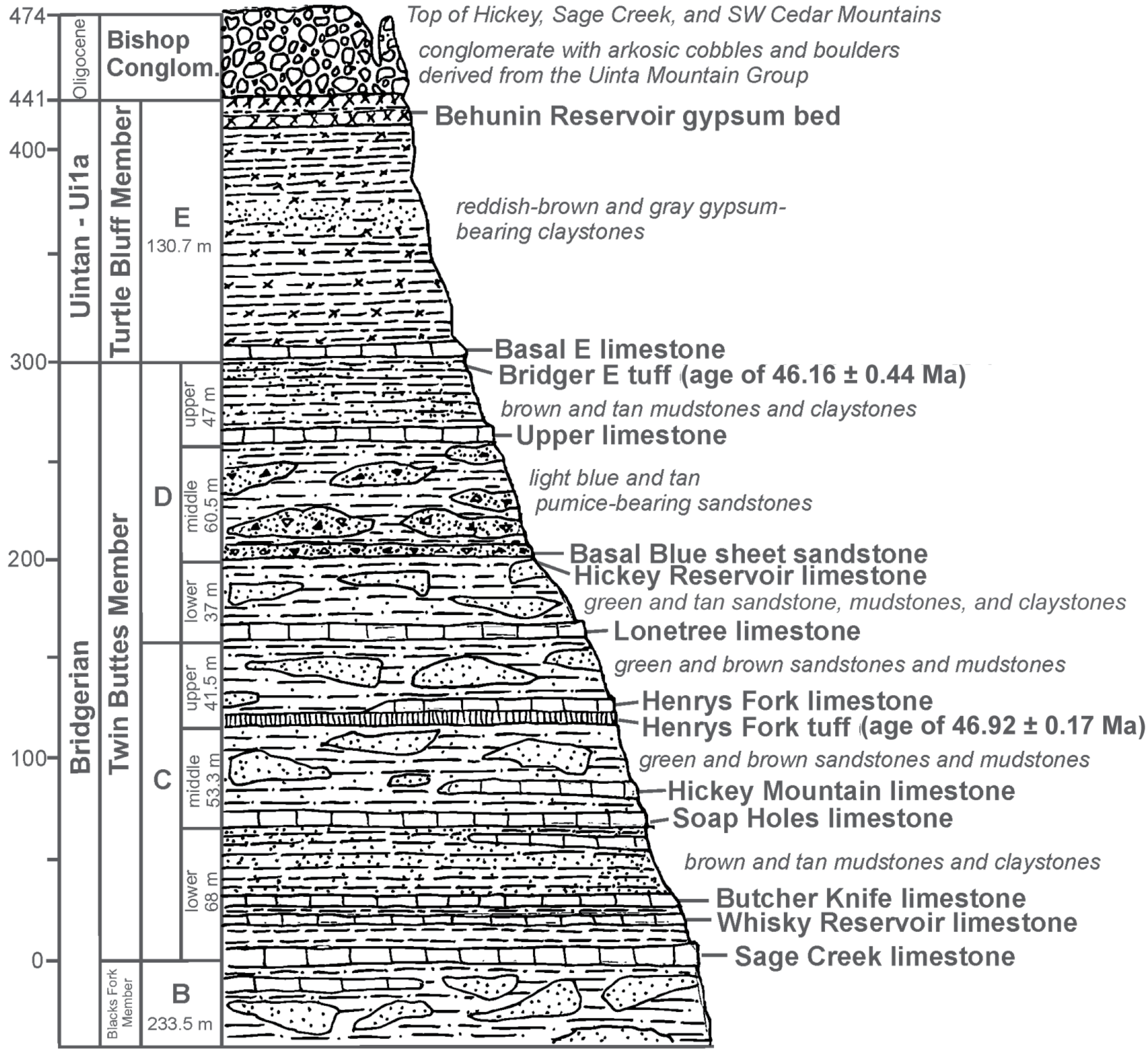


Figure 10. Generalized stratigraphic section of the upper Bridger Formation in the Sage Creek Mountain area, Uinta County, Wyoming. The diagram shows widespread and more localized markers, as well as informal submembers of Matthew (1909). Thicknesses taken from the reference section of the Twin Buttes Member and the type section of the Turtle Bluff Member (from Murphey and Evanoff, 2007).

It has a relatively limited areal distribution, occurring over a distance of approximately 9.0 km (5.6 mi) north of Hickey Mountain and west of Sage Creek Mountain, and is the upper limestone bed exposed on the cliff at this stop. This unit provides an excellent example of one of the most paleontologically prolific depositional settings in the upper Bridger Formation.

The early fossil collectors were the first to notice the close association between vertebrate fossils and the "white layers," which are typically limestone and marlstone beds that were deposited in shallow lakes and ponds. More recently, paleontologists observed that it is not the marlstone beds that contain the majority of vertebrate fossils, but the immediately overlying and underlying mudstone beds. These mudstone beds, which are occasionally carbonaceous, are inferred to have been deposited along lake margins during lake transgressions and regressions (Murphey, 1995; Murphey and others, 2001). Typically, the limestone and marlstone beds contain the remains of mostly aquatic organisms such as snails, clams, fish, amphibians, pond turtles, and crocodilians. The lake margin mudstones contain a mixed aquatic and terrestrial assemblage, and the terrestrial elements include locally abundant reptiles such as lizards, as well as bird bones and mammal bones and teeth. One particularly prolific fossil locality, the *Omomys* Quarry, is located approximately 0.8 km (0.5 mi) west of this stop in the Hickey Mountain limestone and overlying mudstone. This unusual fossil accumulation has produced over 2300 specimens of vertebrates, gastropods, and plants from an 8- to 10-cm-thick (3- to 4-in-thick) deposit in a 4 m^2 (43 ft^2) area (Murphey and others, 2001). What makes the assemblage so unusual is that it contains a high concentration of dental and post-cranial remains of the primate *Omomys*, avian skeletal remains, and eggshell fragments. The unusual components of the fauna are superimposed on a more typical Bridger fauna that occurs at the quarry and lateral to it in the same stratigraphic interval. Four taphonomic agents have been postulated for the formation of the *Omomys* Quarry fossil accumulation: (1) an attritional accumulation of aquatic taxa in lacustrine sediments, (2) an attritional accumulation of both aquatic and terrestrial taxa in shoreline sediments, (3) an attritional accumulation consisting primarily of bird bones and eggshell formed in close proximity to a nesting area, and (4) a predator accumulation dominated by *Omomys* but probably including other vertebrates formed by owls in close proximity to a nest, day roost, or night feeding station. The fauna and flora of the *Omomys* Quarry is listed in table 3.

The same pattern of fossil distribution observed in the Hickey Mountain limestone occurs throughout the upper Bridger Formation as illustrated in figure 11. Most fossils are found in association with lacustrine deposits, although stream channels are also productive. Least productive are the volcaniclastic mudstone and claystone beds that were deposited on low-relief floodplains, and, together with stream-channel deposits, comprise 95% of the total thickness of the upper Bridger. Examples of the floodplain deposits, here consisting of green and gray mudstone and claystone beds, are well exposed at this stop above and below the Soap Holes and Hickey Mountain limestones. Both the Soap Holes and Hickey Mountain limestones are better exposed, with some minor faulting, on the east side of the highway just to the north of this location.

Continue south on Wyoming Highway 414 for 1.8 km (1.1 mi) and turn east onto the gas well road. Follow this road to the east and it will bend to the north for a total distance of 2.5 km (1.6 mi) from Stop 6. Park on the north side of the Henry #10 well pad. The Henrys Fork limestone (type locality of this unit) and the underlying Henrys Fork tuff are exposed above the well pad on the badland hill just to the north. Look for the gray-weathered bed near the top of the badland slope and an overlying thin light gray marlstone, and bring a shovel to examine the tuff.

Stop 7. Type locality of the Henrys Fork limestone (2.6 km [1.6 mi] from Stop 6, cumulative 159.6 km 99.2 mi]): The Henrys Fork limestone (and associated shore margin deposits) is another highly fossiliferous unit, and has produced hundreds of fossil mollusks and vertebrates across its distribution. It is quite widespread, covering an area of approximately 402 km^2 (155 mi^2), and was deposited in an elongate east-west trending basin which formed in the downwarp along the Uinta Mountain front. At this location, which is near the western edge of ancient Henrys Fork Lake, the deposit is only 3 cm (1.2 in) thick, but it attains a maximum thickness of 1.65 m (5.4 ft) on the south side of Cedar Mountain near the center of its depositional basin. It is of taphonomic interest that the upper Bridger Formation with its abundant vertebrate fossils preserved in lacustrine and associated shore margin deposits contains few articulated skeletons or even partially articulated vertebrate remains, most of which have been collected in the Bridger B (see Alexander and Burger, 2001).

Immediately underlying the Henrys Fork limestone is the Henrys Fork tuff, a unit that was first discovered by Emmett Evanoff while conducting field work in the Sage Creek Mountain area in 1991. This ash-fall tuff is the most analyzed tuff in the Bridger Formation, and it is beyond the scope of this paper to report the various ages that have been published. Most recently, Smith and

Table 3. Fauna and flora of the Omomys Quarry with number of identifiable specimens for vertebrates shown in right column. Eggshell is not included. From Murphey and others, 2001.

TAXA			NISP
PLANTAE			
	Division Chlorophyta		
		Chara sp.	
	Division Tracheophyta		
		Dennstaedtiopsis aerenchymata (fern)	
		2 types of dicotyledenous wood	
ANIMALIA			
Phylum Mollusca			
Class Gastropoda			
	Order Lymnophila (freshwater pulmonates)		
		Biomphalaria sp.	
		Omalodiscus sp.	
		Stagnicola? spp.	
		Physa spp.	
	Order Geophilia (land pulmonates)		
		Gastrocopta spp.	
		Oreoconus? sp.	
Phylum Chordata			
		Coprolites	4
Class Osteichthyes			
		Osteichthyes undet.	200
	Order Amiiformes		
		Amia sp.	8
	Order Lepisosteiformes		
		Lepisosteus sp.	98
	Order Siluriformes		14
Class Amphibia			
		Amphibia undet.	4
	Order Anura		
		Anura undet.	4
Class Reptilia			
	Order Chelonia		
		Chelonia undet.	5
		Trionychidae undet.	1
		Echmatemys sp.	1
		Palaeotheca sp.	2
	Order Squamata		
		Lacertilia undet.	117
		Iguanidae undet.	3
		Tinosaurus sp.	1
		Saniwa sp.	1
		Serpentes undet.	2
	Order Crocodilia		
		Allognathosuchus sp.	34
		Crocodilia undet.	4
Class Aves			
	Order Ciconiiformes		
		Juncitarsus gracillimus	4
	Order Falconiformes		
		Accipitridae (2 species)	7
	Order Charadriiformes		
		Burhinidae	5
	Order Gruiformes		
		Rallidae	5
		Geranoididae	8
	Total Aves (includes undet. specimens not listed above)		(191)
Class Mammalia			
		Mammalia undet.	150
	Order Marsupialia		
		Peratherium sp.	13
		Peradectes sp.	1
	Order Rodentia		
		Rodentia undet.	13
		Paramys sp.	1
		Thisbemys sp.	1
		Microparamys sp.	1
		Ischyromyidae undet.	1
		Sciuravus sp.	9
		Pauromys sp.	2
		Sciuravidae undet.	6
	Order Apatemyida		
		Apatemys sp.	1
	Order Lipotyphla		
		Lipotyphlan undet.	28
		Scenopagus sp.	2
		Entomolestes sp.	7
		Centetodon sp.	6
		Apternodontidae undet.	1
		Nyctitherium sp.	4
	Order Plesiadapiformes		
		Uintasorex sp.	1
	Order Primates		
		Notharctus sp.	2
		Omomys sp. nov.	214
	Order Condylarthra		
		Hyopsodus sp.	22
	Order Cetartiodactyla		
		Cetartiodactyla undet.	1
		Homacodon sp.	1
	Order Perissodactyla		
		Hyrachyus sp.	1
		TOTAL	**1183**

(table 3 continued on right)

others (2008) have reported a $^{40}Ar/^{39}Ar$ age of 48.44 ± 0.15 Ma based on sanidine. Ash-fall tuff deposits comprise less than 1% of the total thickness of the upper Bridger Formation, and based on their mineralogy, are believed not to have originated in the Absaroka volcanic field to the north like other volcaniclastic Bridger Formation sediments, but rather in the Challis volcanic field located in central Idaho. At its type locality on the south side of Cedar Mountain, the tuff is 0.95 m (3.1 ft) thick (Murphey and Evanoff, 2007). The tuff is a blocky, non-calcareous, gray to white biotitic claystone with a distinct bottom contact and a diffuse top contact. It contains biotite, zircon, allanite, and apatite crystals. Plagioclase is the most abundant feldspar. It typically consists of a structureless lower unweathered portion with coarse euhedral biotite (up to 1.3 mm [0.05 in] in diameter) which grades upward into a reworked portion with less coarse and less abundant biotite.

The base of the Henrys Fork tuff forms the base of the upper Bridger C, and is 121 m (397 ft) above the base of the Sage Creek limestone in upper Bridger Formation reference section (Murphey and Evanoff, 2007).

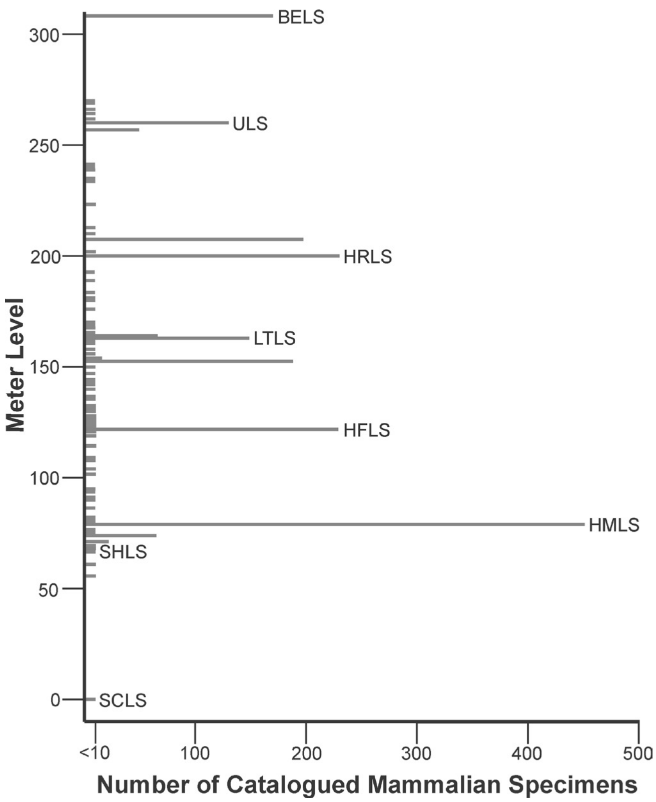


Figure 11. Stratigraphic distribution of catalogued mammalian specimens from the upper Bridger Formation (University of Colorado Museum collections) (SCLS, Sage Creek limestone; SHLS, Soap Holes limestone; HMLS, Hickey Mountain limestone; HFLS, Henrys Fork limestone; LTLS, Lonetree limestone; HRLS, Hickey Reservoir limestone; ULS, Upper White limestone; BELS, Basal Bridger E limestone).

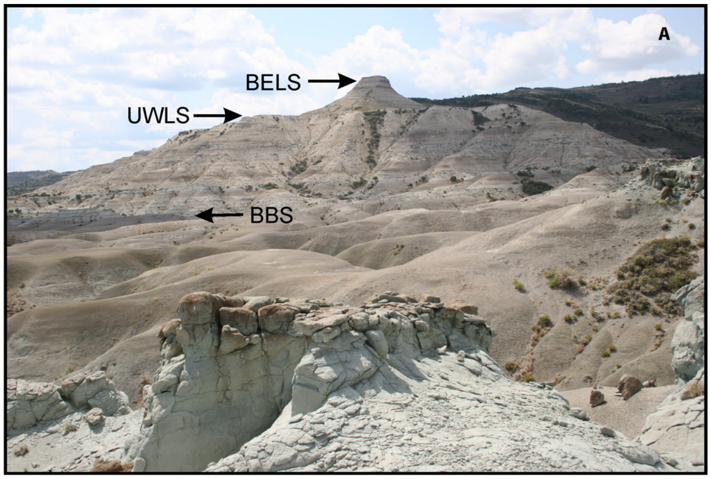
Weathered badland exposures of the Henrys Fork tuff form a distinctive dark gray weathering bed that is readily discernable from other Bridger lithologies, especially when wet.

Return to Wyoming Highway 414 and drive south for 3.0 miles (note the exposures of Henrys Fork tuff which is visible as a subtle gray bed on both sides of the highway just above road level after turning back onto the highway). Then turn west onto the access road for Conoco Fed 20-2 gas well pad. Proceed to the well pad and park (5 km [3.2 mi] from Stop 7). The route you just drove continued up section through the upper Bridger C to the level of the Lonetree limestone (base of lower Briger D) which is at the approximate level of the highway at the Lonetree Divide. This is the stratigraphically highest point that Wyoming Highway 414 attains in the Bridger Formation.

Stop 8. The Lonetree Divide (5.1 km [3.2 mi] from Stop 7, cumulative 164.7 km [102.4 mi]): This area provides some excellent vistas of the upper Bridger Formation and its marker units, especially from the top of the ridge just to the north. The base of the lower Bridger D, the Lonetree limestone (Lonetree white layer of Matthew, 1909), is well exposed at the base of the badland slopes at road level. The base of the middle Bridger D, the Basal blue sheet sandstone, is exposed on the slopes of the prominent conical butte to your west as well as on parts of the ridges to the north and south. The prominent butte, called "Old Hat Mountain" by the locals, is an erosional remnant of Hickey Mountain (figure 12A) to which it is still attached. The 'rim of the hat' is the Upper White limestone (Upper white layer of Matthew, 1909). The butte is capped by a thin interval of red mudstone of the Turtle Bluff Member (Bridger E of Matthew, 1909). To the northeast is Sage Creek Mountain, with a thick sequence of Bridger E (red beds overlying gray beds of Bridger D) visible near its summit. The Basal Bridger E tuff ($^{40}Ar/^{39}Ar$ age of 46.16±0.44 Ma, Murphey and Evanoff, 2007) occurs just below the base of the Bridger E on Sage Creek Mountain. O.C. Marsh called Sage Creek Mountain "Big Bone Butte" because of the abundance of uintathere bones found in the area. Visible to the east is Cedar Mountain, with the thickest and best exposed sequence of Turtle Bluff Member. All three of the mountains in this area (Hickey, Sage Creek, and Cedar) are capped by Oligocene Bishop Conglomerate.

Numerous fossil localities have been documented in the Lonetree Divide area. These include the classic Lonetree localities of Matthew (AMNH expeditions of 1903–1906) and Gazin (USNM expeditions between 1941 and 1969). This area was also worked by Robert M. West of the Milwaukee Public Museum during the 1970s, and by crews from the University of Colorado Museum during the 1990s. Channel sandstone beds in this area indicate paleocurrent directions to the southeast.

Turn south on Wyoming Highway 414 for 3 km (1.9 mi) and turn east onto Cedar Mountain Rim road (BLM



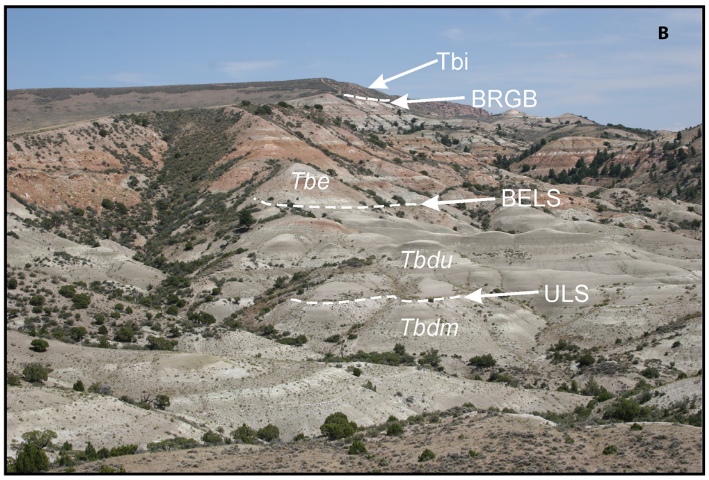


Figure 12. (A) View of the Bridger D and E on "Old Hat Mountain," a prominent butte on the southeast flank of Hickey Mountain, Uinta County, Wyoming. Photo taken looking southwest (BBS, Basal blue sheet sandstone; ULS, Upper White limestone; BELS, Basal Bridger E limestone); (B) View of the Bridger D and Bridger E on the southwest flank of Cedar Mountain, Uinta County, Wyoming. Photo taken looking east (ULS, Upper White limestone; BELS, Basal Bridger E limestone; BRGB, Behunin Reservoir gypsum bed; Tbdm, middle Bridger D; Tbdu, upper Bridger D, Tbe, Bridger E; Tbi, Bishop Conglomerate.

Road 4314). At 4.5 km (2.8 mi) from Stop 8, the road bends to the north and cuts stratigraphically through the upper Bridger C, crossing the Lonetree limestone, and continuing up through the lower and middle Bridger D. At the junction of Cedar Mountain Rim Road and Sage Creek Mountain Road (8.4 km [5.2 mi] from Stop 8), turn south onto a two track road. Drive south on the two track, keeping straight at 9.9 and 10.1 km (6.2 and 6.3 mi) where other tracks diverge, until reaching the Turtle Bluff Member overlook (10.3 km [6.4 mi] from Stop 8). Note that if the ground is wet, it is not advisable to leave the paved highway (Wyoming Highway 414).

Stop 9. The Turtle Bluff Member on Cedar Mountain (10.3 km [6.4 mi] from Stop 8, cumulative 175 km [108.8 mi]): Looking east from this location affords an excellent view of the upper Bridger D, the highest subunit in the Twin Buttes Member, overlain by the Turtle Bluff Member of the Bridger Formation (Matthew's Bridger E). The contact between the two members is shown on figure 12B, and is defined on the basis of a limestone that occurs at the approximate level of the lowest red bed (note that some of the strata observed are slumped). The limestone that supports the bench that you are standing on is the Upper White limestone.

Consisting primarily of banded red, gray, and tan beds of gypsiferous claystone and mudstone, rocks of the Turtle Bluff Member are the least volcaniclastic in the Bridger Formation. Lithologically, the Turtle Bluff Member is somewhat distinct from the rest of the formation, being similar in appearance to the red and brown sandstone, mudstone, and claystone beds of parts of the Washakie and Uinta Formations of similar age. The Turtle Bluff Member occurs only on Hickey Mountain, Sage Creek Mountain, the south end of Black Mountain, and Twin Buttes, but by far the most extensive and thickest exposures occur here on the southwest side of Cedar Mountain. The type section for the Turtle Bluff Member on Cedar Mountain is a 131.5 m (431 ft) thick sequence of reddish-brown and gray claystone beds with a high gypsum content. This gypsum is both primary and secondary. Secondary gypsum consists of selenite and satin spar crystals which are abundant on the upper slopes of Cedar Mountain. Primary gypsum occurs in thin beds, but the Turtle Bluff Member on Cedar Mountain is capped by a thick and laterally extensive gypsum bed. The mostly fine-grained reddish Turtle Bluff sediments were probably derived from the adjacent Uinta Mountains based on their color, unlike those of the Bridger A-D, which were largely derived from more distal volcanic sources.

The Turtle Bluff Member contains two markers: (1) the Basal Bridger E limestone, which marks the base of the member (base of Matthew's Bridger E), and (2) the Behunin Reservoir gypsum bed, which is the youngest and stratigraphically highest well exposed rock unit in the Bridger Formation (note that Behunin is pronounced "Buhannan" by locals). Here on southwest Cedar Mountain, the Turtle Bluff Member contains four additional unnamed limestone beds, and on Twin Buttes there are three. A 2.3-m-thick (7.5 ft) laterally extensive, quartz arenite bed that lies 75 m (246 ft) above the base of the member on Cedar Mountain is the only sandstone bed. Similar sandstone beds in the Turtle Bluff Member also occur on the northwest flank of Hickey Mountain and the south flank of Sage Creek Mountain, and may be roughly stratigraphically equivalent.

The Behunin Reservoir gypsum bed is lithologically unique for the Bridger Formation. Although other gypsum beds occur in the Turtle Bluff Member, they are much thinner. Restricted to just below the southwest rim of Cedar Mountain (below the Bishop Conglomerate), this unit consists of a 7 m (23 ft) thick sequence of gray and tan unfossiliferous bedded gypsum beds interbedded with gypsiferous mudstones and marlstones. It is visible from a great distance as a prominent white bed high on Cedar Mountain. This bed is interpreted as an evaporitic playa lacustrine deposit, and may indicate changing climatic conditions near the end of Bridger Formation deposition.

Because of its sparse fossils and steep, limited exposures, the biochronologic affinity of the Turtle Bluff Member has been difficult to determine. Matthew was the first worker to comment on the age of the member, saying that its few mammal fossils prove sufficiently that it "belongs to the Bridger Age" (Matthew, 1909, p. 296). Osborn (1929) correlated the Bridger E with the Washakie B and Uinta B, although he cited no evidence to support this correlation. Simpson (1933), Wood and others (1941), and Gazin (1976) also regarded the Bridger E as Uintan, although this was apparently not based on fossil evidence. Based on eight isolated rodent teeth identified as *Paramys* cf. *P. delicatior*, and "several" bone fragments identified as brontothere, West and Hutchison (1981) concluded that the Bridger E (their Cedar Mountain Member) was Bridgerian. Subsequent work during the 1990s by crews from the University of Colorado Museum (Evanoff and others, 1994; Murphey and Evanoff, 2007) and in the 2000s by crews from the San Diego Natural History Museum (Walsh and Murphey, 2007) resulted in the collection of a much more diverse faunal assemblage from multiple stratigraphic levels within the Turtle Bluff Member. Donna's locality (UCM Loc. 92189) is near the base of the member, and is the only locality thus far to produce specimens of the newly described species of the omomyid primate *Hemiacodon engardae* (Murphey and Dunn, 2009). Located 105 m (344 ft) above the base of the member, Roll the Bones (SDSNH Loc. 5844) and Red Lenses (SDSNH Loc. 5844) are the stratigraphically highest localities to yield identifiable fossils in the member. Hundreds of fossils have now been collected from these and other localities mostly via screenwashing of sedimentary matrix. Non-Bridgerian taxa include *Epihippus*, *Metanoiamys*, *Pareumys*, *Triplopus*, *Sespedectinae indet*., and *Oromerycidae* gen. and sp. nov. The faunal assemblage of the Turtle Bluff Member is now considered to be earliest Uintan in age (biochron Ui1a of Gunnell and others, 2009), although efforts to obtain additional fossils from this biochronologically important interval member on Cedar Mountain and other locations within the Bridger basin are ongoing. These efforts have produced a much more diverse and abundant mammalian fauna including additional new taxa for the member, both Bridgerian and Uintan. The mammalian fauna of the Turtle Bluff Member has been intensively studied and is formally described in a series of three forthcoming publications (Kelly and Murphey, in press; Murphey and Kelly, in review; Murphey and others, in preparation).

Because of its earliest Uintan biochronologic age, the geochronologic age and magnetic polarity of the Turtle Bluff Member are particularly important for achieving a robust correlation with the geomagnetic polarity time scale. There are currently two published radiometric ages that pertain to the Turtle Bluff Member. Murphey and others (1999) reported an age of 46.14 ± 0.44 Ma (sanidine, plagioclase, biotite) for the Basal Bridger E tuff, which is located stratigraphically 8 m (26 ft) below the base of the Turtle Bluff Member within the Upper Bridger D on Sage Creek Mountain. This date was recalculated by Smith and others (2003) using the Fish Canyon sanidine standard of Renne and others (1998) at 46.83 ± 0.90 Ma. Smith and others (2008) reported an age of 47.45 ± 0.15 Ma (sanidine, corrected, see Smith and others, 2010; Tsukui and Clyde, 2014) for the Sage Creek Mountain pumice, which is located stratigraphically 44 m (144 ft) above the base of the Turtle Bluff Member on Sage Creek Mountain. Two other samples have recently been dated using the U-Pb zircon technique from the Turtle Bluff Member in the thicker stratotype section on Cedar Mountain (Murphey and others, in preparation). These samples, yet to be named, will provide ages for localities that are 74 m and 105 m (243 ft and 345 ft) above the base of the Turtle Bluff Member, respectively. According to Tsukui and Clyde (2014), the Sage Creek Mountain pumice lies within Chron C21n, and suggests that the entire earliest Uintan Turtle Bluff Member sequence and its fauna also lies within Chron C21n.

The Bridger Formation is unconformably overlain by the Bishop Conglomerate, which is visible from this stop capping Cedar Mountain. To the east of this location it forms massive cliffs and spectacular columns. This unit is a very coarse conglomerate composed primarily of arkosic cobbles and boulders derived from the Proterozoic Uinta Mountain Group, with locally common cobbles and boulders of Paleozoic limestone (Bradley, 1964). It is as much as 40 m (131 ft) thick. The Bishop Conglomerate is unfossiliferous, but is Oligocene in age based on isotopic ages of 29.50 ± 1.08 Ma, K/Ar biotite (Hansen, 1986) and 34.03 ± 0.04 to 30.54 ± 0.22 Ma, $^{40}Ar/^{39}Ar$ sanidine (Kowallis and others, 2005) obtained from tuffs that are preserved within it on the south side of the Uinta Mountains.

Return to Wyoming Highway 414, and continue south. The highway crosses the Henrys Fork of the Green River, passes by the hamlet of Lonetree, and bends to the east. There is an excellent view of the Henrys Fork tuff and Henrys Fork limestone on the north side of the highway at Wyoming Highway 414 milepost 128. The Henrys Fork tuff is the prominent gray bed exposed low on the slopes of Cedar Mountain not far above road level, and the Henrys Fork limestone is a prominent white bed immediately overlying the tuff. Continuing east, the highway passes through the hamlet of Burntfork. At highway milepost 130.6 there is a point of historic interest on the south side of the highway. This location is near the site of the first (1825) mountain man fur trading "rendezvous" led by General William Ashley and attended by a then "green" Jim Bridger and Jedediah Smith. At the McKinnon Junction (16.6 miles from Stop 9), turn north onto Sweetwater County Highway 1. Proceed to 18.8 miles from Stop 9 and pull over on the east shoulder next to the road cut.

Stop 10. The McKinnon Road cut (30.3 km [18.8 mi] from Stop 9, cumulative 205.3 km [127.6 mi]): This road cut features the thickest lacustrine sequence in the upper Bridger Formation. The Sage Creek limestone is the thick blocky limestone near the top of the cut. Underlying it are at least 30 m (98 ft) of lacustrine shale, mudstone, marlstone, and limestone, but the total thickness of the lacustrine sequence is unknown. It has been postulated that this sequence and underlying lacustrine strata of unknown thickness represents a final transgressive phase of Lake Gosiute (Laney Shale Member of Green River Formation) (Brand, 2007), although there is little supporting evidence. Whatever the case, this sequence, combined with evidence provided by other upper Bridger lacustrine deposits (thicknesses and areal distribution), suggests that lacustrine deposition during upper Bridger deposition was most prevalent just to the north of the Uinta Mountain front.

Continue north on Sweetwater CR 1. Here, the road is built on rocks of the lower Bridger C and descends into upper Bridger B strata at approximate Sweetwater CR 1 milepost 16.7 before climbing stratigraphically again to the lower Bridger C strata at highway milepost 15.8. At 18.5 km (11.5 mi) from Stop 10, turn east onto a two track road towards the north end of Black Mountain. Twin Buttes is the conical peak to the south of Black Mountain. Bear right at 19.5 km (12.1 mi). Take the left fork at 21 km (13.0 mi) and look for the BLM Wilderness Study Area sign. Park at the base of Black Mountain at 22.2 km (13.8 mi). Note that if the ground is wet, it is advisable to stay on the paved highway.

Stop 11. Twin Buttes and Black Mountain (22.2 km [13.8 mi] from Stop 10, cumulative 227.5 km [141.4 mi]): Although the classic Bridger badlands and collecting areas we have already visited are located far to the west, the Twin Buttes Member and the Twinbutte-an land mammal subage was named for Twin Buttes. Because of this, Murphey and Evanoff (2007) designated their type section of the Twin Buttes Member for the upper Bridger sequence on the south side of Twin Buttes, and established their Twin Buttes Member reference section of the upper Bridger for the sequence in the Sage Creek and Hickey Mountain area. However, the reference section is thicker and contains more marker units. The major stratigraphic features of the upper Bridger in the Twin Buttes and Black Mountain area are shown in figure 13.

In front of this position is another upper Bridger marker bed. The Horse Ranch red bed occurs only in the eastern part of the basin (east side of Cedar Mountain [Mass Mountain], Black Mountain, and Twin Buttes). It is an approximately 4-m-thick (13 ft) sequence of non-calcareous brick red, greenish-gray, and light brown claystone, blocky mudstone, and blocky fine-grained muddy sandstone (Murphey and Evanoff,

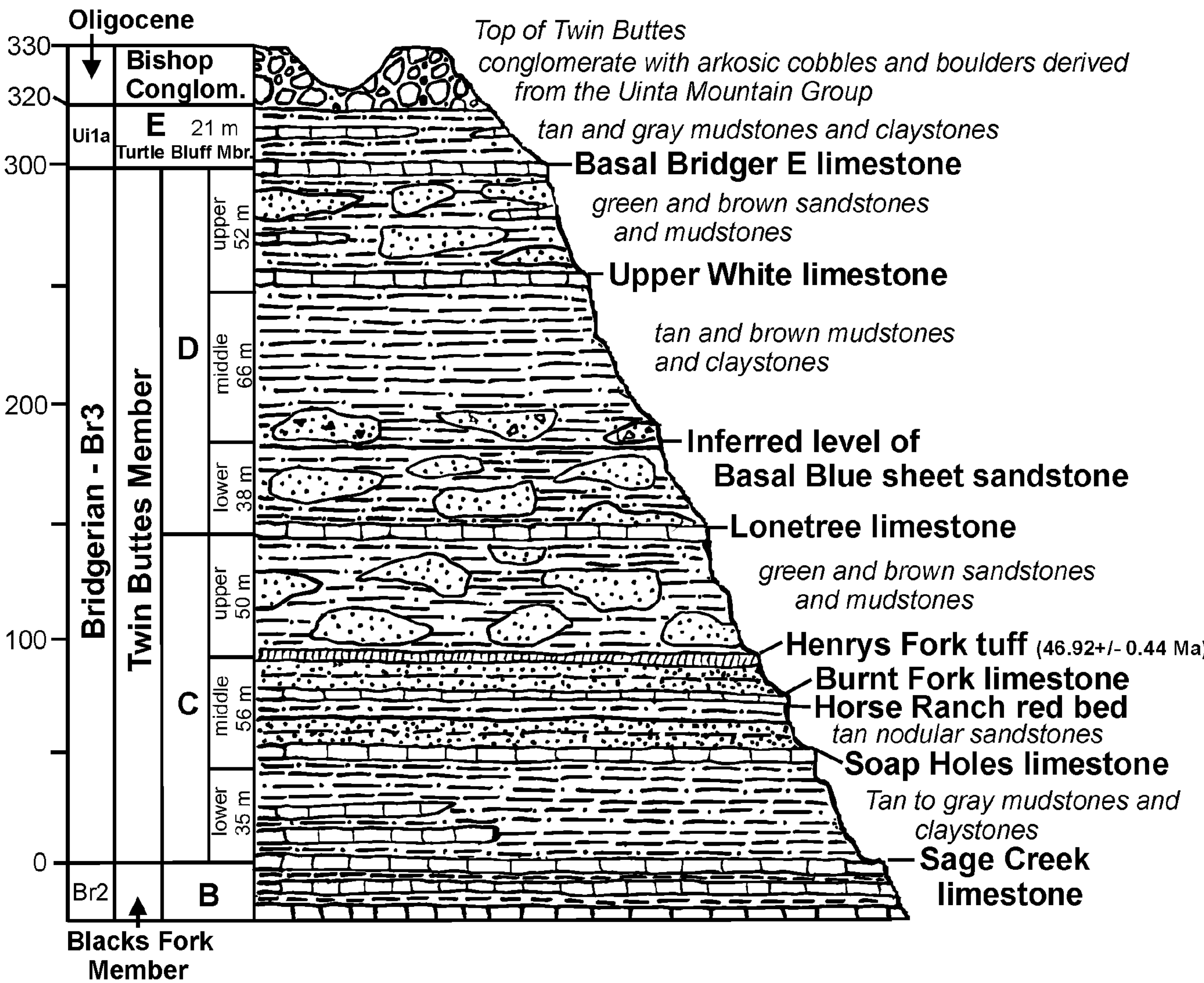


Figure 13. Generalized stratigraphic section of the upper Bridger Formation in the Twin Buttes area, Sweetwater County, Wyoming. The diagram shows widespread and more localized markers, as well as informal submembers of Matthew (1909). Thicknesses taken from the type section of the Twin Buttes Member, which includes the Turtle Bluff Member on Twin Buttes (from Murphey and Evanoff, 2007).

2007). It is locally fossiliferous.

For many years, paleontologists were vexed by the difficulty of correlating between Twin Buttes and Cedar Mountain to the west, especially considering the classic "layer cake geology" of the Bridger with very low dips and laterally persistent marker units. This was because the stratigraphic positions of the "white layers" did not align as expected when using the Sage Creek limestone as a datum. This problem was finally solved by locating the mineralogically diagnostic Henrys Fork tuff not far from here on Black Mountain, and using it as a stratigraphic datum. The reason that earlier workers had difficulties establishing a correlation between the Twin Buttes and Black Mountain area with exposures to the west using the "white layers" is that the lower Bridger C thins dramatically from the west to the east as seen at Twin Buttes, where the thickness between the Sage Creek limestone and Soap Holes limestone is 21 m (69 ft) less than in the nearest correlative sequence to the west.

One is stratigraphically located within the middle Bridger C, and the Henrys Fork tuff is located 42 m (138 ft) above this level. In fact, all of the major marker units present in the Twin Buttes reference section are present in the Twin Buttes type section except for the Basal blue sheet sandstone (base of middle Bridger D). The Lonetree limestone is very well exposed in the saddle between Black Mountain and Twin Buttes, and the Upper white limestone is exposed near the top of Twin Buttes. Only 21 m (69 ft) of Turtle Bluffs Member occurs at Twin Buttes, which is capped by a thin remnant of Bishop Conglomerate. The hike from this stop to the saddle between Twin Buttes and Black Mountain is well worth the effort if you have the time.

This is the end of the Green River Basin (Bridger basin) portion of the field trip. From here we will head south to Manila, Utah, via Sweetwater CR 1 and Wyoming Highway 414, and then continue south over the Uinta Mountains to Vernal and the Uinta Basin.

PART II. UINTA BASIN FIELD TRIP

This portion of the field trip will examine rocks of the Uinta and Duchesne River Formations in the Uinta Basin. The following sections of the field trip guide provide a summary of the early Cenozoic geologic history of the Uinta Basin, as well as the history of investigations, stratigraphy, depositional and paleoenvironmental history, and fossils of the Uinta and Duchesne River Formations. This is followed by a detailed field trip road log.

Early Cenozoic Geologic History

By the late Paleocene (Clarkforkian NALMA), large shallow lakes and ponds occupied a large portion of both the Uinta and Piceance Creek Basins. During the latest Paleocene and early Eocene (late Clarkforkian and early Wasatchian NALMA), there was a return to fluvial sedimentation in both basins, which is represented by rocks of the Wasatch Formation (also called DeBeque Formation by some paleontologists). This was followed by a return to dominantly lacustrine conditions in the early Eocene with the establishment of two large freshwater lakes (one in each basin). Bradley (1931) named the tongue of the freshwater lacustrine unit which was deposited during this brief time of maximum transgression the "basal tongue" of the Green River Formation where it crops out in Indian Canyon in the western part of the Uinta Basin. The two early freshwater lakes in the Uinta and Piceance Creek Basins appear to have been similar to the approximately contemporaneous Lake Luman, the early freshwater stage of Lake Gosiute, which existed in the Greater Green River Basin in Wyoming.

The sediments deposited during lacustrine maximums in both the Uinta and Piceance Creek Basins almost connect over the top of the Douglas Creek arch, suggesting that during at least in part of the freshwater period the two basins were hydrologically connected (Johnson, 1985). During this period, the two basins are believed to have drained externally since the lake waters in both basins remained fresh enough to support abundant freshwater mollusks (Johnson, 1985). At the end of the early Eocene (Wasatchian-Bridgerian boundary), a major transgression associated with expansion and deepening of lake water marked the beginning of Lake Uinta as an unbroken body of water across the Douglas Creek arch in both the Piceance Creek and Uinta Basins (Moncure and Surdam, 1980; Johnson, 1985). Johnson

(1984) named this the Long Point transgression. After the maximum transgression, Lake Uinta extended close to the margins of the combined Uinta and Piceance Creek structural and sedimentary basins; it covered a much larger area than that of the maximum transgression during the earlier freshwater stage of the lake.

Five stages in the developmental history of the larger saline Lake Uinta have been identified based on changes in water chemistry and depositional events (Johnson, 1985). Throughout most of these five stages, the salinity of Lake Uinta increased steadily. Ultimately, salinity increased to the point at which nahcolite and halite were precipitated. The gradual filling of Lake Uinta during the middle Eocene was due to an influx of volcaniclastics from the Absaroka volcanic field in Wyoming to the north and from volcanic centers farther to the west, and then later by an increase in sediment resulting from rejuvenated local Laramide uplifts. There is no direct geologic evidence that Lakes Uinta and Gosiute were ever physically connected. However, fluvially deposited volcaniclastics in Lake Uinta, demonstrably derived from the Absaroka volcanic field in northwestern Wyoming, would be a persuasive line of evidence. This would not rule out the possibility of transport of volcaniclastic material from Lake Gosiute south to Lake Uinta via streams over the lowest drainage divides after the Greater Green River Basin had been filled (Surdam and Stanley, 1980).

As lacustrine deposition in Lake Uinta diminished because of basin filling, fluvial sedimentation resulted in deposition of the Uinta Formation in the Piceance Creek and Uinta Basins (Stokes, 1986). At this time, fluvial deposition began to dominate in the basin as streams flowed into it from the north and east (Stokes, 1986). The east-west flow resulted in the formation of limey siltstone beds and fine-grained Uinta Formation shale in the eastern part of the Uinta Basin, contrasting with the red sandstone, shale, siltstone, conglomerate, and limestone beds in the west (Stokes, 1986). Today, fluvial rocks of the middle Eocene Uinta Formation (Uintan NALMA) are preserved above Green River Formation strata only in the northern part of the Uinta Basin. The late middle Eocene (Duchesnean NALMA) Duchesne River Formation overlies rocks of the Uinta Formation in the north-central and western parts of the Uinta Basin, and the Cretaceous-age Mesaverde Group on Asphalt Ridge. Both the Uinta and Duchesne River Formations were deposited in river channels and on adjacent floodplains (Stokes, 1986) and in river deltas (Townsend, 2004). Riparian environments were forested, and the rivers and streams flowed through a savanna-type environment with some swampy and marshy areas and forested highlands (Hamblin, 1987; Townsend and others, 2010).

Uinta Formation

The Uinta Formation is exposed south of the Uinta Mountains as a discontinuous outcrop belt that can be traced approximately 145 km (90 mi) from near the west edge of the Uinta Basin to as far east as the Utah-Colorado state line (Peterson and Kay, 1931; Bryant and others, 1989; Hamblin and others, 1999; Sprinkel, 2007, 2009, 2015). It overlies the lacustrine Green River Formation, with an interfingering contact between the two formations that reflects their closely related depositional history (Ryder and others, 1976; Hintze, 2005). The Uinta Formation is approximately 1298 m (4257 ft) thick (including subsurface and exposed rock) and contains bitumen in the form of gilsonite veins (Cashion, 1986; Hintze, 2005; Sprinkel, 2007). The Uinta Formation was deposited under fluvial conditions as the lake depositing the Green River Formation was receding (Ryder and others, 1976).

History of Paleontological Investigations

O.C. Marsh led the first paleontological expedition to the Uinta Basin in 1870 as part of a Yale College Scientific Expedition (Betts, 1871; Marsh, 1875a, 1875b). In an unexplored area between the Green and White Rivers, Marsh's party collected numerous fossil mammals, the beginnings of an assemblage that would later define the Uintan NALMA, a time period that spans approximately 46.5 to 40 Ma (Wood and others, 1941; Prothero, 1996; Murphey and Evanoff, 2007). In the 1880s, Francis Speir of Princeton University collected in this same area and the mammalian fossils he collected were studied by W. B. Scott and H.F. Osborn, whose efforts produced the first comprehensive publications on mammals from the Uinta Formation (Scott and Osborn, 1887, 1890; Rasmussen and others, 1999a). At the turn of the century, the Carnegie Museum sent expeditions to the Uinta Basin at different times led by O.A. Peterson and then Earl Douglass (Douglass, 1914; Peterson, 1919). Peterson (1919) initially described many of the medium and smaller-sized mammals from the Uinta Formation, many now recognized as index taxa for the Uintan NALMA and therefore crucial for understanding Uintan biochronology on both the regional and continental scales (Walsh, 1996). After these initial expeditions, museums across North America sent parties to collect small samples of Uintan mammals, the most notable of these being the Smithsonian Institution. In 1993, an expedition from Washington University in St. Louis began what would be a 15+ year project (still ongoing) in the Uinta and Duchesne River Formations, with the goal of collecting small mammals (Rasmussen and others, 1999a, 1999b; Townsend and others, 2006). These latest expeditions have amassed one of the largest assemblages of Uintan mammals from the Rocky Mountain region (Townsend, 2004).

Stratigraphy of the Uinta Formation

Whereas the Uinta Formation has been formally divided into a lower Wagonhound Member and an upper Myton Member, many geologists and paleontologists continue to utilize the informal tripartite scheme in which the formation was initially subdivided from lowest to highest: Uinta A, B, and C, (Wood and others, 1941; Prothero, 1996; Sprinkel, 2007). The tripartite division of the formation is a modification of Osborn's (1929) stratigraphic nomenclature: Uinta A, Uinta B1, Uinta B2, and Uinta C (Peterson and Kay, 1931; Prothero, 1996; Walsh, 1996; Townsend and others, 2006; Sprinkel, 2007). The lowermost unit, Uinta A, intertongues with the underlying Parachute Creek Member of the Green River Formation and is comprised of resistant fine-grained sandstones that are yellowish-brown and yellowish-gray (Sprinkel, 2007). These beds are medium to massive sandstone beds that weather to cliffs, ledges, and softer gray slopes and have been measured to be about 226 m (740 ft) in thickness (Cashion, 1974). Within in Uinta A, there is a 1.8 m (6 feet) thick tuffaceous bed ("a" tuff), and the base of this bed occurs 56 m (185 ft) below the top of the Uinta A (Cashion, 1974). Uinta B is composed of light-gray, light greenish-gray, light-brown, light-purple mudstone and claystone forming non-resistant slopes (Sprinkel, 2007). These are interbedded with green-gray, yellow, and brown fine-grained sandstone beds that form thin resistant ledges (Townsend and others, 2006; Sprinkel, 2007). There are prominent gilsonite veins in this unit (Cashion, 1986). In the eastern part of the basin, the Uinta B is capped by a massive fine- to coarse-grained gray and brown sandstone bed that weathers to dark brown, and was named the *Amynodon* sandstone (Riggs, 1912). This massive sandstone unit is over 1.6 km (1 mi) in length, and was originally defined as the boundary between the Uinta B and Uinta C horizons (Riggs, 1912), but is now known to be local in extent. Uinta C is distinctive in that the lower intervals and upper intervals are strikingly different in terms of rock type and coloration (Townsend and others, 2006). The lower part of Uinta C is comprised of light-gray, light-greenish-gray, and light-brown mudstone and claystone that interbed with fine-grained sandstone beds, which are also greenish gray or commonly yellow or brown (Townsend and others, 2006; Sprinkel, 2007). The upper part is composed of mainly deep red-orange, red, dark-brown, grayish-purple, and yellow mudstone and claystone with thin gray and green fine-grained sandstone beds that form thin ledges (Townsend and others, 2006; Sprinkel, 2007).

The stratigraphy of the Uinta Formation has been less well studied than that of the Green River Formation, and most of the stratigraphic work has been undertaken by paleontologists. The early publications that produced the initial description of the formation has been confused by changes in terminology describing the lithologic horizons and by shifting boundaries of the units that divide these horizons (Riggs, 1912; Osborn, 1929; Stagner, 1941; Cashion, 1986; Prothero, 1996; Townsend, and others, 2006). Osborn (1895) cited Peterson as first dividing the formation into informal units Uinta A, B, and C, and all units were reported to be fossiliferous. All early fossil collections have these horizon designations assigned as stratigraphic data (Prothero, 1996). Osborn (1929) removed the top 120 m (400 ft) of Peterson's Uinta A, and called it Uinta B1, leaving the remaining sandstones of

Uinta A without any known record of fossil vertebrates. Additionally, Osborn designated the *Amynodon* sandstone of Riggs (1912) as the boundary unit between Uinta B (now B2) and Uinta C, further altering Peterson's initial scheme. Osborn's (1929) Uinta B1 had an upper limit bound by another massive unit, the "*Metarhinus*" sandstone. The massive sandstone units of Uinta B1 are not laterally extensive, and a red shale and siltstone unit described by Cashion (1974) might be a more appropriate boundary unit. The various changes in terminology and marker units have caused significant confusion in museum locality data, and has adversely affected the accuracy of the stratigraphic ranges of numerous Uintan taxa.

Prothero (1996) constructed a magnetostratigraphic section correlating the various historical Uinta Formation localities. With the local ranges of various mammalian taxa in disorder due to earlier stratigraphic nomenclatural changes, Prothero's (1996) work was an essential first step in clarifying and correlating localities across the exposed formation in the Uinta Basin. Townsend and others (2006) described a series of stratigraphic sections through the upper intervals of Osborn's (1929) Uinta B2 and Uinta C, up to the contact with the overlying Duchesne River Formation (figure 14A). These authors suggested a new boundary between the Uinta B and Uinta C based on a significant lithologic and color change. The suggested boundary is approximately 73 m (240 ft) higher than the *Amynodon* sandstone of Osborn (1929). Sprinkel (2007) mapped the boundary between the Uinta C and the Duchesne River Formation higher in the section, and because it is associated with such a gradual lithology change in the eastern part of the basin, but noted there was an intertonguing transition zone between the formations. Sprinkel mapped the Uinta B-C boundary using a distinctive and reportedly more laterally persistent greenish-mudstone bed that occurs just below the *Amynodon* sandstone. Stratigraphic work continues in conjunction with the current paleontological work.

Paleoenvironmental History, Paleontology, and Biochronology of the Uinta Formation

The Eocene epoch is the time when many modern orders of mammals first appear in the fossil record (e.g., primates, bats, artiodactyls, perissodactyls, rabbits). Prior to the Eocene, mammalian faunas were comprised of archaic forms that had diversified just after the demise of the dinosaurs at the Cretaceous-Paleogene boundary. During the early Eocene, global climates were exceedingly warm and produced an almost pole-to-pole tropical greenhouse (Zachos and others, 2001). The Uintan NALMA and the final intervals of the preceding Bridgerian, mark the beginning of the end of this global greenhouse, and this is reflected in the ecological diversity of the mammals that lived during this time (Woodburne and others, 2009a, 2009b; Townsend and others, 2010). Tropical arboreal forms, typical of the early Eocene greenhouse began to drop off, and mammals that were more adapted to subtropical, even temperate conditions and habitats began to appear (Townsend and others, 2010). The Uintan NALMA also marks a key transition in the evolutionary history of North American mammalian faunas as approximately 31% of modern mammalian taxonomic families (ancestors of canids, camelids, felids, and some modern rodents) appeared in the fossil record (Black and Dawson, 1966).

The Uinta Formation fossils that form the basis of the Uintan NALMA are from Uinta B1, B2, and C units. The fauna from Uinta B1 comes mainly from the Wagonhound-Bonanza area, an early locality (Well No. 2), and the Willow Creek-Ouray area. The assemblage from this unit is small and includes *Achaenodon uintensis*, *Protoreodon parvus*, *Oromeryx plicatus*, *Harpagolestes*, *Eomoropus amarorum*, *Hyrachyus eximius*, a species of *Triplopus*, and a diverse group of brontotheres and uintatheres (Prothero, 1996; Gunnell and others, 2009). These taxa are considered an early Uintan assemblage corresponding to biochron Ui2 of Gunnell and others (2009).

The Uinta B2 fauna is incredibly diverse (see appendix) constitutes the bulk of the assemblage that is considered early Uintan, and corresponds to biochron Ui2 of Gunnell and others (2009). Strata that have yielded faunas from the Uinta B2 unit include White River Pocket and areas around Kennedy's Hole. Recent fossil collecting efforts have made it possible to formally define biochronologic units and stratotype sections for the Uinta Formation (Gunnell and others, 2009). The beginning of Ui2 is defined by 26 index taxa (outlined in Gunnell and others, 2009). Numerous taxa range through Ui2, but only a few are unique to Ui2 and these are from Uinta B2 beds: *Amynodon reedi, Eobasileus cornutus; Eomoropus amororum, Hyrachyus eximius, Limnocyon potens, Mesonyx obtusidens, Metarhinus fluviatalis, Metarhinus* sp., *Pantolestes longicaudus, Paramys* sp., *Sciuravus popi, Uintatherium anceps* (Gunnell and others, 2009).

Fossil mammals found in Uinta C sediments are typically considered to be late Uintan and correlate to biochron Ui3 of Gunnell and others (2009). Strata that have yielded late Uintan faunas include Myton Pocket (southeast of Myton, Utah), Kennedy's Hole, Leota Ranch, Devil's Playground, Leland Bench Draw, and Antelope Draw. The Uinta C fauna is equally as diverse as the Uinta B2 fauna. Twenty-four taxa define the beginning of Ui3 including *Auxontodon, Colodon, Duchesneodus, Eosictis, Janimus, Mytonius, Mytonomeryx, Pentacemylus, Procyonodictis, Protadjiduamo*, *Protitanotherium*, and *Metatelmatherium*. One of the striking differences between Ui2 and Ui3 faunas is that the younger assemblages is dominated by artiodactyls. Therefore, this biochron was designated the "*Pentacemylus progressus* Interval Zone" reflecting the abundance of this particular taxon (Gunnell and others, 2009). Whereas the taxonomic composition of Ui3 is quite different than Ui2, only a few genera make their first appearance during this interval (Gunnell and others, 2009). Current fieldwork is focused on collecting the upper intervals of the Uinta C unit via excavation and screenwashing in order to increase the sample of small mammals (Westgate and others, 2013, 2014; Townsend and Murphey, 2015).

Uinta Formation Field Trip Stops

Travelling south across the Uinta Basin via State Route (SR) 45, we will cross both the Green and White Rivers and make our way to the base of the Uinta Formation just south of Wagon Hound Canyon. Note that the driving distance from the Utah Field House Museum in Vernal to the first field trip stop is 68.5 km (42.6 mi). Examination of the Uinta Formation begins at the base of the formation where it overlies strata of the Parachute Creek Member of the Green River Formation along the White River. From there travel north across Wagon Hound Canyon to examine rocks of the Uinta A and interbedded Green River Formation. Continuing north are the green siltstone and brown sandstone beds that are typical of Uinta B1. From there, the typical reddish and grayish beds defining Uinta B2 and the orange-red beds that typify the Brennan Basin Member of the Duchesne River Formation are seen in the distance. Most of the day will be spent exploring the typical Uinta B2 localities in the Coyote Wash area with a drive to the Red Wash area where the transition to Uinta C rocks is well exposed. From Red Wash, drive northwest up section to a fossil locality that is stratigraphically high in Uinta C and near the contact with the overlying Brennan Basin Member of the Duchesne River Formation. The final Uinta Formation stop is located to the southwest of this location at a classic Uinta Formation fossil locality, White River Pocket.

Stop 1. Uinta Formation – Green River Formation contact along the White River at Wagon Hound Canyon (0.0 km/mi; cumulative 0.0 km/mi; SR 45 highway milepost 0.8): Peterson in Osborn (1895) described the contact between the Uinta Formation and the Green River Formation as a series of "hard brown sandstones" that conformably overlie the Green River shales. Looking north across the White River, the Parachute Creek Member of the Green River Formation is exposed as sloping yellow-brown, tan, and green-gray mudstone and claystone directly underlying the massive sandstone cliffs of Uinta A (figure 14B). Looking to the east along the White River, the Green River shale beds are exposed as dark brown bands within the member. The "hard brown sandstones" of the Uinta Formation are markedly different from the underlying Green River Formation in that they form massive resistant cliffs of yellow-brown sandstone. There are few reported identifiable vertebrate fossils from the Uinta A with stratigraphically reliable locality data, and none collected thus far are biostratigraphically diagnostic. The Uinta A may be earliest Uintan (Ui1a) in part (or possibly even Br3 in part), and therefore could be partially equivalent with the Turtle Bluff Member of the Bridger Formation (see Murphey and Daitch, 2007).

Drive north on SR 45 and turn left (west) at 2.7 km (1.7 mi; at milepost 2.4) onto a graded dirt road. Bear right at the bottom of the hill 0.16 km (0.1 mi) ahead

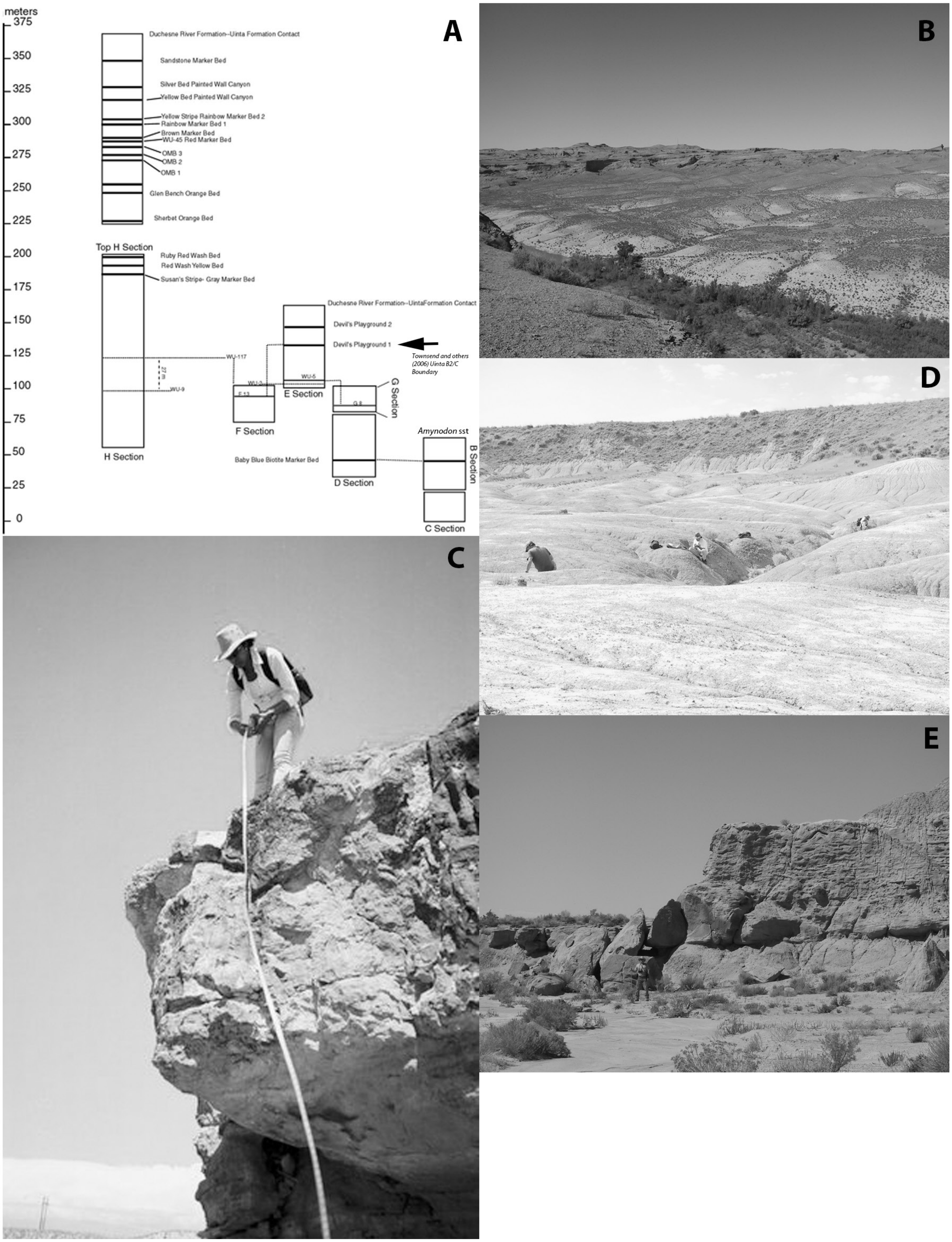


Figure 14. Caption on following page.

Figure 14 (figure on previous page). (A) Stratigraphic sections from Townsend and others (2006) indicating the level of the *Amynodon* sandstone of Osborn (1929) at the top of B section—considered the traditional boundary between Uinta B2 and Uinta C—and the Uinta B2 and Uinta C boundary at Devil's Playground as suggested by Townsend and others (2006) indicated by the arrow at Devil's Playground 1; (B) View of massive cliff-forming Uinta A sandstone beds overlying and interfingering with Parachute Creek Member of the Green River Formation; (C) Measuring one of the massive sandstone units in Uinta B; (D) Collecting at WU-18, a typical Uinta B2 locality; (E) Sandstone channels associated with the WU-110 locality complex.

(cumulative 2.9 km [1.8 mi] from Stop 1), and turn onto a less well-maintained road. Pull off after 0.16 km (0.1 mi), cumulative 3 km (1.9 mi) from Stop 1.

Stop 2. Uinta A and Cashion's "a" Tuff (3 km [1.9 mi] from Stop 1; cumulative 3 km [1.9 mi]): Driving north on SR 45 through Wagon Hound Canyon, turn west onto a graded dirt road. Here the sloping yellow-gray siltstone and cliff-forming sandstone of Uinta A are well exposed. Cashion's (1974) "a" tuff is exposed on the slope and is most visible just below the cliffs to the north. This tuff has not yet been dated because it is so crystal poor. The boundary between the Uinta A and Uinta B is mapped as occurring half way up the cliff above the tuff. Beds of lacustrine shale are interbedded with the lower part of the Uinta A sequence in this general area, reflecting the complex transition from lacustrine to fluvially dominated depositional environments. Fragments of fossilized bone and wood have been found in some of the side canyons in this area.

Optional Stop: Peterson's 1924 *Dolichorhinus* Quarry. Continue southwest from Stop 2. After passing a small gilsonite mine the road will bend to the northwest. After another 0.24 km (0.15 mi), there is a fork in the road. Take the right fork to the top of the hill to the north. At approximately 2.9 km (1.8 mi) from Stop 2, the spoils pile from Peterson's 1924 *Dolichorhinus* Quarry will be visible 0.32 km (0.2 mi) to the east of the road. This historic quarry site was re-located by Vernal paleontologists Evan Hall and Sue Ann Bilbey. Return to Stop 2, then get back on SR 45 and drive north and northeast past the Bonanza gilsonite mining operation. Park on the east shoulder of the highway (5.5 km [3.4 mi] from Stop 2).

Stop 3. Uinta B1 and Metarhinus Sandstone (5.5 km [3.4 mi] from Stop 2, cumulative 8.5 km [5.3 mi]; SR 45 highway milepost 5.6): This unit is composed of a massive yellow-gray sandstone bed underlain by greenish-gray siltstone (figure 14C). The *Metarhinus* sandstone is not a widespread unit. It is the boundary between Osborn's (1929) Uinta B1 and B2. To the west, both the Bonanza and Independent gilsonite veins are visible. The most common vertebrate remains found here are turtle and crocodile. Mammals that have been recovered include mostly brontotheres and other large Uintan mammals.

Continue northwest on SR 45. At 6.3 km (3.9 mi) from Stop 3 (SR 45 highway milepost 9.3), turn northeast at the intersection with Uinta CR 3150. The dark brown, bench-supporting, sandstone bed to your east and west is the *Amynodon* sandstone, which has traditionally formed the boundary between the Uinta B and Uinta C.

Continue down Uinta CR 3150 for 6.4 km (4 mi) to an intersection with a dirt road (the railroad will be to the south). Turn right onto the dirt road and cross over the railroad tracks. After crossing the railroad tracks, veer to the right and then turn left heading south as the dirt road continues. After turning south on the dirt road travel for 1.3 km (0.82 mi) until reaching a two-track road veering to the right. This two-track road goes across Quaternary sediments with Uinta Formation outcrops to the north. The two-track road will veer to the right, towards the outcrops. This is the region of the WU-18 locality. Stop 4 is located 9 km (5.6 mi) from the junction of SR 45 and Uinta CR 3150 (old Bonanza Highway), and 15.3 km (9.5 mi) from Stop 3.

Stop 4. Uinta B2 and WU-18 (15.3 km [9.5 mi], cumulative 23.8 km [14.8 mi]): Driving into Coyote Wash, strata characteristic of Uinta B2 lithologies can be observed; greenish-gray, yellow, and light-pink to red mudstone and claystone. The WU-18 locality or "Gnat-Out-Of-Hell," is a typical Uinta B2 locality in terms of the lithology (figure 14D). WU-18 is the single most productive Uinta B2 locality currently known. The main productive level is a dark-brown, sandy mudstone that has produced numerous mammals, including the early primate *Chipetaia* and large bodied amynodont rhinocerotoids and brontotheres (Rasmussen, 1996; Rasmussen and others, 1999a). Coprolites with small mammal bones from WU-18 indicate that this locality may have been partially accumulated by a diurnal raptor (Thornton and Rasmussen, 2001). Stratigraphically above and to the northeast of WU-18 is the *Amynodon* sandstone, the classic boundary between Uinta B2 and Uinta C (Osborn, 1929). This massive sandstone unit sometimes yields large-bodied ungulates, such as its rhinocerotoid namesake, *Amynodon,* and brontotheres. Screenwashing at WU-18 has resulted in the recovery of multiple bird bones, increased samples of primates and small rodents.

Return to SR 45 and drive north for 1.9 km (1.2 mi), to the left will be a graded turn off just east of a small overpass. Turn off onto this road and follow the road for 4.2 km (2.6 mi). Park on the south shoulder of the road. Notice an expansive gas well pad to the east.

Stop 5. Uinta C WU-117 locality complex (6.3 km [3.9 mi] from turn turnoff of CR 3150 to SR 45, cumulative 30.1 km [18.7 mi]): Looking south from the shoulder of the road is an expanse of thick, gray mudstone capped by a golden sheet sandstone. To the east are massive golden sandstone channels are present. The WU-117 locality complex spans the Uinta B2-Uinta C boundary as defined by Townsend and others (2006). The primary lithology in the area consists of gray-green, tan, and yellow-brown mudstone. A distinctive feature of this complex include large dark-brown, fine- to coarse-grained channel sandstone beds (figure 14E). Numerous fossils have been discovered in a dark-brown siltstone layer that weathers pink at WU-110. These fossils include the primate *Ourayia*, the artiodactyls *Protoreodon* and *Leptotragulus*, as well as numerous rodents. The remaining localities in the area WU-110, 115, 116, have also been quite productive. In addition to more small mammal dentaries, large bodied perissodactyls, carnivore postcrania, and a specimen of *Simidectes* have been recovered.

Return to SR 45 and head north for 0.62 miles and pull off to a graded turnout on the west side of SR 45.

Stop 6. Devil's Playground Red Beds (1 km [0.62 mi] from turnoff to SR 45, cumulative 31.1 [19.3 mi]): To the southwest, there is an expansive section of mudstone; at the top there are two distinctive red beds. Townsend and others (2006) consider these beds to be at the top of the Uinta C and transition to the Brennan Basin Member of the Duchesne River Formation in this eastern region of the basin.

Head north on SR 45 for 4.8 km (3 mi) and turn northeast onto a short graded road at SR 45 highway milepost 14.0. There is an old information kiosk and small wind turbine located approximately 100 m (300 ft) east of the highway at this location.

Stop 7. Uinta Formation-Duchesne River Formation lower transition zone contact (5.8 km [3.6 miles from Stop 6; cumulative 36.9 km [22.9 mi]; SR 45 highway milepost 14.0): This is the approximate stratigraphic location of the base of the transition zone between the Uinta C (Myton Member) and the Brennan Basin Member of the Duchesne River Formation as mapped by Sprinkel (2007).

Drive northwest along SR 45 for 1.1 km (0.7 mi) until coming to an intersection with the paved road, which leads to the Deseret Power Plant. Turn southwest on the power plant road and stop.

Stop 8. Uinta Formation – Duchesne River Formation upper transition zone contact (1 km [0.62 mi] from Stop 7; cumulative 37.9 km [23.5] mi]; SR 45 highway milepost 14.7): Looking east is a view of the approximate stratigraphic location of the top of the transition zone between the Uinta C (Myton Member) and the Brennan Basin Member of the Duchesne River Formation as mapped by Sprinkel (2007).

Continue north on SR 45 for about 8 km (5 mi), turn left at the intersection leading to the Glen Bench Road and Deadman Bench Road. Glen Bench Road is paved and intersects on the right with Wonsits Valley Road (CR 3250) which is a graded dirt road. Take the right onto Wonsits Valley Road and continue across Deadman Bench for 11.1 km (6.9 mi) and then make a left turn to travel south along Wonsits Valley Road going down section through the lower part of the Brennan Basin Member and transitional contact with underlying Uinta Formation. Drive 1.6 km (1 mi) and turn left onto a graded road. Then drive 1.2 km (0.75 mi), still veering left, and pull onto the shoulder of the road.

Stop 9. Uinta C, WU-50, WU-49, lower transition zone contact with the Brennan Basin Member of the Duchesne River Formation (21.9 km [13.6] miles from stop 8; cumulative 59.8 km [37.2 mi]): Nearing the top of the Uinta Formation, the strata are brightly pigmented and weather deep brown, bright orange, and various shades of red. In the WU-50 area, sloping dark-red, gray, and tan mudstone beds are interbedded with large, ledge-forming, blocky yellow-brown sandstone beds. At this stratigraphic level in the formation, the Duchesne River and Uinta Formations are locally interbedded. Conglomeratic resistant sandstone channels typical of the Brennan Basin Member of the Duchesene River Formation can be viewed above the dark-red mudstone of WU-49. These localities and others surrounding it are highly productive and have yielded numerous perissodactyls including early tapiroids, such as *Isectolophus*, and almost complete skeletons of large rodents like *Pseudotomus*.

From the WU-50 locality complex, return to Wonsits Valley Road and head south for approximately 1 mile and turn right. Continue to drive west for 1 mile and pull off the road.

Stop 10. Uinta C, WU-26 locality micromammal screenwash site (3.2 km [2.0 mi] from stop 9; cumulative 63 km [39.2 mi]): The WU-26 fossil locality has yielded the first micro-mammal fauna from the late Uintan (late middle Eocene) from Uinta C of the Uinta Formation in the Uinta Basin. The formation outcrops comprise the type locality for species, which define the Uintan NALMA. Our field crews have processed more than 25 tons of bulk sample from WU-26 and recovered more than 600 micro-mammal specimens identifiable to at least the genus level (figure 15). The fossil-bearing horizon is a 15-cm-thick (6 in), green claystone interepted as pond or oxbow lake deposits, and lies 40 m (130 ft) below thick channel sandstone beds at the base of the Brennan Basin Member of the Duchesne River Formation (figure 16). WU-26 provides a unique glimpse into the micro-mammal community which inhabited the Uinta Basin near the end of deposition of the Uinta Formation. The virtual absence of paleobotanical specimens in the Uinta Formation makes paleoclimatic reconstructions problematic. A tiny palynologic flora recovered from WU-26 is currently under study.

More than 1000 micro-mammal specimens were collected at Texas Memorial Museum locality 42486 from the parallic, late middle Eocene, Laredo Formation, at Laredo, Texas. Micro- and macro-floral remains along with fish and reptilian species indicate the Casa Blanca community lived in a lowland tropical rain forest and coastal mangrove setting. The WU-26 sample size is now large enough to make meaningful comparisons with the Ui3-age Casa Blanca micro-mammal community (table 4). *Protoreodon parvus* is present in both faunas. Several other genera are present in both faunas including *Herpetotherium, Mytonius, Epihippus, ?Amynodon, Microparamys*, *Mytonomys,* and *Pauromys*; indicating that both environments shared habitats compatible for these taxa. That fact and the presence of crocodilians including "*Allognathosuchus*," the carettochelyid turtle *Pseudanosteira pulchra*, along with the tortoise *Hadrianus*, and at least four species of omomyid primates, suggest that the paleoclimatic regime at WU-26 was subtropical or warmer. It is significant that the earliest known North American lagomorph, *Mytonolagus petersoni*, as well as *Janimus*, *Pareumys*, *Sciuravis,* and *Talpavus* are present at WU-26, but absent from TMM 42486, indicating that paleoecological differences also existed. Small mammals in the Casa Blanca fauna not yet discovered at WU-26, include *Mahgarita*, *Laredomys,* and *Microeutypomys.*

Return to SR 45 via Wonsits Valley Road (8.92 miles) and turn left onto SR 45 traveling north. Drive 11.68 miles and pull over at SR 45 highway milepost 31.5, 20.60 miles from stop 10.

Figure 15. Jeffrey Westgate and Dana Cope bulk sampling the 15-cm-thick micro-mammal-bearing green claystone at WU-26. Between 2007-2015, 25 tons of bulk sample were collected from this horizon.

Stop 11. View of Asphalt Ridge (32.2 km [20.6 mi] from Stop 10; cumulative 96.2 km [59.8 mi]; SR 45 highway milepost 31.5): Driving the last 18.8 km (11.7 mi), has been through rocks of the Brennan Basin Member of the Duchesne River Formation. This stop affords an excellent view of Asphalt Ridge, a geologically interesting structure composed of uplifted and tilted strata of the Brennan Basin Member of the Duchesne River Formation unconformably overlying more steeply tilted strata of the Late Cretaceous Mesaverde Group. The structural geology of Asphalt Ridge documents multiple episodes of uplift and erosion related to Uinta Mountain tectonics. Asphalt Ridge contains significant tar sand deposits that mostly saturate sandstone beds of the Mesaverde Group and lowermost part of the Eocene Duchesne River Formation (Ritzma, 1979; Blackett, 1996).

The final Uinta Formation field trip stop is a visit to the classic fossil locality White River Pocket. Detailed directions to this field trip stop are not included in this field trip guide because there are numerous ways to get there. As a result, the mileage to this field trip stop is not connected to the preceding field trip stops. To get to White River Pocket, travel to the point at which SR 88 crosses the White River Bridge south of the hamlet of Ouray.

Table 4. Presence of genera at WU-26 and TMM 42486.

GENUS	WU-26	42486	COMMON NAME
Amia	X		Bowfin
Lepisosteus	X	X	Gar
Psuedanosteira	X		Carettochelyid
Allaeochelys		X	Carettochelyid
Apalone	X	X	Softshell turtle
Hadrianus	X	X	Tortoise
Chelonia undet.	X	X	Misc. turtle frags.
"Allognathosuchus"	X	X	Alligator
Crocodylid undet.	X	X	Crocodilian
Glyptosaurus	X	X	Lizard
Herpetotherium	X	X	Mouse opposum
Talpavus	X		Insectivore
Centetodon		X	Insectivore
Pantolestid	X		Pantolestid
cf. *Omomys*	X		Primate
Mytonius	X	X	Primate
Ourayia	X		Primate
Trogolemur	?		Primate
Mahgarita		X	Primate
Miacid	X	X	Carnivore
Harpagolestes		X	Mesonychid
Sirenian		X	Sea cow
Epihippus	X	X	4-toed horse
Colodon	X		Tapir
Amynodon	?	X	Rhino
Notiotitanops		X	Titanothere
Protoreodon	X	X	Artiodactyl
Leptoredon		X	Artiodactyl
Leptotragulus	X		Artiodactyl
Toromeryx		X	Artiodactyl
Mytonomys	X	X	Rodent
Microparamys	X	X	Mouse
Janimus	X		Mouse
Microeutypomys		X	Mouse
Pauromys	X	X	Mouse
Pareumys	X		Mouse
Sciuravis	X		Mouse
Laredomys		X	Mouse
Mytonolagus	X		Rabbit

X = Genus is present
? = Insufficient material for firm generic identification

Stop 12: White River Pocket: Head South on SR 88 for 0.2 miles. Pull over onto the shoulder. The badland hill and surrounding area to the east is a classic fossil locality called White River Pocket. The fossil assemblage from White River Pocket provided the basis for early Uintan faunas, and are significant because a large number of

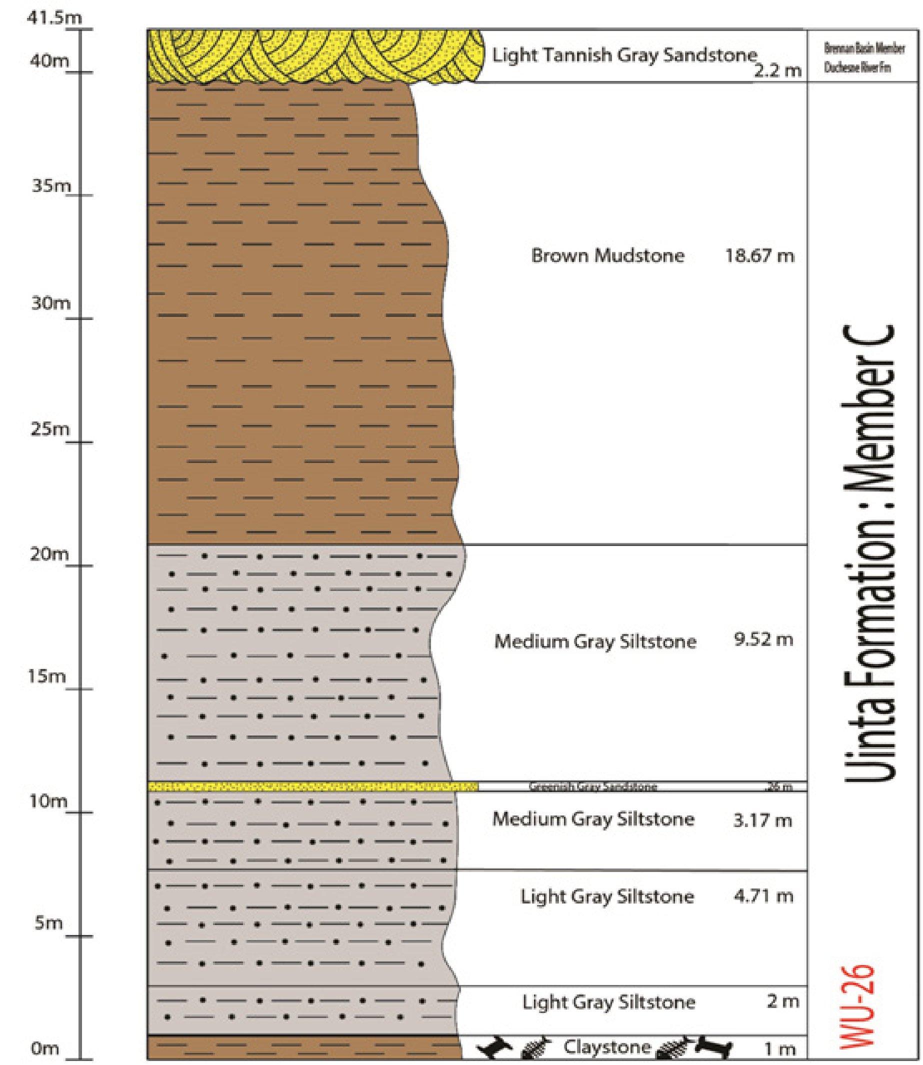


Figure 16. Stratigraphic section from WU-26 quarry in the upper Uinta C Member of the Uinta Formation, up to the base of the Brennan Basin Member of the Duchesne River Formation which lies 40 m above the WU-26 quarry horizon.

small mammal taxa were found there.

Drive north on SR 88 for 18.8 km (11.7 mi). Just past the Pelican Lake Café, turn left onto Uinta CR 2762. Drive west for 7.5 km (4.7 mi) and park on the north shoulder. To the right are spectacular cliffs that are historically known to paleontologists as "Randlett Point," with excellent exposures of the sequence that contains the conformable boundary between the uppermost Uinta C (Myton Member) and the Brennan Basin Member of the Duchesne River Formation, type sequence of the "Randlett Horizon." For further explanation, see Stop 1 of the Duchesne River Formation field trip below.

Duchesne River Formation

The Duchesne River Formation is widely exposed in the northern and western parts of the Uinta Basin. Its definition and stratigraphic history are related to the underlying and apparently conformable Uinta Formation. In the northern part of its distribution along the Uinta Mountain front, it unconformably overlies rocks of Triassic and Jurassic age. The lower part of the Duchesne River Formation also contains tar sand in the Asphalt Ridge area (Ritzma, 1979; USGS, 1980; Blackett, 1996).

The Duchesne River Formation was deposited under mostly fluvial conditions but includes some minor lacustrine deposits. Andersen and Picard (1972) proposed the presently accepted stratigraphy and described the following members in ascending stratigraphic sequence: Brennan Basin, Dry Gulch Creek, Lapoint, and Starr Flat.

The Brennan Basin Member is composed of soft to moderately resistant, light-to-medium red, light-gray, light-brown, yellow, and tan ledgy sandstone, mudstone, conglomerate, shale, and siltstone with a maximum thickness of about 600 m (1970 ft) south of Vernal. This member thins significantly to the east and west. The Dry Gulch Creek Member consists of soft to moderately resistant, light-to-medium gray, medium-red, purplish-gray, and yellow sandstone, mudstone, shale, and conglomerate. It is approximately 149 m (490 ft) thick. The Lapoint Member consists of mostly soft, light-red, tan, and yellow sandstone, siltstone, and mudstone with minor amounts of conglomerate. It contains diagnostic beds of light-gray to medium-gray or bluish-gray bentonite, and ranges in thickness from approximately 119 to 299 m (390–980 ft). The Lapoint ash, which forms the base of the Lapoint Member (where most of the vertebrate fossils have been discovered), has been dated at 39.74 Ma ± 0.07 Ma (Prothero and Swisher, 1992). The Starr Flat Member consists of moderately resistant, light- to medium-red and tan sandstone, mudstone, with a significant amount of red and gray conglomerate. The Starr Flat ranges from 38 to 235 m (124–770 ft) thick (Anderson and Picard, 1972; Rowley and others, 1985). It sporadically crops out along the southern flank of the Uinta Mountains.

The history of stratigraphic nomenclature for the Duchesne River Formation is somewhat confusing (table 5). Clarence King (1878) named the Uinta Group for what we now call the Uinta and Duchesne River Formations. Peterson, in Osborn (1895), proposed that the Uinta Group be subdivided into A, B, C horizons, with the C horizon being equivalent in part to what we now know as Duchesne River Formation and equivalent in part to the upper Uinta Group. Douglas (1914) suggested that the name Uinta Group be replaced by the name Uinta Tertiary to avoid confusion with the Precambrian Uinta Mountain Group. Scott in Peterson (1931) named the Duchesne Formation, and it was renamed Duchesne River Formation by Kay (1934) because the name Duchesne Formation was preoccupied. Kay (1934) defined the Duchesne River Formation by removing the red beds of Osborn's (1895) upper Uinta Group, recognizing they have a younger mammalian fossil fauna. He also recognized three biostratigraphic "horizons:" Randlett, Halfway, and Lapoint. Gazin (1955) removed the Randlett horizon from the Duchesne River Formation, recognizing that it contains a fauna that is almost identical to that of the Uinta C. Warner (1963) recognized two members, the minor bentonite member, equivalent to the Brennan Basin and Dry Gulch Creek Members, and the major bentonite member, equivalent to the Lapoint Member. Andersen and Picard (1972) named the currently recognized members: Brennan Basin, Dry Gulch Creek, Lapoint, and Starr Flat. With regard to Andersen and Picard's (1972) stratigraphic terminology, the Brennan Basin Member is equivalent to the Randlett horizon of Kay (1934) and the lower part of Halfway horizon, the Dry Gulch Creek Member is equivalent with the upper part of the Halfway horizon, and the Lapoint Member is equivalent to the Lapoint horizon.

Fossils and Biochronology of the Duchesne River Formation

In comparison with the underlying Uinta Formation and correlative strata of Duchesnean age in coastal southern California, the vertebrate fossil fauna of the type Duchesne River Formation is sparse. However, it is a critically important period in mammalian evolu-

Table 5. History of Duchesne River Formation stratigraphic nomenclature.

<table>
<tr><th>King (1878)</th><th>Peterson in Osborn (1895)</th><th>Douglass (1914)</th><th>Peterson and Kay (1931)</th><th>Scott in Peterson (1931)</th><th colspan="2">Kay (1934)</th><th>Gazin (1955)</th><th>Warner (1963)</th><th>Andersen and Picard (1972)</th></tr>
<tr><td rowspan="5">Uinta Group (in part)</td><td rowspan="5">C horizon (in part) = upper Uinta Group</td><td rowspan="5">Uinta Tertiary (in part)</td><td rowspan="5">Upper Uinta red beds separated from underlying Uinta Tertiary</td><td rowspan="5">Duchesne Formation</td><td rowspan="5">Duchesne River Formation</td><td>*(not studied)*</td><td>*(not studied)*</td><td>*(not studied)*</td><td>Starr Flat Member</td></tr>
<tr><td>Lapoint horizon</td><td>Lapoint horizon</td><td>Major bentonite member</td><td>Lapoint Member</td></tr>
<tr><td rowspan="2">Halfway horizon</td><td rowspan="3">Halfway horizon</td><td rowspan="3">Minor bentonite member</td><td>Dry Gulch Creek Member</td></tr>
<tr><td rowspan="2">Brennan Basin Member</td></tr>
<tr><td>Randlett horizon</td></tr>
</table>

tion (Lucas 1992; Rasmussen and others, 1999b; Robinson and others, 2004). Although it is the nominal stratotype for the Duchesnean NALMA (Wood and others,1941), its validity has been the subject of some controversy among paleontologists (see Wilson, 1978; Lucas, 1992). Nevertheless, the Duchesnean NALMA has now been widely accepted by paleontologists (Rasmussen and others, 1999b; Robinson and others, 2004). Lucas (1992, p. 88) made the observation that the Duchesne River Formation "has either been questioned, abandoned, subdivided, or defended." Scott (1945) regarded the Duchesne River Formation as Oligocene in age. Simpson (1946) and Gazin (1955) considered it Eocene. Faunally, the importance of the Duchesne River Formation and the Duchesnean NALMA is based on the fact that it records a major faunal replacement in North America, as demonstrated by its large number of first and last occurrences, as well as the small number of genera that are restricted to it (Black and Dawson, 1966; Robinson and others, 2004). Robinson and others (2004) tentatively assigned Duchesnean first appearances to include *Hyaenodon, Duchesneodus*, *Duchesnehippus intermedius, Amynodontopsis,* and *Eotylopus*.

The fauna of the Brennan Basin Member, which was previously assigned to the Randlett horizon and lower part of the halfway horizon of Kay (1934), includes a faunal assemblage that is generally considered to be intermediate between the Uinta C (biochron Ui3, Gunnell and others, 2009) and the Lapoint Member of the Duschesne River Formation, although most workers regard it as late Uintan. The Brennan Basin Member outcrops over a fairly large area, and several somewhat productive localities are known. It contains a reasonably diverse assemblage of Uintan artiodactyls including *Protoreodon*, *Pentacemylus, Diplobunops,* and *Leptotragulus*. Perissodactyls include a mix of Uintan and Duchesnean brontotheres, as well as tapirs and rhinos. Specimens of the Uintan lagomorph *Mytonolagus* and the rodents *Pareumys* and *Mytonomys* have also been collected (Rasmussen and others, 1999b).

Until recently, only two published specimens had ever been reported from the Dry Gulch Creek Member, and these represented the "Halfway Fauna" (Rasmussen and others, 1999b). The specimens include the holotype of *Duchesnehippus intermedius*, a genus of horse that is purportedly intermediate between the Uintan horse *Epihippus* and the Chadronian horse *Mesohippus*, and a femur and astragalus tentatively identified as (?) hyracodontid rhinoceros. Walsh and Murphey (2007) discovered a locality that produced a diversity of small mammals in the Dry Gulch Creek Member (67 identifiable specimens). SDSNH Loc. 5939 ("Halfway Hollow One") is situated roughly in the stratigraphic middle of the Dry Gulch Creek Member (Tdr-dgc), at about the same level as the type locality of *D. intermedius*. The fauna of this locality and other newly documented localities from the Duchesne River Formation was described by Kelly and others (2012). New records form the Dry Gulch Creek Member include *Copedelphys* sp.; Lipotyphla (genera and species indeterminate); *Mytonolagus* sp.; *Pareumys guensburgi*; *Griphomys* sp.; *Heliscomys* sp.; *Passaliscomys* sp.; *Metanoiamys lacus*; *Metanoiamys* sp., cf. *M. korthi*; *Protadjidaumo typus*; *Protadjidaumo* sp., cf. *P. typus*; *Paradjidaumo* sp.; *Adjidaumo* sp., cf. *A. craigi*; *Simiacritomys* sp.; *Microeutypomys* sp.; *Eutypomys* sp.; and *Poabromylus kayi*. Importantly, *Pareumys guensbergi*, *Protadjidaumo typus*, and *Passaliscomys* sp. suggest a Duchesnean age for most or all of the Dry Gulch Creek Member, and that the Uintan-Duchesnean boundary occurs somewhere within the upper part of the Brennan Basin Member or the lower part of the Dry Gulch Creek Member.

The mammalian fauna of the Lapoint Member is considered the type Duchesnean fauna, although misidentifications, data loss, and mistakes made by earlier workers have resulted in considerable confusion regarding what was actually collected at this horizon. Most of these problems seem to have been resolved by the efforts of Rasmussen and others (1999b). The Lapoint fauna contains diverse assemblages of artiodactyls such as *Protereodon*, *Agriochoerus, Simimeryx,* and *Brachyops,* and perissodactyls such as *Colodon*, *Hyracodon*, *Duchesnehippus,* and *Duchesneodus*. Also present are carnivores, the mesonychid *Hessolestes*, the hyaenodont *Hyaenodon*, the lipotyphlan *Centetodon*, and the rodents *Pareumys* and *Protadjidaumo*.

No published accounts of fossils have been reported from the stratigraphically highest Starr Flat Member. However, Paul Murphey and Mark Roeder of the

San Diego Natural History Museum discovered a highly fragmented mammal tooth that was tentatively identified as a partial upper molar of a large artiodactyl from near the base of the member. This specimen was described by Kelly and others (2012).

Although the Lapoint and Brennan Basin Members of the Duchesne River Formation are the most fossiliferous, fossils are generally scarce throughout the formation. Any new discoveries would be highly significant, especially from the Dry Gulch Creek and Starr Flat Members. It is also noteworthy that reptiles in general are poorly represented from the Duchesne River Formation. Much work remains to be done in order to document the faunal changes within the Duchesne River and ascertain the position of the Uintan-Duchesnean boundary.

As concluded by Kelly and others (2012), the mammalian assemblages from the Dry Gulch Creek and Lapoint Members of the Duchesne River Formation are combined as the Halfway/Lapoint fauna and regarded as the "type fauna" of the Duchesnean NALMA. New correlations of the Uintan and Duchesnean faunas from the Sespe Formation of California to the Global Polarity Time Scale are based on taxonomic comparisons of the Sespe faunas to those from the Uinta Basin and radioisotopic data. Based these new correlations, the Uintan-Duchesnean boundary occurs within Chron C19n of the GPTS, or about 41.4 Ma.

Duchesne River Formation Field Trip Stops

Our exploration of the Duchesne River Formation begins at Randlett Point where the contact between the Uinta C of the Uinta Formation (Myton Member) and the overlying Brennan Basin Member of the Duchesne River Formation is well exposed and relatively easy to discern. From there we travel north through strata of the Brennan Basin Member in Halfway Hollow, and then examine exposures of the Dry Gulch Creek Member and discuss the paleontology of this sparsely fossiliferous unit that appears to contain the boundary between the Uintan and Duchesnean NALMA although the precise stratigraphic position of the boundary has not yet been determined. From a distance, we then view the Lapoint Member and overlying Starr Flat Member in Halfway Hollow. Heading east along the Lapoint highway to Twelvemile Wash, our last stop is at the site of the famous Carnegie Museum Titanothere Quarry just above the base of the Lapoint Member, as well as the Lapoint ash at quarry level.

Stop 1. Randlett Point (0.0 km/mi, cumulative 0.0 km/mi): Peterson and Kay (1931) defined the base of the Duchesne River Formation at this location. The boundary between the Uinta C (Myton Member) and overlying Brennan Basin Member in this part of the Uinta Basin is easier to discern than farther to the east in the type area of the Uinta Formation in the Coyote basin. Here the contact is marked by the change from slope-forming pink, purple, light-gray, and red (variegated) mudstone and siltstone beds of the Uinta Formation to ledge-forming orange, reddish-brown, and gray siltstone and sandstone beds of the overlying Brennan Basin Member (figure 17a). The Carnegie Museum's Randlett Quarry is approximately 1.6 km (1 mi) to the north of this location. With the exception of the large Duchesnean brontothere *Duchesneodus*, the fauna of the Brennan Basin Member resembles that of the Uinta C, and the fauna of the lower part of the Brennan Basin Member is regarded by most workers to be Uintan in age.

Drive east on the Ouray-Randlett Road (Uinta County Road 2762) for 4.7 miles to the junction of State Route (SR 88). Turn left (north) on SR 88 and drive to U.S. 40. Turn right (east) on U.S. 40 and drive for about 2.2 miles to the intersection of the Halfway Hollow road and then turn north on th dirt road.

Stop 2. Brennan Basin Member-Dry Gulch Creek Member boundary (30.6 km [19 mi] from Stop 1, cumulative 30.6 km [19 mi]: Andersen and Picard (1972) defined this boundary as the base of the lowest bed of fine-grained rock overlying the highest resistant sandstone of the Brennan Basin Member (figure 17b). This contact was mapped by Rowley (unpublished field maps), Rowley and others (1985), and Sprinkel (2007) as the sandstone bed visible at this stop. This tan sandstone and conglomerate is highly variable in thickness, and crosses Halfway Hollow Road at UTM Zone 12, 609901 mE, 4470184 mN (NAD 27). A widespread

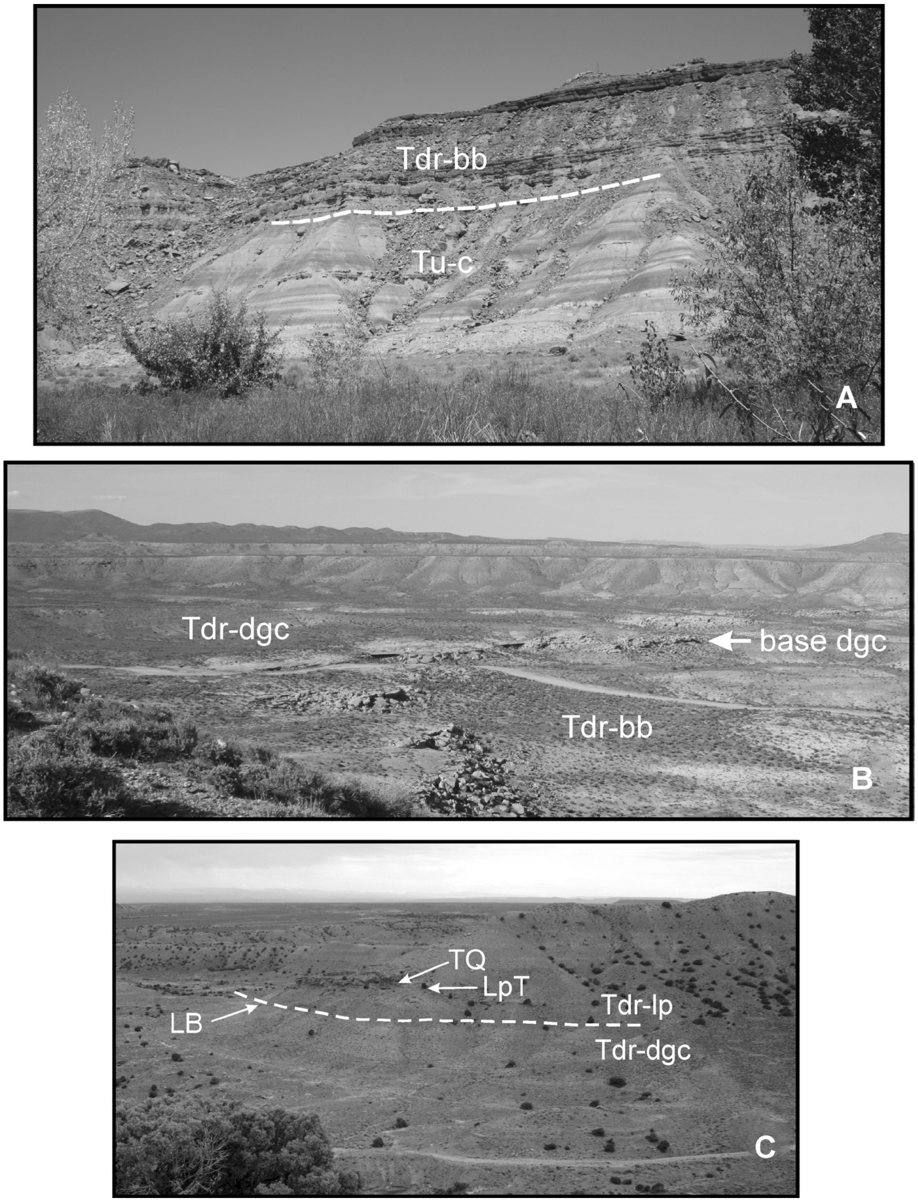


Figure 17. (A) The contact between the Uinta C (Tu-c) and Brennan Basin Member of the Duchesne River Formation (Tdr-bb) at Randlett Point, Uintah County, Utah; (B) View looking northeast at the sandstone bed (base dgc) that divides the Brennan Basin Member of the Duchesne River Formation (Tdr-bb) from the overlying Dry Gulch Creek Member (Tdr-dgc) in Halfway Hollow, Uintah County, Utah; (C) View looking west at the Carnegie Museum Teleodus Quarry (TQ), the lower bentonite bed (LB) that marks the boundary between the Dry Gulch Creek Member (Tdr-dgc) of the Duchesne River Formation and the overlying Lapoint Member (Tdr-lp), and the Lapoint tuff (LpT), Uintah County, Utah.

but thin 0.5-m-thick (1.6 ft) dark-red, indurated, fine-grained sandstone, interpreted by Andersen and Picard (1972) as a paleosol, can be seen approximately 18 m (60 ft) above the top of the sandstone. Fossil snails and bone fragments have been receovered from screen-washing sediments collected from between the boundary sandstone bed and red paleosol approximately 0.4 km (0.25 mi) to the southwest of this location. However, no identifiable mammal fossils have been found to date in these samples.

Continue driving north on Halfway Hollow Road for 3.7 km (2.4 mi). Stop east of a large evaporation pond with five tank batteries located along its southern edge.

Stop 3. Dry Gulch Creek Member fauna (3.8 km [2.4 mi] from Stop 2, cumulative 34.4 km [21.4 mi]): This part of Halfway Hollow has produced the only known mammal fossils from the Dry Gulch Creek Member. A relatively fossil-rich micromammal quarry was discovered just to the east of the road (Halfway Hollow One, SDSNH Loc. 5939) in 2006, and is discussed above. These fossils are currently being formally described, and it is likely that additional screenwashing of sediments from this locality will yield additional mammal fossils. Peterson (1931c, p. 70–71) described the type specimen of *Epihippus* (*Duchesnehippus*) *intermedius* (along with specimens tentatively identified as a partial femur and astragalus of a hyracodontid rhinoceros) as coming from "the west side of Halfway Hollow, from a red clay about 8 feet thick, overlain by a massive brown sandstone and underlain by a reddish nodular clay associated with astragalus and horse jaw." The specimens were collected by John Clark on July 21, 1931 (Alan Tabrum, Carnegie Museum of Natural History, written communication, 2006).

Continue driving north to northeast on Halfway Hollow Road for 1.5 km (0.9 mi) until reaching SR 121 (Lapoint Highway). Stop just beyond the cattle guard.

Stop 4. View of Lapoint and Starr Flat Members (1.5 km [0.9 mi] from Stop 3, cumulative 35.9 km [22.3 mi]): Looking north from this spot is an excellent view of the Lapoint Member, the Starr Flat Member, and the distant Uinta Mountains with Marsh Peak at 3668 m (12,198 ft) on the skyline. The base of the Lapoint Member is defined as the lowest widespread bentonite bed. Thick, laterally persistent bentonite beds are characteristic of this member. Several additional American Museum of Natural History and Carnegie Museum fossil localities are located in this part of Halfway Hollow to the north of the Lapoint highway, although recent efforts to relocate them have proven unsuccessful. The contact between the Lapoint and overlying Starr Flat Members is located at the approximate level of the tops of the red cliffs seen in the distance at the north end of Halfway Hollow. However, the top of the Duchesne River Formation is not visible from this location. As discussed above, the Starr Flat Member has yielded tooth fragments from one locality, but no other fossils have been reported. That said, it has yet to be thoroughly prospected. It is possible that the fauna of the Starr Flatt Member is younger than the Duchesnean NALMA.

Turn east onto the Lapoint highway (SR 121) and drive for 4 km (2.5 mi). Just past the SR 121 milepost 31, turn north onto a two-track road and drive for 1.1 km (0.7 mi) for a total of 5.1 km (3.2 mi) from Stop 4. The Carnegie *Teleodus* Quarry pit is located near the summit of the large hill to the northwest of this location.

Stop 5. Carnegie Titanothere Quarry and Lapoint ash (5.1 km [3.2 mi] from Stop 4, cumulative 41 km [25.5 mi]): This is the site of the famous Carnegie Titanothere Quarry (also known as the *Teleodus* Quarry and the *Duchesneodus* Quarry; figure 17c). For many years prior to the discovery of this quarry, there remained a recognized hiatus between the earlier mammalian faunas of the Rocky Mountain intermontane basins and the younger mammalian faunas of the White River Badlands of South Dakota and Nebraska. In discovering and working this quarry, J.L. Kay of the Carnegie Museum made the first important paleontological discovery to begin to fill this knowledge gap. Peterson (1931a, 1931b, 1931c) and Peterson and Kay (1931) described the fossils from this locality and from other localities in the then Lapoint horizon. These workers regarded the fauna as "perfectly transitional" (Peterson, 1931c, p. 62). In addition to the brontothere fossils collected from the quarry, bunodont and selenodont artiodactyls, a rodent, an insectivore, hyracodontid rhinos, and a creodont and mesonychid were discovered and described. Note that a recent thorough re-inspection of the quarry and surrounding area has failed to yield any additional fossils.

The thin bentonite bed visible on the slope below the quarry is considered to be the base of the Lapoint Member by Andersen and Picard (1972). However, the Lapoint ash (39.74 ± 0.07 Ma, Prothero and Swisher, 1992) is actually the thicker, higher bentonite bed that is cut by the red sandstone channel in which the Carnegie Quarry fossils were preserved (figure 15c). Therefore, the Carnegie Titanothere Quarry is located stratigraphically just above the base of the Lapoint Member and is slightly younger than the Lapoint tuff that was cut by the red sandstone channel.

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